Production and Cost in the U.S. Paper and Paperboard Industry

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Abstract

The United States paper and paperboard industry has experienced significant structural changes over the past twenty-five years, including reductions in the number of 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 global environment. Based on aggregate data from 1965-1996, this paper estimates a short run translog cost function for the industry. The estimated model fits the data well and all sample points satisfy monotonicity and concavity conditions at all points. Among the findings, the industry operates at slightly increasing returns to capital utilization and labor and energy are Allen-Uzawa complements but Morishima substitutes in production. Technological progress generated 0.02% reduction in annual operating costs and consistent with an ailing U.S. industry, estimated marginal costs approximated average operating costs until 1982 after which marginal costs significantly diverged from average operating costs.

JEL: D2, L11, L25, L67, L73

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I. Introduction

During the past quarter century, the U.S. paper and paperboard industry has undergone significant structural changes. The total number of paper and paperboard mills decreased from 351 to 220 (U.S. Census Bureau, http://www.census.gov/econ/census02/data/industry/) between 1967 and 1997, with the number of large integrated mills decreasing 16.3% and experiencing a 65% survival rate during the period. Average annual capacity growth in paper, paperboard, and market pulp fell from 2.4% in 1970-1980 to 1.9% in 1990-2000 (Ince et al., 2001, p. 6). Consistent with these changes, paper and paperboard mills lost 65.9 thousand jobs between 1972 and 2000 (Economagic, http://www.economagic.com/).

Part of the explanation for the changing industry structure is the competitive pressures 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 notwithstanding technological improvements 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 1980-1990 (Bureau of Labor Statistics, Major Sector Multifactor Productivity Indices, Paper Products, http://www.bls.gov/PDQ/outside.jsp?survey=mp).

A number of recent studies have analyzed the industry's competitive structure and capital investments. Based upon detailed mill data between 1900 and 1940, Ohanian (1994) found that vertical integration in the U.S. industry was consistent with a transactions costs model of consolidation, a result that Melendez (2002) confirmed using data for 1975-1995. Christensen and Caves (1997) analyzed investment plans in the North American pulp and paper industry for the period 1978-1991 and concluded that firms in the more competitive segment of the industry and with fewer resources were more likely to abandon previously announced capacity expansions whereas firms in the less competitive segment abandoned fewer projects and were more likely to complete projects when rivals unexpectedly announced expansions. Subject to capacity constraints, they also found that firms priced competitively. Bernstein (1992) developed a dynamic model, incorporating capital adjustment costs and non-competitive behavior in the product and factor markets. Analyzing the Canadian pulp and paper industry from 1963-1987, he found that the industry was in short run equilibrium, competitive in both markets, and experienced small scale economies. For the U.S. industry, Stier (1985) also found evidence of scale economies whereas for fifteen EU countries Chas-Amil and Buongiorno (1999) estimated scale economies that were in the constant returns range.[1]

Comprising a very capital intensive industry, paper and paperboard firms operate at high capital utilization rates. Combined with competitive pricing, this implies that industry wide capital investments drive prices down to levels that cannot cover the cost of capital. One response to this is industry consolidation. In an analysis of thirty-one horizontal mergers in the U.S. paper and paperboard segment during the mid-1980s, Pesendorfer (2003) focused on capacity investments and found that the increased capacity and a larger number of plants of the merged firm generally reduced marginal costs. The mergers had little effect on consumer surplus, consistent with a competitive environment, generally increased producer surplus, reflecting cost reductions, and increased (decreased) profits overall for merged (unmerged) firms.

Aiginger and Pfaffermayr (1997) analyzed welfare losses for fifteen paper companies operating in the European Union during 1989-1993. Arguing that cost differences among active firms in an oligopolistic environment reflected cost inefficiencies, they demonstrated that the associated welfare losses were primarily cost rather than demand side inefficiencies, consistent with Pesendorfer's welfare results and with short run pricing competition.

The objective of this paper is to better understand the production and cost characteristics of the U.S. paper and paperboard industry, particularly in light of structural changes that have occurred during the past twenty-five years. The analysis estimates a short run translog cost model

[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.

and contributes to the existing literature in at least three ways. First, the analysis covers a longer time span, 1965-1996, than previous studies and uses price indices which are expected to more accurately reflect input prices.[2] And in contrast to existing studies on the industry, we correct for first-order serial correlation. Second, to analyze input substitutability, we report Allen-Uzawa (one factor - one price) and Morishima (two factor - one price) elasticities of substitution. Third, we explicitly analyze the behavior of short run average and marginal production costs in order to get additional insight on the industry's competitive environment.

II. Methodology

To explore the production structure of the paper and paperboard industry, we develop and estimate a flexible form cost function model. Although there is no consensus among the several candidate models, two popular forms are the generalized Leontief (Morrison, 1988) and the transcendental logarithmic (translog) specification (Christensen, Jorgenson, and Lau, 1975). This study adopts a translog specification because existing research suggests that a translog functional form is as reliable (Guilkey, Lovell, and Sickles, 1983) as other commonly applied forms and less sensitive to starting point values of the elasticity of substitution (Despotakis, 1986). Further, a generalized Leontief model (with and without correcting for serial correlation) was estimated for this study and the results were uniformly inferior to a translog specification in terms of statistical significance and meeting concavity conditions.[3]

[2] The sample for this study ends at 1996 and uses input price indices from the NBER-CES 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 NBER-CES 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 NBER-CES weighted energy and material input deflators are calculated specifically for each four-digit SIC sector, which take into account varying proportions of the inputs employed in paper and paperboard mills. These input deflators, however, are available only through 1996.
[3] In addition to the translog (TL) and GL models, other flexible form models include the generalized Cobb-Douglas (GCD), the symmetric generalized McFadden (which is comparable to the GL functional form (McFadden (1978)), and the normalized quadratic (NQ) functional form. The results of several assessment studies are mixed. In their study of the TL, GL, and GCD, Guilkey, Lovell, and Sickles (1983) concluded that the TL model was a 'dependable approximation to reality provided that reality is not too complex' (p.

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.[4] Such traditional or smokestack industries as paper and paperboard are capital intensive and unable to immediately adjust their levels of capital stock.[5] 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. Derived from a Taylor series approximation around the industry's sample mean, the short run translog cost function for this analysis is:

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

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^{th} input at time T, and K_t is the quasi-fixed level of capital at time t. T is a time index

614), that, as noted in the text, the alternatives were no more reliable relative to a TL specification, and the GL model was a 'distant third' (p. 614), except in cases characterized by small and positive elasticities of substitution. In an analysis of dynamic factor demands, rather than focusing on regions where functional forms are well behaved (the outer domain), Despotakis (1986) focuses on the inner domain, subregions of the outer domain that provide 'good approximations' of the true technology. In his (with correction by Kittelsen, 1989) analysis of a 3 input constant returns to scale technology, he finds that the TL model is less sensitive than GL to starting point values of elasticities of substitution but that differences in the economic performance of alternative models can be large. And in evaluating these models for use in applied general equilibrium analysis, Perroni and Rutherford (1998) find that TL, GL, and the NQ all tend towards failing concavity conditions when cross price elasticities are large and, collectively, perform poorer than globally regular functions. In an analysis of dynamic factor demands, Mahmoud, Robb, and Scarth (1987) argue for a GL over a NQ because the normalized factor demand in the NQ depends on a different set of variables than those for other variable inputs. In addition, an advantage of the GL form for short run analysis is that one can analytically compute the equilibrium level of the quasi-fixed factor (Morrison, 1988).

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

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

which captures shifts in the cost function due to technological progress in the industry.[6] The bar over a variable indicates a variable's mean value.

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.[7] 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:

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

$$\sum_{i=1}^{n}\beta_{iq} = 0;\ \sum_{i=1}^{n}\beta_{ik} = 0;\ \sum_{i=1}^{n}\beta_{it} = 0. \tag{3}$$

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.[8]

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

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

Allen-Uzawa (Allen 1938, Uzawa 1962) and Morishima partial substitution elasticities, σ_{ij}^{AU} and σ_{ij}^{M}, provide two alternative measures of substitution between factor inputs. Based upon estimated factor shares S_i and price elasticities of demand η_{ij}, the Allen-Uzawa elasticities are one

[6] 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).

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

[8] 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).

factor - one price measures, reflecting the impact on the use of factor x_i due to an increase in the price of factor x_j , all else constant:

$$\sigma_{ij}^{AU} = (\beta_{ij} + S_i S_j) / S_i S_j = \sigma_{ij}^{AU} = \frac{\eta_{ij}}{S_j} \tag{5}$$

An alternative to Allen-Uzawa is Morishima's measure of substitution between inputs, a two factor - one price measure, which more closely reflects substitutability between inputs. In response to a factor price increase, Morishima's measure gives the impact on the input ratio:

$$\sigma_{ij}^{M} = \eta_{ij} - \eta_{jj} = \frac{\partial \ln(x_i / x_j)}{\partial P_j}, \tag{6}$$

where P_j is the price of factor j (Chambers, 1988). In contrast to Allen-Uzawa, the Morishima measure is not sign symmetric. Also, although Allen-Uzawa substitutes are Morishima substitutes, two factors may be Allen-Uzawa complements but Morishima substitutes. Both measures are reported in this paper.

When factors of production are difficult to adjust, the standard formula for calculating returns to scale must be adapted 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:

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

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, β_t and β_{tt} identify shifts in the cost function, with positive (or negative) values for β_{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, the statistical procedure enables us to 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, respectively, for homotheticity (13),

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

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

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

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

homogeneity (14), unitary elasticity of substitution (15), and constant returns to scale (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:

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

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 uses a likelihood-ratio test statistic $\chi^2 = -T\ln(1-\widetilde{R}^2)$ 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 (AF&PA) 2003 Statistics provided data on paper and paperboard output, which averaged 66,390 thousand short

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

Authors' calculations.

tons over the sample period. 1975 and 1982 are years of sharp drops in output – 14% and 5% in comparison to the previous year, respectively.

Short run variable costs, which include labor, energy and the cost of materials, and input cost shares are calculated using data from the NBER-CES Manufacturing Industry Database (Bartlesman, Becker, and Gray, 2000). 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 Bureau of Economic Analysis (BEA) labor compensation data.[9] 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.

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.[10] 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

[9] The share of fringe benefits was calculated as the percentage of total labor compensation. In contrast to the NBER-CES payroll information, the BEA labor compensation series includes fringe benefits but covers the entire Paper and Allied Products industry, i.e. a more aggregated two-digit SIC industry (SIC 26). Also, 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. Hence due to potential data mismatching, using the BEA data on total compensation was not desirable. The BEA data are available from its website on Industry, Annual Industry Accounts, GDP by Industry (http://www.bea.gov/bea/dn2/gdpbyind_data.htm).

[10] Material input mix also differs 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% with the woodpulp portion declining through the 1980s and 1990s. Such variation in material composition among grades presents difficulties in constructing appropriate materials price proxies. Earlier studies employ a variety of approaches to accomplish the task. 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, Farimani, and Chuang (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 function as it constitutes only 1-2% of total material input costs for paperboard production. As discussed in footnote 2, this paper uses the NBER-CES material cost price deflator because it incorporates material input mixes specific to paper and paperboard sectors.

\$26.5 billion dollars.[11] 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. Despite the oil shocks of the 1970s-1980s, nominal energy costs remained relatively flat.[12] Material and energy prices are approximated by relevant NBER deflators which take into account industry-specific input mixes.[13]

Total short-run nominal costs grew from \$5.23 billion in 1965 to \$41.06 billion in 1995, reflecting an annual average increase equal to 21.4%. The largest increases in operating costs occurred after the two oil shocks in the 1970s. Operating costs increased 15% and 30% in 1972 and 1973 and 16% in 1979 and again in 1980.[14]

V. Estimation Results

Table 2 presents the results for estimating equations (1) and (4) subject to the conditions in equations (2)-(3) and (13)-(16). 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 paper and paperboard 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.[15]

[11] In real terms, the increase is from \$3 to \$6 billion (1965) dollars.
[12] Similar to material costs, industry-specific energy consumption patterns and volatile energy markets complicate obtaining appropriate proxies for energy input prices. 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% in the early 1970s to only about 13% in the 1990s. In 1996, the three top energy sources for the industry were natural gas, coal, and electricity with 40%, 28%, and 14% shares. 1965-1996 marks the period of high volatility in energy prices with especially dramatic increases in the mid-1980s. Finally, AF&PA 2003 Statistics also report that the share of purchased energy decreased from 60% to 45% during 1972-1996 with the rest generated internally at the mills. As with material input prices, we selected the industry-specific and weighted energy deflator from the NBER-CES database.
[13] All factor prices are normalized to 1965.
[14] Real operating costs 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.
[15] 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

Table 2
Translog Cost Function – Parameter Estimates

Parameter	Estimate	Standard Error	t Value	Pr > |t|
β_0	9.991	0.058	172.26	<.0001
β_q	0.818	0.510	1.61	0.125
β_k	0.203	0.395	0.52	0.612
β_l	0.267	0.013	21.25	<.0001
β_e	0.128	0.012	11.17	<.0001
β_{qq}	-1.652	2.225	-0.74	0.467
β_{kk}	-0.706	0.771	-0.91	0.372
β_{ll}	0.131	0.020	6.41	<.0001
β_{ee}	0.069	0.047	1.48	0.151
β_{qk}	0.411	1.296	0.32	0.755
β_{lq}	-0.121	0.110	-1.11	0.280
β_{lk}	-0.008	0.082	-0.1	0.921
β_{eq}	-0.047	0.108	-0.43	0.669
β_{ek}	0.060	0.080	0.75	0.461
β_{le}	-0.038	0.012	-3.12	0.004
β_t	-0.306	0.112	-2.73	0.013
β_{tt}	-0.111	0.025	-4.35	0.000
ρ_1	0.679	0.255	2.67	0.013

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

Authors' calculations.

The overall fit of the model is good with a system $\widetilde{R}^2$ equal to 0.9857 indicating that the model explains 98.5% of the system wide variance.[16] 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

298.13) and fewer variables were statistically significant. In addition, the Allen-Uzawa 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.

[16] 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).

matrix of substitution elasticities, which are based on the fitted factor shares, is negative semi-definite and this condition is also satisfied at all points in the sample.

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 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.

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, β_l and β_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.[17] And the linear homogeneity restriction implies that materials comprise 60.5% ($1 - \beta_l - \beta_e$) of operating costs at mean 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. An analysis of fitted shares and costs found that the fitted input shares generally tracked the actual shares well, particularly for materials. Fitted energy shares tended to underestimate actual shares until 1987 when fitted shares were consistently greater than actual shares. Actual and fitted short run costs track well, with a 0.993 correlation coefficient and a root mean square error equal to 0.069.

V.1 Returns to Capital Utilization

The first order coefficient for output, β_q, is 0.818 and significant at a 0.12 level on a two-sided test.[18] Given that capital is a fixed factor of production, a value of β_q that is less than 1 indicates that the paper and paperboard 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

[17] The maximum likelihood parameter estimates presented in Table 2 normalize on materials input shares.
[18] Theoretically, an increase in output increases costs justifying a one-sided test. On this basis, the coefficient for output is significant at a 0.062 level.

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 $(\hat{\beta}_q - 1) \big/ \hat{\sigma}_{\hat{\beta}_q}$ = (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.[19]

V.2 Technological Change

The estimated model reported in Table 2 also includes time in order to capture technological and other time-related changes that have occurred in the paper and paperboard industry throughout the sample period. Based upon preliminary work, the best model included (ln T) and (ln $\overline{T}$)^2 as explanatory variables. The estimated coefficient for the level and squared specification is significant at the 0.025 and 0.01 levels, respectively. The results suggest that technological progress generated a very modest 0.02% annual reduction in short run operating costs.[20]

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

[20] From (1), the elasticity of short run costs with respect to time is $\beta_t + (\beta_{tt} / T)(\ln T - \ln \overline{T})$. Evaluating the time index t, which runs from 1 through 32, at its mean of 16.5, substituting the estimated coefficients for β_t and β_{tt}, calculating the elasticity for each observation and taking the mean gives 0.02. Various specifications for technology change were estimated, including ln T and (ln T)^2 without normalizing at the mean and T and T^2 , with and without normalizing at the mean. The reported model was uniformly superior to these specifications. Also, models which accommodated factor augmentation for the variable and quasi-fixed factor of production were estimated. In these alternative models, the time variables were either not

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

Table 3

Hypotheses	**# Restrictions**	**χ^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

Authors' calculations.

between input prices and output equal to 0, i.e. β_{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 β_q to 1 yields a homothetic and homogeneous function with constant returns to scale. Further restricting the cross price terms to 0, i.e. β_{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 paper and paperboard 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.

significant or less significant, not all observations satisfied concavity conditions, and none of the biased technology coefficients were significant.

V.4 Substitution and Demand Elasticities

Table 4(a) and 4(b) report the Allen-Uzawa and Morishima elasticities of substitution. From Table 4(a) we see that materials input is a substitute for labor and energy in the production of paper and paperboard. Further, the extent of substitutability is similar as reflected in the

Table 4
Elasticity of Substitution Measures

(a) Allen-Uzawa[a]

σ_{ll}^{AU}	-0.894				
σ_{le}^{AU}	-0.236	σ_{ee}^{AU}	-2.175		
σ_{lm}^{AU}	0.429	σ_{em}^{AU}	0.561	σ_{mm}^{AU}	-0.304

(b) Morishima[a]

σ_{ll}^{M}	0.0	σ_{el}^{M}	0.215	σ_{ml}^{M}	0.529
σ_{le}^{M}	0.252	σ_{ee}^{M}	0.0	σ_{me}^{M}	0.620
σ_{lm}^{M}	0.449	σ_{em}^{M}	0.529	σ_{mm}^{M}	0.0

Authors' calculations.

a $\sigma_{ij}^{AU} = \frac{\eta_{ij}}{S_j}$, $\sigma_{ij}^{M} = \eta_{ij} - \eta_{jj}$ where η_{ij} is the input (cross) price elasticity of demand and S_j is input j's cost share. Each measure approximates the percentage change in the marginal rate of substitution resulting from a 1% increase in input price ratio. σ_{ij}^{AU} (σ_{ij}^{M}) is a one (two) factor - one price measure.

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 0.4% - 0.5%.[21] 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 0.23% reduction in the relative productivity of energy.

Table 4(b) presents the Morishima elasticity of substitution estimates which, with one exception, are generally consistent with the Allen-Uzawa measures. Labor-materials and energy-

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

materials are substitutes in production, and materials use is more sensitive to the price of labor and price of energy, respectively, than the reverse (0.529 versus 0.449 for labor; 0.620 versus 0.529 for energy). However, labor and energy are Allen-Uzawa complements but Morishima substitutes in production. From equations (5) and (6), the substitute relationship reported in Table 4(b) indicates that with an increase in the price of labor (energy), labor (energy) use falls more quickly than energy (labor) use resulting in an increase in the labor-energy (energy-labor) input ratio, that is, raising the input price increases the relative use of the other input consistent with a substitution relationship. Because the Morishima measure is not symmetric and accounts for changes in both factors from the input price change, the resulting elasticities provide additional insights into the production relationship between factors.

Table 5 reports the estimated input own and cross price elasticities with industry demand most sensitive to energy prices. A 10% increase in energy prices reduces industry demand by a

Table 5
Own and Cross Price Elasticities

	Mean	Standard Deviation	Range Min, Max
η_{ll}	-0.239	0.018	-0.267, -0.216
η_{ee}	-0.277	0.118	-0.406, -0.063
η_{mm}	-0.186	0.007	-0.200, -0.168
η_{le}	-0.024	0.015	-0.047, 0.005
η_{lm}	0.263	0.030	0.220, 0.319
η_{em}	0.343	0.062	0.233, 0.401

Authors' calculations.

bit less than 3%. Demand for labor is less sensitive to changes in materials prices ($\eta_{\text{labor, materials}} = 0.263$) than is the demand for energy ($\eta_{\text{energy, materials}} = 0.343$). In contrast, and consistent with the Allen-Uzawa results, labor and energy are complements in production with a cross price elasticity, $\eta_{\text{labor, energy}}$, equal to -0.024. Over the sample period, the own price elasticity for labor and materials remained relatively stable, 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, reflected in Table 5 by a large range and a standard deviation which is at least an order of magnitude larger than that for labor and materials. In the last year of the sample, the own price elasticity for energy was double its value in 1965.

The cross price elasticity between labor and energy moved within a relatively small range, (-0.047, 0.005). Although for most of the period, and at mean production, labor and energy were complements, they were substitutes in production for the years 1982, 1983, and 1985. Labor was consistently a substitute for materials with relatively little absolute variation, ranging between 0.22 and 0.32.[22] In contrast, there was greater movement in the cross price elasticity between energy and materials, with a (0.23, 0.40) range and increasing from 0.25 in 1965 to 0.40 in 1981 and remaining just below that level for the rest of the sample period.

V.5 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. As a result of increasing competition from Europe, South America, and Asia, the U.S. paper and paperboard 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 pricing power, profit maximization implies

[22] From Tables 4 and 5, labor and materials are consistently substitutes in production. To understand this, grades produced (e.g. coated and uncoated groundwood, coated and uncoated freesheet, tissue and sanitary, unbleached kraft, recycled paperboard, solid bleached paperboard) reflect different types and levels of materials (e.g. hardwoods, softwoods, chlorine, lime, sodium hydroxide) used in pulping and papermaking processes. Different grades have different implications for the amounts of employed labor and materials implying trade-offs between the inputs. To illustrate, using indices of hours worked and non-energy materials inputs in paper and allied products (SIC 26), non-energy materials per hour worked was regressed on the annual capacity shares of newsprint, groundwood, coated freesheet, uncoated freesheet, tissue and paper, other recycled paperboard, and solid bleached paperboard for the period 1970-2000. Relative to the capacity shares of other products, an increase in the share of all but coated and uncoated freesheet reduced materials per labor hour required. Coated freesheet was not significant at a .05 level and uncoated freesheet significantly increased materials per hour worked.

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 1 depicts the estimated marginal and average operating costs for the paper and paperboard industry during the sample period. Through 1982, average and marginal costs were

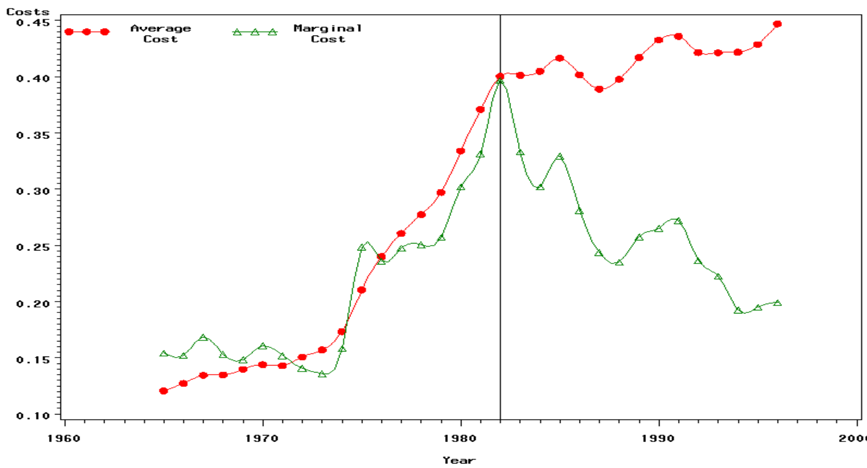

Figure 1
Paper and Paperboard Operating Costs, 1965 - 1996

reasonably close. However, after 1982 the industry's average operating costs were significantly above its marginal cost of production. Consistent with Bernstein's (1992), Christensen and Caves' (1997), and Pesendorfer's (2003) findings of competitive pricing, this suggests that industry pricing generated a return on investment that was insufficient to cover its cost of capital. For the period 1985 – 1996, the estimated average cost of production was 0.419, 72% higher than the estimated marginal cost at 0.244. This difference seems to have been apparent to the industry as the 1980s were a period of significant merger activity, industry consolidation (Pesendorfer, 2003), and, relative to the 1970s, lower capacity growth.

VI. Summary and Conclusions

In order to better understand the production and cost characteristics of the U.S. paper and paperboard industry in a competitive environment that has changed significantly, this paper presents new estimates for the industry's short run operating costs. The results indicate that the industry operates at constant or slightly increasing returns to capacity utilization, similar to Bernstein (1992), and are consistent with an environment of competitive pricing, as found in Bernstein (1992) and Christensen and Caves (1997). And notwithstanding significant consolidation in the mid-1980s, industry's attempt to 'get control' of its capacity and pricing was unsuccessful, which is consistent with the generally failing economic health of the industry. 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.[23]. The results also identified large volatility in the own price elasticity of energy during the 1970s oil crises, which has direct relevance in today's environment where the price of oil has increased from $60 a barrel in the early part of 2007 to $140 a barrel in summer 2008.

There are a number of extensions to this work. Although the paper and paperboard industry is often identified as relatively homogeneous, there are differences among industry sub-sectors. Analyses of these product categories (e.g. wrapping and packaging, newsprint, printing and writing papers, and household and sanitary papers) would improve our understanding of the competitive differences among these groups and this could help explain differences in the economic performance and growth of the industry. Second, this study focused on the industry's short run production and cost characteristics and a natural extension would explore long run production and cost to determine where on the long run average cost curve a 'representative' firm in the industry operates. A third area of future research relates to globalization and its affect on industry cost structures. Although interpreted as technological progress, the time variable also reflects other significant developments that have occurred over time including globalization and increasing competition from abroad.

[23] 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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