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FACTOR-ADJUSTMENT COSTS AT THE INDUSTRY LEVEL

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Abstract

Recent theoretical and econometric developments allow estimation of dynamic cost functions that include optimal adjustment of quasi-fixed factors. Such a cost function is estimated for the U.S. steel industry for the years 1954-1985 to investigate the cost of adjusting blue- and white-collar labor stocks, and to examine the importance of the specification of the adjustment-cost function.

I. Introduction

Advances in both cost-function analysis and in econometric theory now allow the estimation of cost functions that explicitly include adjustment costs for quasi-fixed factors. Pindyck and Rotemberg (1983) estimate a dynamic cost function for the U.S. manufacturing sector that includes adjustment costs for both capital and labor. Their results indicate that capital is costly to adjust, as expected, but that the cost of adjusting labor is insignificant. In this paper we use their model (hereafter the PR model) to estimate a dynamic cost function for a single industry so that we may examine adjustment costs for labor and capital at a lower level of aggregation.

We are particularly interested in the adjustment cost of labor. Finding that capital is costly to adjust, but that labor is not, is intuitively appealing for situations where firms are building new plants and increasing employment over time. But it seems likely that these results will be different if large, permanent reductions in employment are occurring: the cost of adjusting the labor stock will increase if job security provisions are included in worker contracts and if more white collar workers, who may be more expensive to lay off,[1] are included among the terminations. Indeed, our results indicate that for at least one declining industry, the cost of adjusting labor may be more important than the aggregate estimates suggest.

We also make a preliminary attempt at evaluating the importance of the specification of the adjustment cost equations. Adjustment costs are usually modeled as a function of absolute changes in factors, largely because this specification is analytically tractable. But it has been suggested that adjustment costs are arguably more closely related to the size of the relative change in factor usage (Gould [1968]).[2] Because the latter specification can be easily accommodated within the PR model framework, we are able to investigate this possibility.

We estimate a cost function for the U.S. steel industry using annual industry data from the years 1954-1985. This industry seems likely to exhibit high labor-adjustment costs because blue-collar workers are unionized and because large numbers of both blue- and white-collar workers have been permanently laid off by steel firms, particularly during the later years of the sample.

The industry's capital adjustment costs, on the other hand, may or may not differ from those experienced by the manufacturing sector as a whole. The sample period includes years when the industry was still expanding its capacity (mostly the 1950s), years when industry investment was largely devoted to capital deepening (the 1960s), and years when industry capacity peaked and began to decline (the 1970s). Also, the industry has a history of maintaining excess capacity, a practice that could bias adjustment cost estimates. Our difficulty in estimating the cost of adjusting the capital stock during this period suggests that a more sophisticated model of capital stock adjustment than is generally employed may be necessary.

We estimate the model using percentage changes in capital and labor as the arguments of the adjustment-cost equations, and then again using the more typical format of changes in the absolute levels of capital and labor stocks.

We find much stronger evidence for the existence of adjustment costs when using the former specification, suggesting that exactly how factor changes are specified in adjustment-cost equations is an important factor.

The PR model is quickly reviewed in Section II. Section III is a discussion of the estimation technique, and Section IV contains a brief description of the data. Section V presents the results, including the estimated adjustment cost coefficients and the implied short- and long-run factor elasticities. Section VI is the conclusion.

II. Model and Specification

The PR model assumes that firms use all available information as they choose cost-minimizing factor combinations subject to adjustment costs for quasi-fixed factors.[3] The factors are energy (E_t), materials (M_t), white-collar labor (LW_t), blue-collar labor (LB_t), and capital (K_t), with prices e_t, m_t, s_t, w_t, and v_t, respectively. Both types of labor, and capital, are assumed to be quasi-fixed factors.

The function C is the restricted cost function to be minimized; it is conditional on capital, blue- and white-collar labor, and output, all at time t:

$$(1)\quad C(e_t,\ m_t,\ LW_t,\ LB_t,\ K_t,\ Q_t,\ t).$$

We first assume that adjusting capital or labor stocks in either direction becomes increasingly costly as the proposed magnitude of change in capital or labor rises. The quadratic adjustment cost functions are thus written:

(2) $c1 = (1/2)\beta_1(LW_t - LW_{t-1})^2$,

(3) $c2 = (1/2)\beta_2(LB_t - LB_{t-1})^2$,

(4) $c3 = (1/2)\beta_3(K_t - K_{t-1})^2$.

Alternatively, we assume adjustment costs are a quadratic function of the percentage change in labor or in capital. Equations (2), (3), and (4) become:

(2a) $c1 = (1/2)\beta_1[(LW_t - LW_{t-1})/LW_{t-1}]^2$,

(3a) $c2 = (1/2)\beta_2[(LB_t - LB_{t-1})/LB_{t-1}]^2$,

(4a) $c3 = (1/2)\beta_3[(K_t - K_{t-1})/K_{t-1}]^2$.

The dynamic optimization problem is:

(5) $$\min_{\substack{K,LW,LB \\ e,\ m}} \underline{E}_t \sum_{\tau=t}^{\infty} R_{t,\tau} [C(e_t, m_t, LW_t, LB_t, K_t, Q_t) + s_tLW_t + w_tLB_t + v_tK_t + c1(f(LW_t, LW_{t-1})) + c2(f(LB_t, LB_{t-1})) + c3(f(K_t, K_{t-1}))],$$

subject to the arguments of the adjustment cost functions c1, c2, and c3. $\underline{E}_t$ is the conditional expectation operator, and R_t is the discount rate;

the expectation is taken over the future values of factor prices and output levels, all of which are treated as random.

The first-order conditions of the cost minimization problem are:

$$(6)\quad E_t = \delta C_t/\delta e_t,$$

$$(7)\quad M_t = \delta C_t/\delta m_t,$$

$$(8)\quad \frac{\delta C_t}{\delta LW_t} + s_t + \frac{\delta c1[f(LW_t,\ LW_{t-1})]}{\delta LW_t} + \underline{E}_t\ \{R_t\ \frac{\delta c1[f(LW_{t+1}, LW_t)]}{\delta LW_t}\} = 0,$$

$$(9)\quad \frac{\delta C_t}{\delta LB_t} + w_t + \frac{\delta c2[f(LB_t,\ LB_{t-1})]}{SLB,} + \underline{E}_t\ \{R_t\ \frac{\delta c2[f(LB_{t+1}, LB_t)]}{SLB,}\} = 0,$$

$$(10)\quad \frac{\delta C_t}{\delta K_t} + v_t + \frac{\delta c3[f(K_t,\ K_{t-1})]}{\delta K_t} + \underline{E}_t\ \{R_t\ \frac{\delta c3[f(K_{t+1}, K_t)]}{\delta K_t}\} = 0,$$

where equations (6) and (7) are the result of Shepherd's Lemma, and equations (8), (9), and (10) indicate that the optimal factor stocks are reached at the point where the marginal benefit of adjusting the factor stock (from having lowered variable costs) equals the cost of the last unit plus the changes in current and expected adjustment costs.

These first-order conditions, plus the restricted cost function C, form a set of equations that can be used to estimate the parameters of the cost function and the parameters of the adjustment cost functions without actually solving the model.[4]

We use a **translog** cost function with capital and labor quasi-fixed. The cost equation is:

$$(11)\ \ln C_t = \alpha_1 + \ln m_t + \alpha_2 \ln(\frac{e_t}{m_t}) + \alpha_3 \ln LW_t + \alpha_4 \ln LB_t + \alpha_5 \ln K_t + \alpha_6 \ln Q_t + \lambda T$$

$$+ \frac{1}{2} \gamma 11 [\ln(\frac{e_t}{m_t})]^2 + \gamma_{12} \ln(\frac{e_t}{m_t}) \cdot \ln LW_t + \gamma_{13} \ln(\frac{e_t}{m_t}) \cdot \ln LB_t$$

$$+ \gamma_{14} \ln(\frac{e_t}{m_t}) \cdot \ln K_t + \gamma_{15} \ln (\frac{e_t}{m_t}) \cdot \ln Q_t$$

$$+ \frac{1}{2} \gamma 22 [\ln LW_t]^2 + \gamma_{23} \ln LW_t \cdot \ln LB_t + \gamma_{24} \ln LW_t \cdot \ln K_t$$

$$+ \gamma_{25} \ln LW_t \cdot \ln Q_t$$

$$+ \frac{1}{2} \gamma 33 [\ln LB_t]^2 + \gamma_{34} \ln LB_t \cdot \ln K_t + \gamma_{35} \ln LB_t \cdot \ln Q_t$$

$$+ \frac{1}{2} \gamma 44[\ln K_t]^2 + \gamma_{45} \ln K_t \cdot \ln Q_t + \frac{1}{2}\gamma_{55} (\ln Q_t)^2.$$

Under this specification, the Euler equations become:

$$(12)\ S_{et} = \frac{E_t \cdot e_t}{e_t E_t + m_t M_t} = \frac{\delta \ln C_t}{\delta \ln e_t} = \alpha_2 + \gamma_{11} \ln(\frac{e_t}{m_t}) + \gamma 12 \ln LW_t + \gamma_{13} \ln LB_t$$

$$+ \gamma_{14} \ln K_t + \gamma_{15} \ln Q_t,$$

$$(13)\ S_{mt} = \frac{m_t M_t}{e_t E_t + \%\%} = 1 - Set,$$

$$(14)\ C_t S_{LWt}/LW_t + s_t + \beta_1 \frac{\delta f(LW_t, LW_{t-1})}{\delta LW_t} - \underline{E}_t \{R_t \beta_1 \frac{\delta f(LW_{t+1}, LW_t)}{\delta LW_t}\} = 0,$$

$$(15)\quad C_t S_{LBt}/LB_t + w_t + \beta_2 \frac{\delta f(LB_t,\ LB_{t-1})}{\delta LB_t} - \underline{E}_t\ \{R_t\beta_2 \frac{\delta f(LB_{t+1},\ LB_t)}{\delta LB_t}\} = 0,$$

$$(16)\quad C_t S_{Kt}/K_t + v_t + \beta_3 \frac{\delta f(K_t, K_{t-1})}{\delta K_t} - \underline{E}_t\ \{R_t\beta_3 \frac{\delta f(K_{t+1},\ K_t)}{\delta K_t}\} = 0,$$

where f(.)/ (.) depends on how changes in the factor stock are measured, and where S_{LWt}, S_{LBT}, S_{Kt} are equal to:

$$(17)\quad S_{LW_t} = \frac{\delta \ln C_t}{\delta \ln LW_t} = \alpha_3 + \gamma_{12}\ln(\frac{e_t}{m_t}) + \gamma_{22}\ln LW_t + \gamma_{23}\ln LB_t + \gamma_{24}\ln K_t + \gamma_{25}\ln Q_t,$$

$$(18)\quad S_{LB_t} = \frac{\delta \ln C_t}{\delta \ln LB_t} = \alpha_4 + \gamma_{13}\ln(\frac{e_t}{m_t}) + \gamma_{23}\ln LW_t + \gamma_{33}\ln LB_t$$

$$+ \gamma_{34}\ln K_t + \gamma_{35}\ln Q_t,$$

$$(19) \quad S_{Kt} = \frac{\delta \ln C_t}{\delta \ln K_t} = \alpha_5 + \gamma_{14}\ln(\frac{e_t}{m_t}) + \gamma_{24}\ln LW_t + \gamma_{34}\ln LB_t$$

$$+ \gamma_{44}\ln K_t + \gamma_{45}\ln Q_t.$$

(Note that the "share" equations for fixed factors will be negative, as they represent the change in variable cost caused by small changes in the fixed factors.)

III. Econometrics

We use nonlinear, three-stage least squares to jointly estimate equations (11, (12, (14, (15) and (16). This procedure is equivalent to using the generalized instrumental variables technique discussed in Hanson (1982), and in Hanson and Singleton (1982), when the errors are conditionally homoscedastic. The technique is a natural one to use to estimate this model because actual future values of variables can be used as proxies for their expected future values in the Euler equations. The residuals from estimates of the Euler equations can then be thought of as expectational errors, which have mean zero, conditional on the information available to economic agents at time t.

The information available at time t is assumed to be adequately represented by the set of instrumental variables. Thus, the generalized instrumental variables technique, which minimizes the correlation between the residuals and the instrumental variables, is designed for exactly this application. Agents forming rational expectations based on an information set given by the instrumental variables would also act to minimize the correlation between the residuals and the variables in their information set.

The fit between this method of estimation and the static share equations is less precise. While in principle the share equations should hold exactly, in actual fact they will not, and the residuals can be expected to be correlated with variables known at time t. We follow Pindyck and Rotemberg (1983) by assuming that the share equations hold in expectation with respect to the conditioning set represented by our list of instrumental variables. This conditioning set excludes current variables from entering the cost-minimization problem.

We report Hanson's J-statistic for each specification estimated. These statistics have Chi-square distributions, with degrees of freedom equal to the number of instruments multiplied by the number of equations, minus the number of estimated parameters. Large values of J lead to rejection of the overidentifying restrictions of the model.[5]

IV. Data

The data required for the estimation are output, an output price, usage and prices of materials (scrap steel and iron ore), energy (coal, natural gas, electricity, and fuel oil), blue- and white-collar labor, and capital services.

Output figures are from various issues of AISI Annual Statistical Report (ASR), and represent millions of net tons of steel, of all grades, produced by both integrated and nonintegrated mills. The output price is a price index for all steel-mill products, and is also taken from various issues of the ASR.

The materials data series is a Divisia Index of scrap steel and iron ore. Price and consumption data for both these materials are reported by the Bureau of Mines in Minerals Yearbook (MY).

The energy data are a weighted sum of the quantities and prices of coal, natural gas, fuel oil, and electricity, where all quantities are converted to millions of BTUs, and all prices to dollars per million of BTUs. The quantities of coal (consumed making coke), natural gas, fuel oil, and electricity that the industry used are reported in various issues of the ASR. Data on energy prices comes from various issues of a variety of sources, including: Minerals Yearbook, the State Energy Price and Expenditure Report, 1970-1982, and annual updates for subsequent years; Platt's Oil Price Handbook and Oilmanac; and the Statistical Year Book of the Electric Utility Industry.

Data on total man-hours are reported in the Annual Survey of Manufactures and the Census of Manufactures for "Blast Furnaces and Steel Mills" (SIC 3312). Hours of production workers are reported directly; nonproduction workers are assumed to work 2,000 hours each year. The total cost per hour of labor is the industry's payroll, plus supplementary labor payments, divided by the man-hours used. Payroll and supplemental labor costs are also reported in the Annual Survey of Manufactures and the Census of Manufactures.[6]

Data on the hours and total cost of blue-collar workers alone are taken from AISI Annual Statistical Report. (The figures are adjusted to correct for the changing percentage of the industry represented by the AISI figures.) The total hourly cost of white-collar workers is then calculated as the total cost of wage workers minus the cost of all labor, divided by white-collar hours.[7]

Capital services are assumed to flow in constant proportion from the capital stock, so the annual value of the capital stock is used to measure the quantity of capital services consumed in a year. We calculate the starting (end-1953) capital stock by summing up investments made by all steel firms since 1926. (Investments made before 1926 are assumed to have zero value by 1954.) Annual investments are depreciated at a constant rate of 12 percent; thus, the capital stock in any year is the sum of past net investment.

The price of capital services is from Wharton Econometrics, and is an index of the user price of capital in the primary metals sector. Because this "price" is an index, and because the flow of capital services is assumed to be proportional to the capital stock, the cost share of capital is calculated as the product of the index and the capital stock. We then adjust this figure to equate the capital cost calculated from these indices with an independent measure available in Deily (1988).[8]

Finally, the industry has a history of maintaining excess capacity, a practice that could bias the adjustment cost of capital downward and distort the measure of capital services. We therefore multiply the capital stock figures by the utilization rate for the iron and steel sector reported by the Federal Reserve. The estimated adjustment cost coefficient for capital thus measures the cost of adjusting utilized capital, which equals the cost of changing the utilization rate of the capital in place plus the cost of adjusting the capital stock itself.

V. Estimation Results

The estimated adjustment-cost coefficients are presented on table 1, and the cost function coefficients are reported on table 2. In both tables, the estimation results derived from models using percentage changes in factor stocks in the adjustment cost equations are presented in columns 1 and 2, while estimation results for models using changes in levels of the fixed factors are presented in columns 3 and 4.

We consider first the estimation results using aggregate labor (columns 1 and 3). When adjustments are measured in percentage terms, the adjustment-cost coefficient for labor is positive and significant; when adjustments are measured by changes in the level of labor, the adjustment-cost coefficient is negative and significant. The results confirm that the method used in measuring the change in the labor stock affects the estimated adjustment cost coefficient substantially. And, if percentage changes in the labor stock reflect actual costs more closely, the results imply that adjusting the labor stock may be costly in some industries.

But, contrary to expectation, the estimation results when labor is disaggregated suggest that the cost of adjusting blue-collar labor is higher than the cost of adjusting white-collar labor. In general, one might expect the opposite to be true, since hiring or laying off white-collar workers usually involves costly reorganization. It is possible, however, when layoffs are occurring because of plant closings, that blue-collar workers might be more costly to lay off, because of severance pay and pensions, than the relatively unprotected white-collar workers.

It is difficult, however, to draw conclusions from the estimations in columns 2 and 4; tests of the restrictions based on the J-statistics lead to overwhelming rejection of the overidentifying restrictions for these models. In contrast, of the models estimated using aggregated labor, neither the model specifying adjustment costs based on percentage changes nor the model specifying adjustment costs based on changes in levels lead to rejection of the overidentifying restrictions.[9]

Estimation of the adjustment-cost coefficients for capital were less successful than for labor: none of the estimated coefficients are positive and significant. Additional estimates (not reported) of models using utilized capital in the restricted cost function and aggregate capital in the cost-of-adjustment equation (so that the firm minimizes variable cost conditional on a utilization rate), or aggregate capital stock in both equations, give similar results: while the cost of adjusting labor is positive and significant, the cost of adjusting capital is either positive but insignificant; or, negative, and in some cases significant.[10]

These results for capital are disappointing, since it seems very unlikely that capital can be adjusted without cost. Rather, the relationship between the flow of capital services and the aggregate capital stock in an industry that matures and then declines may be more complex than our relatively simple adjustment-cost model can capture, despite attempts to adjust for changes in the utilization rate.[11]

In addition, the influence of technological change is confined to its effect on variable costs in these models, even though several major capital-saving innovations may have reduced fixed costs for steel firms during this period. Because we ignore the increased productivity of later vintages of capital, the cost of adjusting the capital stock is underestimated.

We calculated the short- and long-run elasticities implied by the estimations for each of the models. Since the estimated cost function is best interpreted as representing the aggregate technology of all the firms in the industry rather than a particular steelmaking technology, we present price rather than Allen elasticities.[12] Table 3 presents the elasticities calculated from the estimations in columns 1 and 3. (See tables A.l and A.2 in Appendix A for all the elasticities for each model.)

The short-run, own-price elasticities of all four models are consistent with cost-minimizing behavior by the industry. But the estimated long-run elasticities give familiar evidence of noncost-minimizing behavior by the steel industry.[13] Own-price elasticities of quasi-fixed factors are sometimes positive; in particular, this elasticity is always positive for white-collar labor, and is sometimes positive for capital and for blue-collar labor.

The short-run elasticities of substitution are fairly similar, qualitatively, across estimations, and indicate that as a whole the industry uses labor and capital as substitutes for energy and for materials. The long-run elasticities, however, indicate that some factor pairs, such as capital and blue-collar labor, may be complements.[14]

In summary, the estimated elasticities, the J-statistics, and the cost-of-adjustment parameter estimates reveal that model 1, in which labor is aggregated and adjustment costs are based on percentage changes, is the model which most successfully fits the steel data. Adjustment costs are positive for labor and capital, although insignificant for capital; short-run elasticities are negative for both energy and materials; and long-run elasticities for energy, materials, and labor, though not for capital, are also negative.

However, even this model is not entirely successful in fitting a neoclassical model to the steel industry. But as stated above, the result is not entirely unexpected, given that prior researchers are almost unanimous in reporting violations of the neoclassical restrictions in estimates of steel production technology.

VI. Conclusions

The evidence presented in this paper indicates that the estimated adjustment cost coefficients are very sensitive to the method used for measuring changes in the factor stock. Though theoretically less tractable, the percentage change in the stock seems more likely to be related to the cost of adjustment of the stock, and indeed the most sensible results for labor adjustment costs are achieved when this method is used. Such a result indicates the need for further research into the underlying microeconomics of adjustment costs, so that less ad hoc specifications may be tested.

Estimation results obtained when using the percentage-change specification indicate that labor may be costly to adjust in the steel industry. This result may be peculiar to the steel industry, or may be a consequence of the industry's overall decline during the estimation period. If the latter is true, then costly labor adjustment may generally occur in declining industries, and policies that affect the output levels of such industries, such as quotas, may have employment effects over several years, prolonging employment of both blue- and white-collar workers.

Finally, the poor estimates of the cost of adjusting capital probably indicate the need for a more sophisticated model of capital adjustment. Further research is needed into the problem of optimally adjusting capital in a situation where utilization rates may be varied over some range of output, and in which overall industry capacity is contracting.

Footnotes

1. See Soligo (1966) for a discussion of this point.

2. Gould (1968) makes this point about adjustments to the capital stock, and a similar argument can be made for changes in the labor force. In the steel industry, for instance, the cost of laying off a worker rises with his seniority (Deily, 1988). Thus, higher percentages of layoffs in any size firm will be directly related to the adjustment cost, since the probability of more senior workers being laid off may be more closely related to the overall percentage of persons laid off than to the absolute number of layoffs.

3. The following section is a very brief review of the PR model; see Pindyck and Rotemberg (1983), and references therein, for a more complete discussion. The model presented here includes separate adjustment costs for white- and blue-collar labor, an extension that these authors did not pursue in their original article. We estimate models both with and without disaggregated labor series, but present the full model for the sake of clarity.

4. Three transversality conditions specifying that firms approach optimal use of each fixed factor in the long run complete the model. The information in these conditions is not included in the estimation. See Prucha and Nadiri (1984) for an alternative method of estimating dynamic factor demands that does include this information. We do not employ their method because the PR model is more robust with respect to alternative assumptions concerning expectations and the stochastic processes governing the distribution.

5. See Appendix B for a more detailed description of the data set.

6. Data on supplemental payments were not reported until 1967. These payments were estimated by the authors for earlier years.

7. This convoluted method is used because the supplemental labor cost reported by the Census is not separated into payments made to blue- and white-collar workers. The cost data for wage workers from the AISI includes all supplemental payments.

8. Multiplication by .30 adjusts the cost share of capital so that it approximately coincides with the share of capital costs in the total cost of steel production. The figure is based on the industry's total cost and total variable cost per ton of steel for the year 1976, as reported in Deily (1988).

9. A natural question is whether the J-statistics may be used to test the restriction that labor may be aggregated specifically, perhaps using some kind of likelihood ratio test. But the two sets of models employed here are not nested, due in part to the log-log specification.

10. We also estimated a model in which the utilization decision and the cost of adjusting the utilization rate were modeled separately, in addition to the cost of adjusting the aggregate capital stock. The cost of adjusting the labor stock was again positive and significant, while the cost of adjusting the utilization rate was positive but not significant, and the cost of adjusting the aggregate capital stock was negative and significant.

11. In addition, decisions made by firms about adjusting the capital stock may be affected by such considerations as the usefulness of excess capacity as an entry barrier, or by the necessity of maintaining excess capacity in an environment of random production and demand where a fluctuating backlog of orders functions as an implicit futures market (De Vany and Frey, 1982).

12. Three distinct steelmaking technologies were in use in differing amounts during much of the sample period, sometimes all three at the same time in the same plant. Thus, factor elasticities derived from industry data do not represent factor-substitution possibilities available for users of particular steelmaking technologies. See Karlson (1983) for estimates of factor elasticities within a given technology.

13. See Karlson (1983) and Moroney and Trapani (1981). Moroney and Trapani speculate that the reaction of firms to changing environmental regulations may have affected their efforts to minimize costs. In our case, the exclusion of the extra constraints in the transversality conditions may also affect the results.

14. This finding is interesting in light of the argument in Lawrence and Lawrence (1985) that the union was able to bargain up the real wage for steelworkers because the industry's state of decline limited its ability to substitute capital for labor.

Table 1: Adjustment-Cost Coefficients

Parameters	(1)	(2)	(3)	(4)
β_L	6031.2	--	-.0184	
	(2.44)		(-1.78)	
β_{LW}	--	2195.2	--	-.0009
		(4.73)		(-.37)
β_{LB}	--	2807.7	--	.0548
		(2.78)		(3.99)
β_K	3026.51	-1236.9	.00003	-7.1E-05
	(1.48)	(-1.82)	(.49)	(-3.16)

Note: See text for definitions of parameters and column headings. T-statistics in parentheses.

Source: Authors' calculations.

Table 2: Estimates of Cost-Function Parameters

Model:	(1)	(2)	(3)	(4)
α_1	-36.82	26.91	-17.62	18.78
α_2	.38	1.98	-.31	2.11
α_1	-36.82	26.91	-17.62	18.78
α_2	.38	1.98	-.31	2.11
α_3	1.22	.43	-.10	1.30
α_4	--	1.06	--	-.15
α_5	8.41	.006	9.52	-2.52
α_6	1.32	-9.38	-7.50	-.64
$\gamma 11$	.21	.002	.30	-.09
$\gamma 12$	.17	.04	.39	-.05
$\gamma 13$	--	-.33	--	-.43
$\gamma 14$	-.01	-.09	.001	-.08
$\gamma 15$	-.08	.24	-.19	.38
$\gamma 22$	-.29	-.26	.16	-.31
$\gamma 23$	--	.12	--	-.03
$\gamma 24$	-.76	-.14	-.85	-.27
$\gamma 25$	1.49	.28	1.43	.52
$\gamma 33$	--	-1.22	--	-1.13
$\gamma 34$	--	-.18	--	.11
$\gamma 35$	--	1.23	--	.96
$\gamma 44$	-2.36	-.10	-2.74	.47
$\gamma 45$	3.55	.45	4.14	-.30
$\gamma 55$	-8.50	-.23	-7.72	-.47
ι	-.02	-.02	-.02	-.02
J:	$5.53e^1$	$5.99e^5$	$5.68e^1$	$4.06e^5$

Note: When the model is estimated over aggregate labor, all terms in equation (11) referring to blue-collar labor drop out, and LW becomes L, aggregate labor.

Source: Authors' calculations.

Table 3: Short- and Long-Run Elasticities

Model 1: With Aggregate Labor and Percentage Changes of Factor Stocks

Elasticity of Demand For:

	E	M	L	K
e	-.072	.005		
m	.072	-.005		
Q	1.829	2.138		
L	-.517	-1.226		
K	-.374	-.353		
e	-.091	-.050	.118	-.114
m	-.066	-.490	.413	-.203
Q	.986	.869	.642	1.364
s	.252	.669	-.585	.135
v	-.096	-.129	.053	.182

Model 2: With Aggregate Labor and Absolute Changes in Factor Stocks

Elasticity of Demand For:

	E	M	L	K
e	.107	-.090		
m	-.107	.090		
Q	1.684	2.467		
L	-.009	-1.593		
K	-.363	-.369		
e	.132	-.035	-.012	-.070
m	-.042	-.520	.428	-.190
Q	1.187	.684	.627	1.354
s	-.035	-.129	-.455	.108
v	-.056	.969	.046	.153

Source: Authors' calculations.

Appendix A

Table A-1: Short-Run Elasticities

	(1)	(2)	(3)	(4)
$\epsilon(E,e)$	-.072	-.633	.107	-.911
$\epsilon(E,m)$	.072	.633	-.107	.911
$\epsilon(E,Q)$	1.829	2.950	1.684	3.381
$\epsilon(E,L)$	-.517	--	-.009	--
$\epsilon(E,LB)$	--	-1.856	--	-2.137
$\epsilon(E,LW)$	--	-.051	--	-.331
$\epsilon(E,K)$	-.374	-.585	-.363	-.537
$\epsilon(M,e)$	.055	.356	-.090	.487
$\epsilon(M,m)$	-.055	-.356	.090	-.487
$\epsilon(M,Q)$	2.138	1.900	2.467	1.698
$\epsilon(M,L)$	-1.226	--	-1.593	--
$\epsilon(M,LB)$	--	-.407	--	-.230
$\epsilon(M,LW)$	--	-.230	--	-.104
$\epsilon(M,K)$	-.353	-.204	-.369	-.164

Source: Authors' calculations.

Table A-2: Long-Run Elasticities

	(1)	(2)	(3)	(4)
ε(E,e)	-.091	-2.017	.132	-3.696
ε(E,m)	-.066	-.389	-.042	.273
ε(E,Q)	.986	8[illegible]4	1 [illegible]87	.131
ε(E,w)	--	1.333	--	3.111
ε(E,s)	.252	.470	-.035	.407
ε(E,v)	-.096	.603	-.056	-.095
ε(M,e)	-.050	-.219	-.035	.146
ε(M,m)	-.490	-.549	-.520	-.541
ε(M,Q)	.869	1.154	.684	1.200
ε(M,w)	--	.753	--	.457
ε(M,s)	.669	-.048	-.129	-.038
ε(M,v)	-.129	.063	.969	-.024
ε(LB,e)	--	.517	--	1.212
ε(LB,m)	--	.519	--	.333
ε(LB,Q)	--	.857	--	1.177
ε(LB,w)	--	-.582	--	-1.180
ε(LB,s)	--	-.359	--	-.380
ε(LB,v)	--	-.095	--	.016
ε(LW,e)	.118	1.023	-.012	.775
ε(LW,m)	.413	-.187	.428	-.137
ε(LW,Q)	.642	.995	.627	.846
ε(LW,w)	--	-2.017	--	-1.856
ε(LW,s)	-.585	.593	-.455	.677
ε(LW,v)	.053	.588	.046	.541
ε(K,e)	-.114	.637	-.070	-.112
ε(K,m)	-.203	.118	-.190	-.053
ε(K,Q)	1.364	.812	1.354	.845
ε(K,w)	--	-.259	--	.047
ε(K,s)	.135	.285	.108	.336
ε(K,v)	.182	- 7[illegible]1	15[illegible]	-.218

Source Authors' calculations

Appendix B

Scrap

Data on the quantity consumed are taken from "consumption by manufacturers of steel ingots and castings" (which represents consumption of both purchased and home scrap), reported in the Bureau of Mines Minerals Yearbook (MY). The price of scrap is represented by the composite price for #1 heavy melting scrap, as reported in MY. For the years 1954 and 1955, prices from Chilton's Iron Age: Annual Report were used. For the year 1985 the producer price index was applied to the 1976 Minerals Yearbook price.

Iron Ore

Data on consumption of iron ore is from "Salient Iron Ore Statistics," also reported in MY. Price data for iron ore is the average value at the mines, reported on the same table in MY.

Coal

Price data for the years 1954-1976 is the cost of coal at merchant coke ovens as reported in MY. The same data for the years 1977-1980 comes from the Energy Information Agency, Coal Data: A Reference, October 1982. The same data for the years 1981-1985 is from the Energy Information Agency, Quarterly Coal Report, various issues.

Natural Gas

Price data for the years 1954-1970 is taken from the Bureau of Mines, Mineral Yearbook, Fuels, which publishes data on the value, at point of consumption, of natural gas used for fuel by industrial consumers. Prices for the years 1970-1984 are from the Energy Information Administration, State Energy Price and Expenditure Report, 1970-1982, and the Energy Information Administration, State Energy Price and Expenditure Report, 1984.

The 1985 price was calculated from data reported in the EIA Natural Gas Annual 1985 on the quantity and value of natural gas delivered to industrial consumers. Natural gas prices calculated from this data are quite close to those reported in the State Energy Price and Expenditure Report, 1984, but are not identical. This source is used because 1985 data is otherwise unavailable.

Fuel Oil

Data on the average wholesale price of residual fuel oil for the United States are taken from Platt's Oil Price Handbook and Oilmanac, 1985.

Electricity

The electricity prices used are the average revenues per kilowatt-hour sold by the total electric utility industry, and are from the Edison Electric

Institute, Statistical Year Book of the Electric Utility Industry. For the years 1954-1959, the "large light and power" figures are used; for subsequent years, the average revenues from industrial consumers are used. Because of the publishing lag, the 1984 figure used is preliminary and the 1985 figure is estimated from the price reported by the Energy Information Administration in the Monthly Energy Review, September 1986. The price is divided by .94, the average adjustment factor that appears to have been applied to the preceding five years of data in order to get the EIA figures.

The Capital Stock

Investment data for early years is available in Schroeder (1950), who reports the dollar value of gross property additions made by 12 steel firms (which represented virtually all steelmaking capacity) for five-year intervals. The five-year totals are divided among the years equally (in nominal terms), and then adjusted to 1958 dollars using the implicit price deflator for producers' durable equipment. Data from the Census Bureau on investment totals for the industry (SIC 3312) is used for years after 1945, with the exception of the years 1946 and 1948, for which investment figures were estimated by the authors.

The depreciation rate used--12 percent--is a weighted average of the average national rate of depreciation for equipment (13.5 percent) and for structures (7.01 percent). These rates are from an OBE capital stock study of U.S. manufacturing, 1929-1968, and are reported in Berndt and Christensen (1973).

The weights used to sum these depreciation rates reflect the relative sizes of investment in new equipment and new structures by the steel industry. Industry investment patterns for the years 1947 and 1949-1985 were used to calculate the weights. Varying the years included does not change the implied depreciation rate significantly, even though the proportion of equipment to structures rises over time, as might be expected in a mature and subsequently declining industry.

Finally, we adjusted the capital stock to correct for losses due to plant closings. We estimated the remaining depreciated value at time of closing for large plants that were shut down during the period, and subtracted it from the capital stock at that point.

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