# Production and Cost in the Pulp and Paper Industry: A Translog Cost Function Analysis

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## Abstract

The United States pulp and paper industry has experienced significant structural changes over the past twenty-five years, including reductions in the number of pulp and paper mills, lower rates of capacity growth, employment cutbacks, and a loss of market share to foreign competitors. These structural shifts portray an industry that increasingly has difficulty adapting to a more competitive environment and earning sufficient profits to generate a return on investment that covers opportunity costs. Based on aggregate data from 1965-1996, this paper estimates a translog cost function for the industry's short run costs. Adjusting for first order serial correlation, the estimated model fits the data well and all sample points satisfy the monotonicity and concavity conditions. Among the findings, the industry operates at slightly increasing returns to capital utilization and labor and energy are complements in production whereas materials is a substitute in production for the other inputs. Technological progress generated 0.037% reduction in annual operating costs at the mean but the effect was asymmetric with a much larger impact during the early part of the period. Consistent with an ailing industry, estimated marginal costs approximated average operating costs until 1981 after which marginal costs significantly diverged from average operating costs.

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## I. Introduction

During the past quarter century, the U.S. pulp and paper industry has undergone significant structural changes. Between 1975 and 1995, the total number of pulp and paper mills (integrated and non-integrated) decreased from 1,065 to 961 (Melendez, 2002) with the bulk of the decrease occurring in non-integrated paper mills. The number of integrated mills decreased from 269 in 1975 to 233 in 1995. Further, the survival rate of integrated and paper only mills, in existence in 1975 and that survived to 1995, was 65% and 40% respectively. And the average annual capacity growth in total paper, paperboard, and market pulp fell from 2.4% during 1970-1980 to 1.9% during 1980-1990 (USDA, Forest Products Laboratory, 2001). Consistent with these trends, employment in paper and paperboard mills has decreased from 201.4 thousand in 1965 to 171.2 thousand in 1996 (NBER-CES Manufacturing Industry Database, 2000).

Part of the explanation for the changing structure of the industry is the competitive pressure that the U.S. industry is experiencing from Europe, Asia, and South America. As a proportion of world consumption of pulp and paper, the U.S. industry share fell from 41.4% in 1965 to 28.1% in 2000. And although there have been technological improvements to boost industry productivity during the past twenty-five years, growth in average annual output per hour (1992 dollars) in the paper and allied products industry fell from 1.94% during 1970-1980 to 1.57% for in 1980 – 1990 (Bureau of Labor Statistics, Major Sector Multifactor Productivity Indices, Paper and Allied Products Industry).

A number of studies have analyzed the production and cost characteristics of the pulp and paper industry. There is mixed evidence on returns to scale. Buongiorno and Gilless (1980) and Chas-Amil and Buongiorno (1999) estimated returns that were in the constant returns to scale range whereas Stier (1985), Sutton (1973), and Sandwell (1960) found evidence of increasing returns to scale. Buongiorno and Gilless (1980) also found that energy was a substitute for labor, pulp, and capital. Stier (1985), on the other hand, excluded energy from his model due to estimation problems, an omission which may explain his finding that the industry operates under increasing returns to scale. Buongiorno and Gilless (1980) also found that technological improvements reduced input requirements 1.4% per year for the paper sector; for the pulp sector, the authors found no such effect.[1]

This study contributes to the existing literature in exploring industry production and cost structure over a longer time span than previous studies, while adjusting for first-order serial correlation and using price indices which are expected to more accurately reflect input prices. Conditioned on the stock of real capital, the current study estimates a short run translog cost function for the pulp and paper industry for the period 1965-1996.[2]

Among the findings, energy and labor, with few exceptions, are found to be complements in production throughout the period. Unique to this study is the finding that estimated short run marginal costs tracked estimated average operating costs reasonably well until 1982 after which year average costs were substantially higher than marginal costs. In that the industry is highly commoditized, this finding suggests that marginal cost pricing will lead to low returns on investment, which is consistent with the evidence during the eighties and most of the nineties. The analysis also finds that energy own and cross-price elasticities were generally more volatile over the sample period than those for labor and materials inputs.

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[1] Stier (1985) found some wood-using bias over time. And in related work, Lee and Ma (2001) estimated a translog restricted profit function on annual data for the paper sector from 1958 – 1985 to explore substitution possibilities between unpriced pulp and wastepaper. The study found positive but statistically insignificant substitution possibilities.

[2] The sample for this study ends at 1996 and uses input price indices from the CES-NBER Manufacturing Industrial Database. The database was a joint effort between the National Bureau of Economic Research (NBER) and U.S. Census Bureau's Center for Economic Studies (CES) (available at http://www.nber.org/nberces/nbprod96.htm). A major advantage of the CES-NBER database is that energy and materials input prices reflect industry specific input mixes. Data on payroll, cost of material, energy, and real capital stock are for paper and paperboard sub-sectors with 2621 and 2631 as their corresponding SIC codes. Similarly, the CES-NBER weighted energy and material input deflators are calculated specifically for each four-digit SIC sector, which takes into account varying proportions of the inputs employed in paper and paperboard mills. These input deflators, however, are available only through 1996. In contrast, post-1996 price indices, available from the Bureau of Labor Statistics, are at more aggregate levels and are not calibrated explicitly for paper and paperboard mills. Examples of such more aggregated series include lumber and/or woodpulp producer price indices for material inputs and industrial electricity and/or natural gas producer prices indices for energy inputs.

## II. Translog Cost Model

To explore the production structure of the pulp and paper industry, we develop and estimate a flexible form transcendental logarithmic (translog) cost function (Christensen, 1973). Analyzing an industry's cost function provides information on various production and cost characteristics, including scale economies, input demands, substitution elasticities, and measures of average and marginal cost.[3] Traditional or smokestack industries, such as pulp and paper, are capital intensive and unable to immediately adjust their levels of capital stock.[4] Short-term changes in output primarily occur through changes in variable inputs including labor, energy, and materials. For this analysis we assume that capital $K$ is quasi-fixed so that the interpretation of scale economies is more appropriately associated with capital stock utilization. Additionally, the specified short run translog cost function employs a Taylor series approximation around the industry's sample mean as follows:

$$\begin{aligned}
\ln VC_t &= \beta_0 + \beta_q(\ln Q_t - \ln \overline{Q}) + \beta_k(\ln K_t - \ln \overline{K}) + \beta_t \ln T + \sum_{i=1}^{n} \beta_i(\ln P_{it} - \ln \overline{P}_{it}) \\
&+ \frac{1}{2}\beta_{qq}(\ln Q_t - \ln \overline{Q})^2 + \frac{1}{2}\beta_{kk}(\ln K_t - \ln \overline{K})^2 + \frac{1}{2}\beta_{tt}(\ln T)^2 + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij}(\ln P_{it} - \ln \overline{P}_{it})(\ln P_{jt} - \ln \overline{P}_{jt}) \\
&+ \sum_{i}^{n} \beta_{iq}(\ln P_{it} - \ln \overline{P}_{it})(\ln Q_t - \ln \overline{Q}) + \sum_{i=1}^{n} \beta_{ik}(\ln P_{it} - \ln \overline{P}_{it})(\ln K_t - \ln \overline{K}) + \beta_{qk}(\ln Q_t - \ln \overline{Q})(\ln K_t - \ln \overline{K}),
\end{aligned} \tag{1}$$

where $VC_t$ is the industry's variable cost of producing output $Q_t$ at time $t$, $P_{it}$ ($i = 1, \ldots, i$) is the price of the $i^{\text{th}}$ input at time $t$, and $K_t$ is the quasi-fixed level of capital at time $t$. $T$ is a time index which captures technological shifts in the industry's cost function.[5] The bar over a variable indicates a mean value.

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[3] Shephard (1970) theoretically demonstrated that under the assumption of exogenously-determined output levels and input prices there exists an unique relationship between an industry's production and cost functions.

[4] Construction time of a new paper machine is 18-20 months (Diesen, 1998, p. 127).

[5] Significant technological improvements in paper industry are typically achieved through changes in speed and capacity-handling of paper/paperboard machines. For example, in 1955 the maximum speed on a new newsprint machine was 400 meters/minute. In 1995, speed on new newsprint machines was 1,600 meters/minute, a fourfold increase (Diesen, 1998, p. 145).

To be well-behaved, a cost function with a quasi-fixed factor must satisfy several conditions: (a) linear homogeneity in factor prices and (b) symmetry in factor prices, (c) monotonicity and (d) concavity.[6] A cost function is homogenous of degree one in prices when a given change in prices results in a proportionate change in total costs, all else equal. The following restrictions ensure that the cost function satisfies these properties:

$$\sum_{i=1}^{n}\beta_i = 1,\ \sum_{i=1}^{n}\beta_{ij} = \sum_{j=1}^{n}\beta_{ji} = \sum_{i=1}^{n}\sum_{j=1}^{n}\beta_{ij} = 0 \qquad (2)$$

$$\sum_{i=1}^{n}\beta_{iq} = 0;\ \sum_{i=1}^{n}\beta_{ik} = 0;\ \sum_{i=1}^{n}\beta_{it} = 0\cdot \qquad (3)$$

The symmetry restriction requires that $\beta_{ij} = \beta_{ji}$. Under monotonicity input shares have positive signs at all observations and under concavity the matrix of substitution elasticities is negative semidefinite for any combination of cost shares.[7]

The translog cost function in (1) imposes no a priori restrictions on input substitution possibilities and allows scale economies to vary with output and input shares to vary with time. Further, by differentiating the cost function with respect to factor prices (Shephard, 1970) one can get cost shares $S_i$'s for each input *i* in the total variable cost:

$$\mathrm{S_i} = \beta_\mathrm{i} + \frac{1}{2}\sum_{\mathrm{i=1}}^{\mathrm{n}}\beta_\mathrm{ij}(\ln \mathrm{P_{jt}} - \ln \overline{\mathrm{P}}_\mathrm{jt}) + \beta_\mathrm{iq}(\ln \mathrm{Q_t} - \ln \overline{\mathrm{Q}}) + \beta_\mathrm{ik}(\ln \mathrm{K_t} - \ln \overline{\mathrm{K}}). \qquad (4)$$

Allen-Uzawa (Allen 1938, Uzawa 1962) partial substitution elasticities, $\sigma_{ii}$ and $\sigma_{ij,}$ identify the extent of substitution among factor inputs and are functions of the estimated factor shares $S_i$. And, given constant output and constant prices of all other factors, estimates for own and cross price factor demand elasticities, $\eta_{ii}$ and $\eta_{ij}$ , depend upon partial substitution elasticities and factor shares as expressed in equations (5) – (8)

$$\sigma_{ii} = (\beta_{ii} + S_i^{\,2} - S_i)/S_i^{\,2};\ \sigma_{ij} = (\beta_{ij} + S_iS_j)/S_iS_j;\ \text{and} \qquad (5, 6)$$

$$\eta_{ii} = \sigma_{ii}S_i;\ \eta_{ij} = \sigma_{ij}S_j. \qquad (7, 8)$$

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[6] Berndt and Wood (1975), Christensen, Jorgenson, and Lau (1975), and Caves et al. (2002).

[7] A cost function satisfies monotonicity when it is non-decreasing in factor prices. A symmetric matrix is negative semidefinite if all characteristic roots are nonpositive (Greene, 2000, p. 47).

When factors of production are difficult to adjust, the standard formula for calculating returns to scale must be adjusted to account for these quasi-fixed factors. Caves et al. (2002) demonstrate that for the single output case, returns to scale at time *t* are

$$ES_t = \frac{\left(1 - \frac{\partial \ln VC_t}{\partial \ln K_t}\right)}{\frac{\partial \ln VC_t}{\partial \ln K_t}} = \frac{1 - \left(\beta_k (\ln Q_t - \ln \overline{Q}) + \beta_{kk} (\ln K_t - \ln \overline{K}) + \beta_{qk} (\ln Q_t - \ln \overline{Q}) + \sum_i^n \beta_{ik} (\ln P_{it} - \ln \overline{P}_t)\right)}{(\beta_q + \beta_{qq} (\ln Q_t - \ln \overline{Q}) + \beta_{qk} (\ln K_t - \ln \overline{K}) + \sum_i^n \beta_{iq} (\ln P_{it} - \ln \overline{P}_t)}.$$

Note that at mean values of production, capital, and input prices, $ES_t$ is simply $(1/\beta_q)$. Finally, the translog cost function enables one to incorporate technological change and its effects on input factors. For this study, $\beta_t$ and $\beta_{tt}$ identify shifts in the cost function, with positive (or negative) values for $\beta_{it}$ indicating increases (or decreases) in the shares of the respective factor.

## III. Estimation Considerations

Let $Y_t$ be a ($n$ x 1) vector of variable production costs and input cost shares, $X_t$ is a ($n$ x $m$) matrix that includes output $Q$, capital stock $K$, input prices $P_i$ , and year $t$, and $u_t$ is a ($n$ x 1) vector of disturbance terms. Following Berndt (1991), we specify the seemingly unrelated regression (SUR) equation system as:

$$Y_t = X_t \beta + u_t , \tag{10}$$

where $t$ is time and

$$u_t = R u_{t-1} + e_t , \tag{11}$$

which controls for 1st order serial correlation. $R$ is a ($n$ x $n$) autocovariance matrix and $e_t$ is vector of disturbances with mean zero and constant variance. Lagging equation (10), premultiplying by $R$, and subtracting from $Y_t$ yields:

$$Y_t = RY_{t-1} + ( X_i RX_{t-1} )\beta + e_t . \tag{12}$$

To estimate the model using maximum likelihood (12), one of the share equations is dropped. Berndt and Savin (1975) demonstrate that the resulting parameter estimates will be invariant to the equation dropped if *R* is diagonal and its diagonal elements are equal.

Further, we can test various hypotheses related to the production technology that underlies the cost function. Specifically, adding restrictions (13) through (16) to restrictions (2) and (3) enables one to test for homotheticity (13), homotheticity and output homogeneity (14),

$$\beta_{iq} = 0 \tag{13}$$

$$\beta_{iq} = 0 \ , \beta_{qq} = 0 \tag{14}$$

$$\beta_{iq} = 0 \ , \beta_{qq} = 0 , \ \beta_q = 1 \tag{15}$$

$$\beta_{iq} = 0 \ , \beta_{qq} = 0 , \beta_{ij} = 0 , \ \beta_q = 1 \tag{16}$$

homotheticity and output homogeneity with constant returns to scale (15), and Cobb-Douglas technology (16).

Finally, the usual measure of goodness of fit, $R^2$, is not appropriate for the system of equations. Berndt and Khaled (1979) propose a “generalized $R^2$” or pseudo $R^2$:

$$\tilde{R}^2 = \{1 - \exp[2(L_r - L_{un})/T]\}, \tag{17}$$

where $L_r$ and $L_{un}$ is the log-likelihood ratio from the restricted and unrestricted models, respectively, and *T* is the total number of observations. This analysis a the likelihood-ratio test statistic $\chi^2 = -T \ln(1 - \tilde{R}^2)$ to test the hypotheses embodied in equations (13) – (16).

## IV. Data

Table 1 presents descriptive statistics for the U.S. paper and paperboard output and production costs for a 32-year period from 1965 to 1996. The American Forest and Paper Association 2003 Statistics provided data on paper and paperboard output, which averaged 66,390 thousand short tons over the sample period. 1975 and 1982 are years of sharp drops in output – 14 and 5 percent in comparison to the previous year, respectively.

## Table 1
## Descriptive Statistics

| Variable | | N | Mean | Standard Deviation |
|---|---|---|---|---|
| Real Ouput | Thousand Short Tons | 32 | 66,390 | 14,183 |
| Total Short-Run Cost | Millions Current Dollars | 32 | 21,666 | 12,258 |
| Cost of Materials | Millions Current Dollars | 32 | 13,346 | 7,948 |
| Real Capital Stock | Millions of 1987 Dollars | 32 | 200 | 63 |
| Fringle Benefits | Percentage of Total Compensation | 32 | 0.15 | 0.03 |
| Payroll without Fringe | Millions Current Dollars | 32 | 1,615 | 9,862 |
| Payroll with Fringe | Millions Current Dollars | 32 | 5,519 | 2,842 |
| Energy Costs | Millions Current Dollars | 32 | 2,801 | 1,634 |
| Share of Materials Input | Cost of Materials / Short-run Costs | 32 | 0.61 | 0.02 |
| Share of Labor Input | Payroll with Fringe / Short-run Costs | 32 | 0.27 | 0.03 |
| Share of Energy Input | Energy Input / Short-run Costs | 32 | 0.12 | 0.03 |
| Price for Materials | Weighted Price Deflator, 1965=100 | 32 | 295 | 139 |
| Price for Labor | Payroll with Fringe / Employment, 1965=100 | 32 | 370 | 207 |
| Price for Energy | Weighted Price Deflator, 1965=100 | 32 | 435 | 240 |

Short run variable costs, which include labor, energy and materials, and input shares are calculated using data from the CES-NBER Manufacturing Industry Database. In order to better reflect total compensation to labor, we supplemented the NBER payroll data with fringe benefits using the share of fringe benefits implicit in the BEA labor compensation data.[8] Based on the BEA data, Paper and Allied (SIC 26) industries exhibit a steady increase in fringe benefits, from 9% ($152.7 million) in 1965 to 18% ($1,699.8 million) in 1994, and 17% ($1,663.9 million) in 1996. Actual labor share decreases from 30% of total short-run costs in the 1960s to about 20% in 1996. Similar to other cost studies, dividing total compensation by total employment in paper and paperboard sub-industries is a proxy for the price of labor.

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[8] The share of fringe benefits was calculated as the percentage of total labor compensation. In contrast to the CES-NBER payroll information, the BEA labor compensation series includes fringe benefits, but cover the entire Paper and Allied Products industry, or a more aggregated two-digit SIC industry (SIC 26). Additionally, the BEA paper industry mix changes twice, once in 1987 and again in 1997 when the NAICS system replaces the SIC industry re-numeration system. And from 1998 onward, the BEA reports data on the NAICS basis only. Due to these shortcomings, using the BEA data on total compensation was not desirable. The BEA data are available at the Bureau’s site section on Industry, Annual Industry Accounts, GDP by Industry at: http://www.bea.gov/bea/dn2/gdpbyind_data.htm.

Materials costs, consisting of roughly 40% of pulpwood for paperboard and 20% for paper production, present the highest share of short run costs for the industry and exhibit the highest growth rates.[9] Actual shares of materials costs are relatively constant at 60% of total short-run costs, but increase to 70% in 1996. In nominal terms, materials costs grew from $3 to $26.5 billion dollars.[10] Actual average cost shares for energy are around 12% but markedly increase after 1973, peaking to about 18% in the early 1980s, falling back to the 10% level by the end of the 1990s (Figure A-1 in the Appendix). Despite the oil shocks of the 1970s-1980s, nominal energy costs remained relatively flat.[11] Material and energy prices are approximated by relevant NBER deflators which take into account industry-specific input mixes.[12]

Total short-run nominal costs for paper and paperboard grew from $5.23 billion in 1965 to $41.06 billion in 1995, reflecting an annual average increase equal to 21.4 percent. The largest

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[9] Material inputs also differ by type of paper produced. For instance, the single largest input (up to 40%) for paperboard production is pulpwood, while paper production uses pulpwood, chemicals, and woodpulp in approximately equal shares of about 20 percent with the woodpulp portion declining through the 1980s and 1990s. Such variation in material composition among grades presents difficulties in constructing appropriate material price proxies. Earlier studies employ a variety of methodologies to accomplish the task. For instance, Stier (1985) constructs the proxy by weighting the prices of southern pine, northern hardwood and northern softwood pulpwood according to the weights that reflect the share of each group in total production. This approach appears as the most comprehensive and was attainable for the studied period (1948-1972) given the availability of annual data on pulpwood usage. Eckstein and Wyss (1972), Strazheim and Strazheim (1976), and Chung (1979) choose a lumber price index as a proxy for the price of materials. Boungiorno et al. (1983) argue that paper mills use lumber, or more accurately lumber residues, to a very limited extent and its price index is not representative of materials input prices for paper production. By the same token we argue that a woodpulp index is unsuitable for paperboard cost functions as it constitutes only 1-2 percent of total material input costs for paperboard production. As discussed in footnote 2, this paper uses the CES-NBER material cost price deflator because it incorporates material input mixes specific to paper and paperboard sectors.

[10] In real terms, the increase is from $3 to $6 billion (1965) dollars.

[11] Similar to material costs, energy usage mix is not easy to proxy through available price indices. According to the AF&PA 2003 Statistics, over the 20-year period the shares of energy inputs have steadily increased with the exception of residual fuel oil, which dropped from over 40 percent in the early 1970s to only about 13 percent in the 1990s. In 1996, the three top energy sources for the industry were natural gas, coal, and electricity with 40, 28, and 14 percent-shares. Additionally, 1965-1996 is the period of highly volatile energy prices. Figure A1 in the Appendix depicts prices for gas fuels, commercial and industrial electricity price indices, and the CES-NBER energy deflator, computed specifically for paper and paperboard sectors. All four indicators dramatically increase in the mid-1980s. Also, according to the AF&PA 2003 Statistics, purchased energy and fuels constitute only 45 percent of total energy used; the rest is generated internally at the mills. The percent of purchased energy decreased from 60 in 1972 to 45 in 1996. As with material input prices, we selected the industry-specific and weighted energy deflator from the CES-NBER database.

[12] All factor prices are normalized to 1965.

increases in operating costs occurred after the two oil shocks in the 1970s. With the exception of 1975 (with a 2.3% drop in costs), operating costs increased between 15% and 30% during these years.[13]

## V. Estimation Results

Table 2 presents the results for estimating equations (1) and (4) subject to the conditions in equations (2)-(3). Following Lau and Tamura (1972), who argue that output exogeneity is a reasonable assumption for large capital intensive manufacturing facilities that produce intermediate goods as inputs to other production activities and that have long term supply agreements, this analysis assumes that pulp and paper output is exogenous. In addition, in order to avoid potential problems associated with price endogeneity, price lagged one year is included as an instrumental variable for each of the input prices.

The overall fit of the model is good with a system $\tilde{R}^2$ equal to 0.9857 indicating that the model explains 98.5% of the system wide variance.[14] In addition, the estimated cost function satisfies the monotonicity and concavity conditions. For monotonicity, the cost function must be nondecreasing in input prices, which requires that the fitted shares be positive at each observation. For the reported model, the fitted shares are non-negative at all points, are highly correlated with the actual shares, and (necessarily) sum up to one. Concavity requires that the matrix of substitution elasticities, which are based on the fitted factor shares, is negative semi-definite and all points in the sample satisfy this condition.

Adjusting for serial correlation, the model's parameters are invariant to the equation dropped if the autocorrelation coefficient is restricted to be equal across share equations. From

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[13] Real operating costs during the period increased on average 1% per year. The largest drop, at 15%, mirrored the 1975 drop in nominal costs and the largest increases in real costs, at 9%, occurred in 1976 and 1984.

[14] Normality tests on the residuals produced mixed results. The Shapiro-Wilk W univariate test rejected the null hypothesis of normality for the cost and labor share equation but could not reject the null for the energy share equation. In contrast, the Henze-Zirkler T multivariate (system) normality test could not reject the null hypothesis of normality (Henze and Zirkler, 1990).

Table 2, we see that the estimated autocorrelation coefficient is 0.679 and rejects the null hypothesis of no serial correlation at the 0.025 level.[15]

From the descriptive statistics, mean industry production throughout the sample period was 66.4 million short tons at a mean cost of $21.6 billion (current dollars). The first order coefficients for labor and energy, $\beta_l$ and $\beta_e$, respectively, are significant at a 0.01 level and indicate that, at mean production, labor and energy comprised 26.7% and 12.8% of production costs, consistent with the mean values presented in Table 1.[16] And the linear homogeneity restriction implies that materials comprise 60.5% ($1 - \beta_l - \beta_e$) of operating costs at mean

**Table 2**
**Translog Cost Function – Parameter Estimates**

| Parameter | Estimate | Standard Error | t Value | Pr > \|t\| |
|---|---|---|---|---|
| $\beta_0$ | 9.991 | 0.058 | 172.26 | <.0001 |
| $\beta_q$ | 0.818 | 0.510 | 1.61 | 0.125 |
| $\beta_k$ | 0.203 | 0.395 | 0.52 | 0.612 |
| $\beta_l$ | 0.267 | 0.013 | 21.25 | <.0001 |
| $\beta_e$ | 0.128 | 0.012 | 11.17 | <.0001 |
| $\beta_{qq}$ | -1.652 | 2.225 | -0.74 | 0.467 |
| $\beta_{kk}$ | -0.706 | 0.771 | -0.91 | 0.372 |
| $\beta_{ll}$ | 0.131 | 0.020 | 6.41 | <.0001 |
| $\beta_{ee}$ | 0.069 | 0.047 | 1.48 | 0.151 |
| $\beta_{qk}$ | 0.411 | 1.296 | 0.32 | 0.755 |
| $\beta_{lq}$ | -0.121 | 0.110 | -1.11 | 0.280 |
| $\beta_{lk}$ | -0.008 | 0.082 | -0.1 | 0.921 |
| $\beta_{eq}$ | -0.047 | 0.108 | -0.43 | 0.669 |
| $\beta_{ek}$ | 0.060 | 0.080 | 0.75 | 0.461 |
| $\beta_{le}$ | -0.038 | 0.012 | -3.12 | 0.004 |
| $\beta_t$ | -0.306 | 0.112 | -2.73 | 0.013 |
| $\beta_{tt}$ | -0.111 | 0.025 | -4.35 | 0.000 |
| $\rho_1$ | 0.679 | 0.255 | 2.67 | 0.013 |

$\tilde{R}^2 = .9857$
Number of Observations: 32
Log-likelihood at convergence: 298.132

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[15] When not adjusting for serial correlation, a Godfrey lagrange multiplier test (Godfrey, 1978a,b) rejected the null hypothesis of no autocorrelation in each of the models. Additionally, seven observations failed to meet the concavity conditions.

[16] The maximum likelihood parameter estimates presented in Table 2 normalize on materials input shares.

production. Also at mean production, estimated short run costs are $21.5 billion, less than 1/2% difference from the actual costs reported in Table 1.

In addition, as seen in Figures 1-3, the fitted input shares generally track the actual shares well, particularly for materials. Fitted energy shares tend to underestimate actual shares until 1987 when fitted shares are consistently greater than actual shares. Figure 4 depicts actual and fitted short run costs and we see fitted costs track actual costs well, as indicated by a 0.993 correlation coefficient with a root mean square error equal to 0.069.

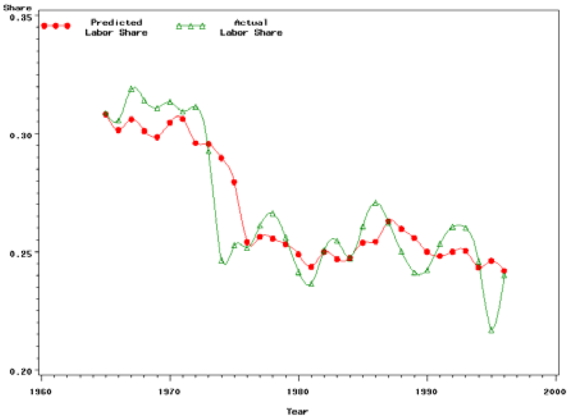

Figure 1

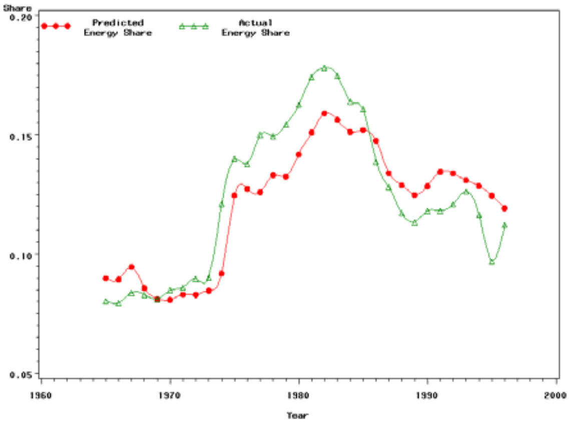

Figure 2

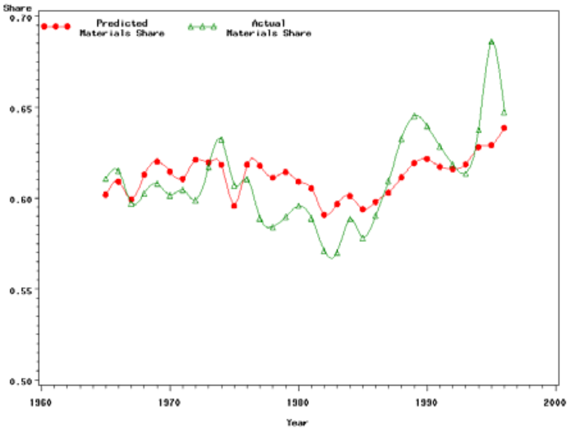

Figure 3

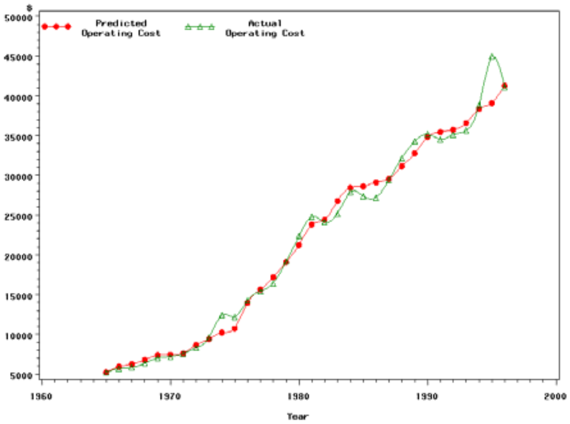

Figure 4

## *V.1 Returns to Capital Utilization*

The first order coefficient for output, $\beta_q$, is 0.818 and significant at a 0.12 level on a two-sided test.[17] Given that capital is a fixed factor of production, a value of $\beta_q$ that is less than 1 indicates that the pulp and paper industry is operating under increasing returns to capital utilization. At mean production, a 1% increase in output leads to a 0.818% increase in short run costs, implying returns to capital utilization equal to $(1/\beta_q) = 1.22$. However, the test statistic for the null hypothesis that $\beta_q = 1$ is $(\hat{\beta}_q - 1)/\hat{\sigma}_{\hat{\beta}_q} = (0.818 - 1)/0.51 = -0.364$, that is, we cannot reject the null hypothesis that, at mean production, inputs, and quasi-fixed factor, the industry in the United States operated under constant returns to capital stock utilization.

Further, at mean production, the coefficient for capital is positive (0.203) but we cannot reject the null hypothesis that the coefficient is zero at any reasonable level of significance. This suggests that capital stock increases had relatively little impact on short run operating costs. With large fixed costs, capital intensive industries have strong economic incentives to operate their capital at full capacity (capital utilization percentage generally ranges from the upper 80’s to lower 90’s) and these results are consistent with an industry whose scale of operations is sufficiently large that further capital investments have little impact upon operating costs.[18]

## *V.2 Technological Change*

The estimated model reported in Table 2 also includes time in order to capture technological and other time-related changes in the pulp and paper industry throughout the sample period. Based upon preliminary work, the best model included $(\ln T)$ and $(\ln T)^2$ as explanatory variables. The estimated coefficient for the level and squared specification is

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[17] Theoretically, an increase in output will increase costs justifying a one-sided test. On this basis, the coefficient for output is significant at a 0.062 level.

[18] Also consistent with this result is that capital investment and changes in real capital stock often reflect machine rebuilds rather than new capacity.

significant at the 0.025 and 0.01 levels, respectively. The results suggest that technological progress generated a 0.037% annual reduction in short run operating costs.[19]

### *V.3 Tests on Properties of the Production Function*

Table 3 reports results for testing more restrictive forms of the cost function and underlying production technology. To test for homotheticity, set all coefficients of the cross terms between input prices and output equal to 0, i.e. $\beta_{iq}$ ($i = 1, \ldots, n$) = 0. If, in addition, $\beta_{qq} = 0$, then the cost function is homothetic and homogeneous in output of constant degree ($1/\beta_q$). And restricting $\beta_q$ to 1 yields a homothetic and homogeneous function with constant returns to scale. Further restricting the cross price terms to 0, i.e. $\beta_{ij}$ ($i, j = 1, \ldots, n$; $i \neq j$) = 0, gives a Cobb-Douglas specification under constant returns to scale. Based upon a likelihood ratio test (equation 18), the results reject the null hypothesis in each case at a 0.05 critical value, indicating that the underlying production technology in the pulp and paper industry is neither homogeneous nor homothetic. However, using a more restrictive 0.01 level, the null hypothesis for homotheticity is accepted, providing some evidence that output can be increased at constant input ratios. Also, given the reported test results for homotheticity and output homogeneity, it is not surprising that the estimation results also reject a Cobb-Douglas technology.

**Table 3**

| **Hypotheses** | **# Restrictions** | **$\chi^2$ value** | **p-value** |
|---|---|---|---|
| Homotheticity (equation 13) | 2 | 8.58 | 0.0190 |
| Homotheticity and output homogeneity, degree ($1/\beta_q$) (equation 14) | 3 | 15.86 | < 0.01 |
| Homotheticity and output homogeneity, degree 1 (equation 15) | 4 | 44.56 | < 0.01 |
| Cobb-Douglas (equation 16) | 5 | 47.55 | < 0.01 |

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[19] From the specified model, $(\beta_t/t) + (\beta_{tt}/t)$ ($\ln t$) gives the percentage change in short run costs with respect to time. Evaluating the time index $t$, which runs from 1 through 32, at its mean of 16.5 and substituting the estimated coefficients for $\beta_t$ and $\beta_{tt}$ gives -0.037.

### *V.4 Substitution and Demand Elasticities*

Tables 4(a) and (b) report the Allen-Uzawa elasticities of substitution and the short run own and cross price elasticities of demand. From Table 4, we see that materials input is a substitute for labor and energy in the production of pulp and paper. Further, the extent of substitutability is similar as reflected in the quantitative estimates at mean production. In both cases, a 1% increase in the relative price of labor and energy, respectively, increases the relative productivity of materials on the order of 0.3%.[20] Energy, on the other hand, is complementary to labor in the production process. All else constant, a 1% increase in the price of labor relative to the price of energy generates a 0.58% reduction in the relative productivity of energy.

**Table 4(a)**

**Elasticities of Substitution**

| | | | | | |
|---|---|---|---|---|---|
| $\sigma_{ll}$ | -0.906 | | | | |
| $\sigma_{le}$ | -0.582 | $\sigma_{ee}$ | -2.612 | | |
| $\sigma_{lm}$ | 0.371 | $\sigma_{em}$ | 0.379 | $\sigma_{mm}$ | -0.339 |

$\sigma_{ij}$ is the percentage change in the marginal rate of substitution resulting from a 1% increase in input ratio.

**Table 4(b)**

**Input Demand Elasticities**

| | | | | | |
|---|---|---|---|---|---|
| $\eta_{ll}$ | -0.267 | | | | |
| $\eta_{le}$ | -0.047 | $\eta_{ee}$ | -0.406 | | |
| $\eta_{lm}$ | 0.220 | $\eta_{em}$ | 0.233 | $\eta_{mm}$ | -0.200 |

$\eta_{ij}$ is the percentage change in the demand for input i from a 1% increase in the price of input *j*.

Table 4(b) presents the own and cross elasticities of demand where each factor input is price inelastic. With an own elasticity of demand equal to -0.406, the industry is most price sensitive to energy. A 10% increase in energy prices reduces industry demand by a bit over 4%. And consistent with the results reported in Table 4(a), the cross price elasticity between labor and

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[20] This interpretation assumes that input markets are competitive.

materials is similar to that between energy and materials. Also, as expected from Table 4(a), energy and labor are complements in production.

Figures 5 – 10 depict the own and cross price elasticities over the sample period. In Figures 5 – 7, we see that the own price elasticity for labor and materials remained relatively stable throughout the thirty-two years, varying between (-0.27, -0.22) and (-0.19, -0.17) respectively. Whereas energy was relatively price inelastic in the early part of the sample, during the oil price shocks of the 1970s, there was a dramatic and permanent increase, in absolute value, in the own price elasticity of demand. In the last year of the sample, the own price elasticity for

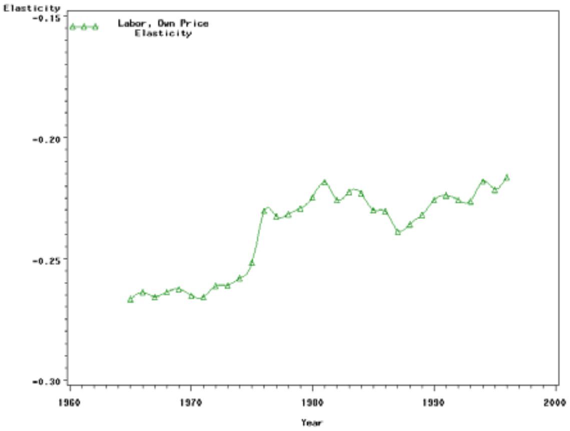


**Figure 5**
**Labor, Own Price Elasticity**

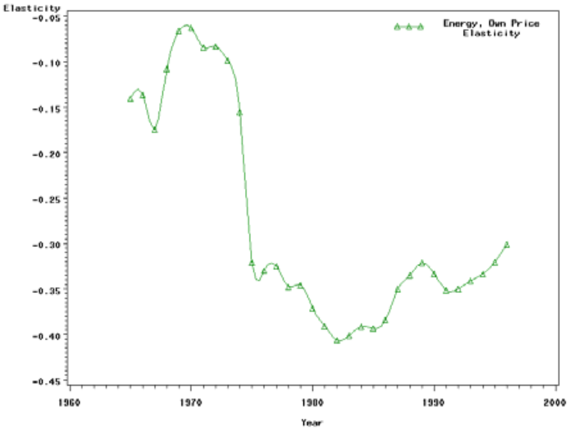


**Figure 6**
**Energy, Own Price Elasticity**

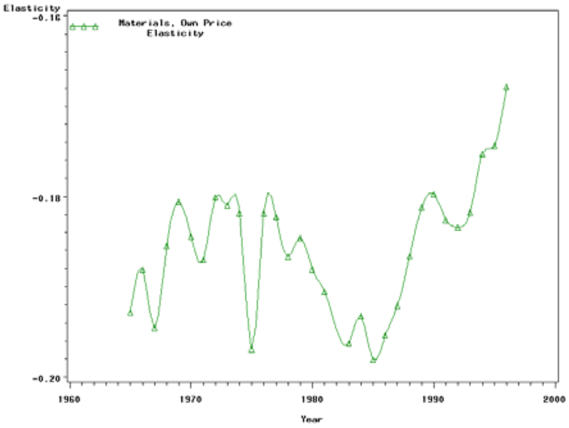


**Figure 7**
**Materials, Own Price Elasticity**

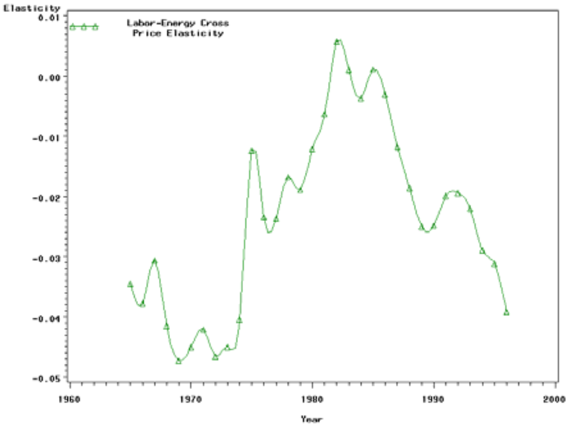
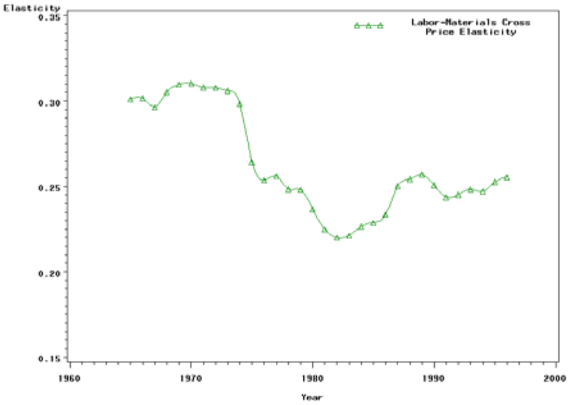


**Figure 8**
**Labor-Energy, Cross Price Elasticity**



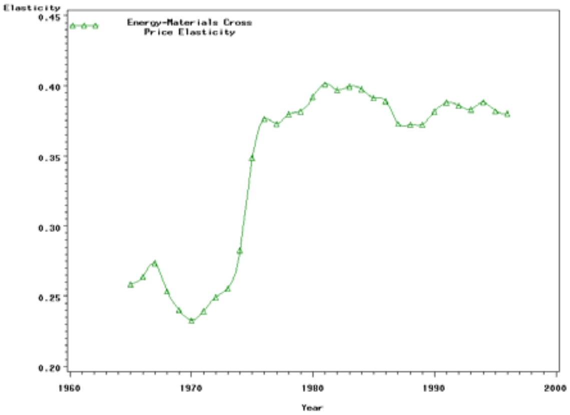


**Figure 9**
**Labor-Materials, Cross Price Elasticity**

**Figure 10**
**Energy-Materials Cross Price Elasticity**

energy was double its value in 1965. From Figures 7 – 9, we see that the cross price elasticity between labor and energy moved within a relatively large range, (-0.35, 0.05). Although for most of the period, and at mean production, labor and energy were complementary in production, they were substitutes in production for the years 1982, 1983, and 1985. Labor was consistently a substitute for materials with relatively little absolute variation in the cross price elasticity, ranging between 0.22 and 0.30. In contrast, there was greater movement in the cross price elasticity between energy and materials during the sample period. With a (0.24, 0.40) range, the cross price elasticity increased from 0.25 in 1965 to 0.40 in 1981 and remained just below that level for the rest of the sample period.

### *V.5 Technological Progress*

On average, the pulp and paper industry experienced a .037% annual decrease in operating costs throughout the sample period. Figure 11 depicts the pattern of cost reductions and indicates that the industry experienced considerably higher cost reductions in the late 1960s. By the early 1970s, annual costs due from technological innovations decreased in the .05% – .10% range. And by the early to mid-1980s, the operating cost reductions from technological progress lay in the .03% - .04% and .02% in the 1990s.

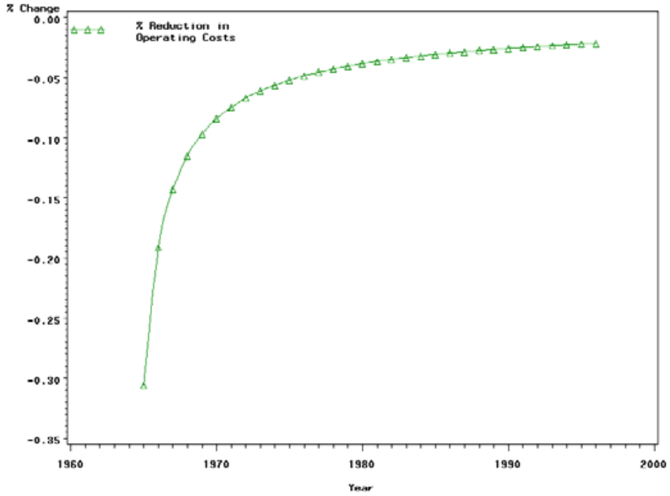


**Figure 11**
**Cost Reduction from Technological Progress**

### *V.6 Industry Operating Profits*

At the sample mean, the average cost of production was $0.301 million, significantly above the estimated marginal cost at $0.230 million. Buffeted by increasing competition from Europe, South America, and Asia, the U.S. pulp and paper industry struggled throughout this period, particularly since the 1980s. Historically, the U.S. industry has not enjoyed significant pricing power and the increased competition from abroad reinforces the competitive environment that the U.S. industry faces. In the absence of significant pricing power, profit maximization implies marginal cost pricing. And the results of this analysis suggest that marginal cost pricing will not cover operating costs let alone the industry's total costs of production.

Figure 12 depicts the estimated marginal and average operating costs for the pulp and paper industry during the sample period. Through 1982, average and marginal costs were reasonably close. However, after 1982 the industry's average operating costs were significantly above its marginal cost of production suggesting that marginal cost pricing generated an industry return on investment that was insufficient to cover its cost of capital. For the period between 1985 and 1996, the estimated average cost of production was $419 (0.419), 72% higher than the

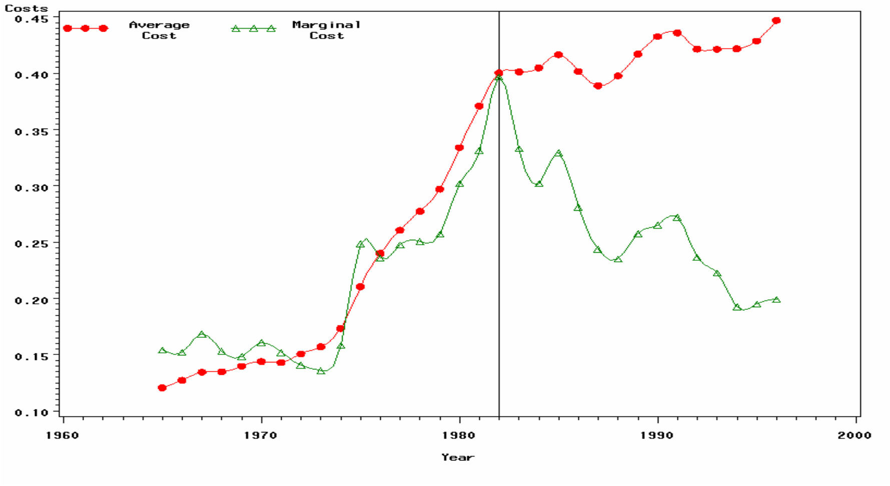


**Figure 12**
**Pulp and Paper Operating Costs (000), 1965 - 1996**

estimated marginal cost at $244 (0.244). This difference was apparent to the industry as the 1980s were a period of significant merger activity and industry consolidation. Between 1975 and 1995, the number of integrated mills fell from 269 to 233 respectively. And between 1975 and 1985 average capacity increased at an annual rate of 5.3% in comparison with 2.5% between 1985 and 1995 (Melendez, 2002).

## VI. Summary and Conclusions

In order to better understand the production characteristics of the U.S. pulp and paper industry, this paper developed and estimated a translog cost function for the industry’s short run or operating costs. In contrast to other cost analyses of the industry, the present model spans a thirty-two year time period, 1965-1996, accounts for three primary inputs that go into the production of pulp and paper (labor, energy, and materials), and employs input price indices that more accurately reflect the mix of inputs in the production process. Assuming quasi-fixed capital and adjusting for first order serial correlation, the estimated model fits the data well with the system explaining more than 98% of system-wide variance. Further, the estimated model satisfies the monotonicity and concavity conditions at all sample points and rejects simpler specifications such as the Cobb-Douglas model.[21]

The results indicate that the U.S. industry operated at slightly increasing returns to capital utilization although a t-test at a .05 level could not reject the null hypothesis that the industry operated under constant returns to scale. Further, in-sample predictions of input shares and short run costs (evaluated at the sample mean and with materials share determined from the constraint that the sum of shares must equal one) also indicate that the model fits the data well.

At mean production, labor and energy are complements in production whereas materials is a substitute in production for both labor and energy. Of particular interest is the relative volatility of price sensitivity to energy throughout the period. The own price elasticity of energy as well as the cross price elasticities with respect to energy prices reflected greater variation throughout the sample period. Although comprising less than 15% of total operating costs, the effects of changes in the energy markets are clearly visible in the estimated elasticities.

To the extent that time captures technological progress in the industry, the results indicate that innovation generated 0.037% reduction in annual operating costs at the sample mean. But innovation played a much larger role in the latter part of the 1960s, reducing costs by 0.30%. By the 1990s, technology-induced cost reductions had fallen to a meager 0.02% per year, which raises obvious concerns about the industry's ability to compete in today's global marketplace

An important and unique finding is that from 1965 through 1981 marginal costs reasonably approximated average operating costs. But from 1982 onwards, estimated marginal costs have significantly diverged from estimated average operating costs. This is consistent with reduced importance of innovation and, more generally, with the failing economic health of the

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[21] To assess whether the results were robust to price indices, the model was also estimated using more aggregated input price indices, i.e. indices that do not reflect industry-specific input mixes. Consistent with expectations, the results led to an inferior fit. The log-likelihood at convergence was lower (277.27 versus 298.13) and fewer variables were statistically significant. In addition, the own elasticity of substitution for labor was half the value reported in Table 4(a) and more than twice the value for energy. There were also large differences in the elasticities of demand for labor and energy.

industry during the past twenty-five years. Between 1975 and 2002, the North American industry earned an average 6.7% return on total capital in comparison with a 11% average cost of capital during this period.[22]

The findings in this research provide a number of insights into costs and production in the pulp and paper industry at an industry-wide level which aggregates all industry output. Extensions to this work include a disaggregated analysis by product type as well as by observation. Analyses of product categories such as paper and paperboard, wrapping and packaging, newsprint, printing and writing papers, and household and sanitary papers would improve our understanding of differences that exist in the cost structures of alternative products that could help explain differences in the economic performance and growth of these sectors. In addition, this analysis conditions on the level of capital and focused on short run operating costs that the industry faces. How would the results change in a long run analysis of the industry and where on the long run average cost curve does a ‘representative’ firm operate in the short run? The existing study deepens our knowledge of the U.S. industry and, along with answers to these other questions will foster improved decision-making by pulp and paper managers and others grappling with increasing competitive pressures from outside the U.S.

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[22] McNutt, J. A. 'State of the North American (and Maine) Pulp and Paper Industry', in, *Maine Pulp and Paper Industry Foundation*, 2003).

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# Appendix

Figure A1