Estimating Supply Elasticity for Disaggregated Paper Products: A Primal Approach

Roger Brown and Daowei Zhang

Abstract: Most existing elasticity estimates for the pulp and paper industry are based on aggregate products (e.g., total paper, paperboard, or paper except newsprint). Using United States data, we present and evaluate econometric output supply models for four relatively disaggregated paper products: newsprint paper (NP), printing/writing paper (PWP), tissue paper (TP), and packaging paper (PP). Sample periods vary from 14 years for PP (1987–2001) to 20 years for NP and PWP (1981–2001). Each paper type is specified using a two-stage least squares geometric distributed lag model in log–log form using monthly data. Estimated long-run (short-run) output price elasticities are 2.75 (0.69) for NP, 2.45 (1.07) for PWP, 1.77 (1.77) for TP, and 0.41 (0.24) for PP. Input demand elasticities for capital, wood fiber, labor, electricity, and wastepaper are also estimated for each paper type. FOR. SCI. 51(6):570–577.

Key Words: Newsprint, tissue paper, packaging paper, output supply elasticity, factor demand elasticity

MOST EXISTING ECONOMETRIC STUDIES of the pulp and paper industry are based on aggregate product groups. For example, Sherif (1983) examines factor demand for Canadian pulp and paper mills using gross industry output. Quicke et al. (1990) look into the structure of the US paper industry using data for total paper output excluding building paper. Providing slightly more differentiation, Buongiorno et al. (1983) analyze price formation in the US paper and paperboard industry for five commodity groups: newsprint, paperboard, paper excluding newsprint, paper including newsprint, and total paper and paperboard. Hseu and Boungiorno (1997) distinguish four more specific products (pulp, newsprint, other paper, and paperboard) in their nonparametric analysis of output supply and input demand in the United States and Canadian pulp and paper industries.

As such, most existing elasticity estimates are useful primarily to producers of those paper products that comprise relatively large shares of the output for whatever aggregate commodity the model analyzes. For example, Hseu and Buongiorno (1997) report an output elasticity of 1.2 for "paper except newsprint". This aggregate category usually includes printing/writing paper, tissue paper, and packaging paper. The resulting elasticity estimate is perhaps more informative for printing/writing paper producers who, as shown in Table 1, produce the majority (66%) of paper in this highly aggregated category. In contrast, packaging paper comprises only a very small portion (16%) of the paper in this aggregated group. Hseu and Bongiorno's (1997) results would seem comparatively less relevant to and likely a distortion of the actual price responses of packaging paper producers [1].

In fact, there are a number of good reasons to believe that elasticity estimates may differ for aggregated versus disaggregated paper types (see Table 2). The pulp and paper industry is conventionally composed of three distinct products: market pulp (an intermediate raw material for papermaking), paperboard (includes components for corrugated cardboard), and paper (a highly heterogeneous final product). Paper is further subdivided into the four products that we examine in the present analysis: newsprint (NP), printing and writing paper (PWP), tissue paper (TP), and packaging paper (PP). Output substitution opportunities within each of these four paper categories vary substantially. Mills that produce PWP are, for instance, able to produce relatively many different kinds (grades) of these papers (e.g., coated or uncoated PWP) in response to changing market conditions. Likewise, TP mills may switch between industrial (usually brown) and at-home (usually white) grades of TP. PP mills, in contrast, generally use more product-specific production technologies that limit output substitution among various PP grades (Ince 2001). Paper types produced at mills that have more diverse output possibilities (e.g., PWP and TP) are expected to have relatively higher supply elasticity estimates.

Second, over the period examined, capacity utilization varies from around 70% for PP to some 95% for NP. Capacity constraints can retard output price responses especially for short-run price increases and can, as a result, yield relatively lower output elasticity estimates. Third, growth trends also vary widely among the various paper types. Between 1980 and 2000 capacity growth for PWP approached 80% while PP faced a 6% capacity decline nationwide. Declining industries typically face different choices with respect to profit maximization particularly in the short-run when output decisions may result in economic

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Table 1. Average production shares by weight.

Product	Share (%)
Paper	
Printing and writing paper (PWP)	54
Newsprint paper (NP)	18
Tissue paper (TP)	15
Packaging paper (PP)	13
Total	100
Paper except newsprint	
Printing and writing paper (PWP)	66
Tissue paper (TP)	18
Packaging paper (PP)	16
Total	100

Calculation based on *Pulp and Paper Magazine*'s "Month in Statistics" publication, 1981–1998.

losses. Uncompetitive mills may reduce output or shut down more reluctantly than expected as a result of nonprice considerations (e.g., labor union pressures). Fourth, although we assume that all markets for the paper products studied here are competitive, some markets (e.g., TP) are likely more competitive than others. Entrepreneurial success in more competitive markets may require greater sensitivity with respect to input and output choices (i.e., relatively higher elasticities). Finally, output price volatility across the four paper types differs. Firms that comprise markets with higher price volatility (e.g., PP) may be more apt to disregard (i.e., be less responsive to) the sharpest price swings and therefore have lower elasticities.

In addition to aggregating paper products, most existing econometric studies of US pulp and paper supply follow the "dual" rather than the "primal" approach (see Beattie and Taylor 1993). The dual approach requires first an estimation of the appropriate objective (cost or profit) function and subsequent derivation of supply relationships through optimization. For example, elasticities of input demand are obtained by Boungiorno and Gilless (1980) and Boungiorno et al. (1983) by first estimating generalized Cobb–Douglas cost functions. More flexible forms, such as the translog, are used by Stier (1980, 1985), DeBorger and Boungiorno (1985), and Quicke et al. (1990) with US data. In Canada, Sherif (1983), Martinello (1985), and Nautiyal and Singh (1986) also use translog cost functions, whereas Bernstein (1989) and Hseu and Boungiorno (1997) use profit functions to obtain estimates of input demand and output supply.

As described, most empirical studies rely on flexible functional forms (FFF) such as the translog, normalized quadratic, and generalized Leontief, to estimate output supply and input demand in the paper industry. The use of FFF allows a less restrictive approximation of the underlying production technology than, say, a log–log specification. Furthermore, deriving a set of output supply and input demand functions and estimating jointly makes use of more information in estimation than the single-equation approach. Third, the estimated parameters can be used to test for consistency with economic theory (e.g., symmetry, homogeneity, concavity) and elasticities can easily be derived. However, due to data limitations, we were unable to attempt such dual approaches. Instead, the present analysis couples the alternative primal approach with independent log–log specification models. The primal approach involves regressing output supply as a function of output price and the relevant input costs. These data are readily available for each disaggregated paper product, whereas other data (needed to follow the dual approach and run one of the FFF) are not.

The remainder of the present article introduces and evaluates four independent supply models (one for each paper type) based on each paper type's specific input requirements. To model paper output independently (as proposed), we must assume that multiproduct output and input substitution possibilities are nonexistent, implying that input prices are separable and exogenous at the level of the industry. This seems plausible. On the output side, inflexible production technologies generally limit output substitution *among*—but as pointed out in the preceding discussion, not necessarily *within*—the four categories of paper examined (Smook 1992, Hodgson, G, University of Washington, personal communication, Jan. 9, 2004). Likewise, mill closures may alter regional fiber prices (implying some endogeneity among inputs), but such localized geographic idiosyncrasies arguably have less impact in models using aggregated national data.

Theoretical Model

Competition and pricing based on market forces best characterize the US paper industry. Coordinated anticompetitive behavior is unlikely given that market concentration is modest and competition from foreign paper producers is significant. The market share of the top five North American producers for each paper grade ranges from 60% for PWP to 80% for TP (Roberts, D. Center for International Trade in Forest Products, Seattle, WA, available at www.cintrafor.org 2001). Average US tariffs on paper are near zero, making efforts by large US suppliers to attract monopoly-type rents generally unrealistic (Gullichsen and Paulapuro 1998). In both cases, numerous foreign and other domestic firms stimulate competition within the US paper industry with respect to pricing and production decisions. Thus, we assume that the subsegments of the paper industry studied in this article are competitive or close to competitive.

For a competitive firm facing competitive factor markets, the supply function is found by taking the first derivative of the profit function using Hotelling's lemma (Newman 1987). For firm j, assume a twice continuously differentiable production function for each paper product,

$$Q_{ijt} = q_{ij}(K_{ijt}, F_{ijt}, L_{ijt}, E_{ijt}, W_{ijt}) \quad (1)$$

where i = NP, PWP, TP, PP; $j = 1, \ldots, N$; t = monthly observations (1980, . . . , 2000 for NP and PWP; 1983, . . . , 1998 for TP; 1987, . . . , 1998 for PP); Q_{ijt} is the quantity of paper product i produced by firm j in period t; and K_{ijt}, F_{ijt}, L_{ijt}, E_{ijt}, and W_{ijt} are, respectively, the quantities of capital,

Table 2. Relevant differences between newsprint (NP), printing/writing paper (PWP), tissue paper (TP), and packaging paper (PP).

	NP	PWP	TP	PP
Primary outputs	Newsprint; calendered groundwood papers	Coated and uncoated groundwood papers; coated and uncoated free sheet papers	Industrial and at-home grades of bathroom tissue, napkins, and absorbent sanitary products	Sack paper; unbleached kraft wrapping paper; wax paper; sand paper; filter paper
Output substitution[1]	moderate	high	moderate	low
Capacity utilization[2]	95%	89%	87%	70%
Growth trend[3]	+40%	+79%	+38%	−6%
Market competitiveness[4]	lower	lower	higher	lower
Price volatility[5]	1.18	1.00	1.02	1.30
Retail orientation[6]	wholesale	wholesale	retail	wholesale
Primary fiber source	softwood, pulpwood	market woodpulp	mixed pulpwood	mixed pulpwood
Wastepaper utilization[7]	42%	10%	60%	15%

[1] Characterizes technological potential at the mill level to switch between primary outputs in response to market conditions.
[2] Average annual percentage ratio (1980–2000) of output tonnage (from *Pulp & Paper* magazine) to capacity (Ince et al. 2001).
[3] Percent change in capacity, 1980–2000 (Ince et al. 2001).
[4] Ince et al. 2001.
[5] Index of coefficient of variation for market price from BLS study data (PWP = base).
[6] Unlike other paper types, TP is typically marketed and sold directly to retail customers (Ince et al. 2001).
[7] Percentage ratio by weight of recovered paper use to output (Ince and McKeever 1995).

fiber, labor, energy, and wastepaper that firm j uses in period t.

Each paper product trades competitively in the national and international market, and, as such, the final good prices, P_{NP}, P_{PWP}, P_{TP}, and P_{PP}, are exogenous. The profit function for firm j in industry i in period t is thus

$$\text{Max } \Pi_{ijt} = P_{it}Q_{ijt}(K_{ijt}, F_{ijt}, L_{ijt}, E_{ijt}, W_{ijt}) - R_{K_{it}}K_{ijt} - R_{F_{it}}F_{ijt} - R_{L_{it}}L_{ijt} - R_{E_{it}}E_{ijt} - R_{W_{it}}W_{ijt}, \quad (2)$$

where RK_{it}, RF_{it}, RL_{it}, RE_{it}, and RW_{it} are, for the particular industry, the prices of capital, fiber, labor, energy, and wastepaper.

Applying Hotelling's lemma, each firm's supply of paper product i in period t is a function of market price and the prices of all inputs in production. The supply curve for firm j in industry i (S_{ij}) is derived by differentiating the profit function with respect to market price (Varian 1992). Thus,

$$\partial\Pi_{ijt}/\partial P_{it} = S_{ij}(\underset{+}{P_{it}}, \underset{-}{R_{K_{it}}}, \underset{-}{R_{F_{it}}}, \underset{-}{R_{L_{it}}}, \underset{-}{R_{E_{it}}}, \underset{-}{R_{W_{it}}}), \quad (3)$$

where the signs below the variables represent the expected effects on output supply given an increase in output price or input costs.

If all the firms in the United States maintain the same production function and face the same input prices, a national output supply equation can be found by aggregating the N individual firms' supply functions. Thus,

$$S_i(P_{it}, R_{K_{it}}, R_{F_{it}}, R_{L_{it}}, R_{E_{it}}, R_{W_{it}}) = \sum_{j=1}^{N} S_{ij}(P_{it}, R_{K_{it}}, R_{F_{it}}, R_{L_{it}}, R_{E_{it}}, R_{W_{it}}). \quad (4)$$

Equation 4 serves as the theoretical model for the present analysis and shows that output supply is a function of market price and various input costs, including capital, wood fiber, labor, energy, and wastepaper.

Empirical Model

In the empirical analysis that follows, Equation 4 is adapted in two important ways. First, a two-stage least squares (2SLS) procedure is used to correct for simultaneous equation bias in each model. Preliminary ordinary least squares estimates returned many parameters with incorrect signs, suggesting that market price and output quantity are jointly determined. This intuition was confirmed using the Hausman specification test for simultaneous equations bias (Pindyck and Rubinfeld 1998). Corrections were made using a 2SLS procedure following Greene (2000) [2]. The 2SLS approach includes a preliminary or first-stage regression that estimates, in the present case, how market price changes are influenced by demand. To identify these effects, economic variables that are highly correlated with product demand are regressed against output price. Predicted price values from this first-stage regression are then used in place of output price in the second stage.

Second, Equation 4 is adapted to identify dynamic output supply adjustments that may take place over time. The general supply equation assumes that adjustments in output occur instantaneously given regular updates about output price and input costs. However, in practice, such changes often require some time for full adjustment. This may be especially true for production of products like paper that require large capital investments and longer planning periods to expand production (Edwards 1959). Distributed lag models may be used to account for this sort of "lagged" transition to the optimal output level. Nerlove (1958) provides theoretical evidence that, when compared with the more traditional static approach, analyses using dynamic models with lag-dependent variables explain the data better, generate coefficient estimates that are more reasonable in sign and magnitude, and have fewer problems with autocorrelation.

A number of distributed lag specifications are available with selection being essentially ad hoc. We have tried all of them. The widely used geometric distributed lag model is used in this article because it avoids problems related to degrees of freedom and multicollinearity that are associated with some other specifications (e.g., polynomial lag). (In general, alternative lag specifications were characterized by lower R^2 and/or more insignificant explanatory variables.) Kmenta (1997) outlines two variations that he defines as the adaptive expectations model and the partial adjustment model. In the present context, the latter rationalization is most appropriate. The partial adjustment model assumes that suppliers adjust to the optimal or desired output level over more than one period (i.e., one month) because of technological constraints, institutional rigidities, or persistence of habit. This assumption is built into the empirical model by including output quantity lagged one period as an explanatory or right-hand-side variable. In the present case, all static models but one (TP) were improved slightly (i.e., higher adjusted-R^2 and more reasonable coefficient estimates) using a partial adjustment model. The coefficient on the lag variable for TP was insignificant, meaning that statistical evidence does not support a dynamic specification for that model [3]. As Kmenta (1997) shows, the estimate for the market price variable is properly interpreted as the short-run elasticity (E^{SR}) whereas the long-run elasticity (E^{LR}) is obtained by dividing the same by one minus the estimate of the lag quantity parameter (LAG). That is, $E^{LR} = E^{SR}/(1 - \text{LAG})$.

These two adaptations to Equation 4 result in 2SLS partial adjustment models for three of the four paper types (NP, PWP, and PP). The two-stage empirical model is as follows [4]:

Stage 1

$$\ln P_t = \alpha + \beta \ln Q_{t-1} + \sum_{p=1}^{11} (\delta_p \ln D_{pt}) + \sum_{q=1}^{5} (\lambda_q \ln F_{qt}) + \sum_{r=1}^{s} (\varphi_r \ln Z_{rt}) + \varepsilon_t \quad (5)$$

Stage 2

$$\ln Q_t = \alpha + \beta \ln Q_{t-1} + \sum_{p=1}^{11} (\delta_p \ln D_{pt}) + \sum_{q=1}^{5} (\lambda_q \ln F_{qt}) + \varphi \hat{P}_t + \varepsilon_t \quad (6)$$

where P_t = market price at month t; Q_{t-1} = output quantity at month $t - 1$; D_{pt} = monthly dummy variables for all $P = 1, 2, \ldots, 11$ at month t; F_{qt} = factor price variables for all $q = 1, 2, \ldots, 5$ at month t; Z_{rt} = instrumental variables (2 for PP and 1 for NP, PWP, and TP) for product r; and $\hat{P}_t$ = predicted values for market price at month t from first stage regression. The empirical model for TP differs only in that the lag-quantity parameter ($\beta \ln Q_{t-1}$) is omitted from both the first and second stages.

Factor Costs and Data

Although production across all paper types is fairly uniform with respect to factor inputs, some important distinctions do exist. Table 3 presents cost shares for a typical NP mill. The five largest input costs from Table 3 (capital, wood fiber, labor, energy, and wastepaper) are included in each of the four empirical models. Only wood fiber and wastepaper inputs vary by paper type.

Capital is generally recognized as the single largest input cost. Paper production depends on large, capital-intensive facilities, and the pulp and paper industry ranks near the top of all industries in terms of capital expenditure per employee (Tillman 1985). When compared to all US manufacturing, the high capital intensity of paper production requires that most firms operate at relatively high operating rates to earn revenues beyond this largest cost (Sinclair 1992). Capacity utilization, in fact, is sometimes used as a proxy for capital cost (Quicke et al. 1990). Paper mill capacity utilization rates in the United States have averaged between 70% for PP and 95% for NP between 1981 and 2000 (Table 2). In all four empirical models, the US prime rate (www.federalreserve.gov/releases/h15/data/a/prime.txt) measured monthly is used as the opportunity cost of capital.

Wood fiber is generally the second leading input cost and the primary raw material used in most paper production. Wood inputs tend to vary more or less predictably *among* each paper type, though *within* each group substitution among fibers is quite common, particularly in the long-run (Ince et al. 2001). The primary material input for NP is softwood pulpwood. PWP is a somewhat more heterogeneous paper type that includes groundwood and free sheet papers that may be either coated or uncoated. While groundwood production typically uses softwood fibers, PWP is most dependent on a mix of hardwood and softwood pulps used to make uncoated free sheet, which accounts for 57% of all capacity from 1981 to 2000 (Ince et al. 2001). TP and PP have more variable wood fiber requirements, generally drawing on a mix of softwoods and hardwoods. Historically, TP production has used hardwood pulpwood primarily. However, the share of TP capacity in the South has steadily increased from 17% to 37% between 1970 and

Table 3. Paper production cost shares.

Factor	Share (%)
Capital	27
Wood fiber	15
Labor	14
Energy	13
Wastepaper	8
Chemicals	7
Maintenance materials	6
Operating materials	4
Packaging materials	2
Other	4
Total	100

Based on a 450,000 tons/year NP mill with two modern paper machines operating at full production (adapted from Gullichsen and Paulapuro 1998).

2000. As a consequence, TP is increasingly dependent on softwood pulpwood as a wood fiber input. PP production remains concentrated in the South and is thus heavily dependent on softwood pulpwood but not as exclusively as NP. In the empirical models, monthly producer price index data from the Bureau of Labor and Statistics (BLS) (www.bls.gov) are used to measure wood fiber input prices. BLS indices used include softwood pulpwood (NP), woodpulp (PWP), and pulpwood (TP and PP).

Labor and energy are two other significant factor inputs. Labor costs comprise some 14% of typical paper-mill production expenses. Union membership among production employees is strong with labor agreements typically negotiated for 5–6-year periods (NAF 2002). The data series for labor costs is constructed by deflating the BLS-reported average wage of paper-mill production workers (dollars/hour) by the BLS consumer price index for urban wage earners and clerical workers. Energy use among US pulp, paper, and paperboard mills accounts for about 12% of all energy used within the domestic manufacturing sector, ranking it second only to chemical production in terms of energy intensity (NAF 2002). On average, over half of total fuel and electricity used by all paper mills is self-generated primarily from spent pulping liquors, wood residues, and bark. PWP production (specifically uncoated free sheet production based on chemical pulp) accounts for the majority of this self-generated energy. Monthly data for electricity is taken from the BLS index for industrial electric power.

Secondary fiber—also called recycled, recovered, or wastepaper—is an increasingly significant input for environmental, legal, and marketing reasons. Unlike other inputs, wastepaper demand by paper mills in the United States is not motivated exclusively or even predominately by price considerations. Instead, government legislation often mandates minimum secondary fiber content levels for certain paper grades in an effort to reduce landfill loadings and lessen dependency on forest resources (Smook 1992). Among the paper types examined in the present analysis, NP and TP are most dependent on wastepaper (42% and 60% of the fiber used, respectively). Two BLS data series are used for the cost of wastepaper: newspaper wastepaper (for NP) and wastepaper (for PWP, TP, and PP).

Data for the dependent variable, output quantity, is taken from the "Month in Statistics" section of the monthly *Pulp and Paper* magazine. The data are already disaggregated into seven different paper types: (1) newsprint, (2) uncoated groundwoods, (3) coated paper, (4) uncoated freesheet, (5) other printing/writing paper, (6) total packaging and other paper, and (7) tissue. Products 2, 3, 4, and 5 are combined for total PWP production. Products 1, 6, and 7 comprise the monthly production of NP, PP, and TP, respectively.

First-stage instrumental variables for Equation 5 are needed to isolate supply side price effects. In the case of NP, the price of newspapers is the obvious choice because NP use in North America is dominated by the US daily newspaper industry that consumes 60% of production (NAF 2002). For the other three paper types (PWP, TP, and PP), gross domestic product (GDP) is used as an instrumental variable because paper consumption in the United States (as elsewhere) is highly correlated with economic living standards, both on a long-term and cyclical basis (NAF 2002). Quarterly US GDP figures (www.bea.gov; chain-weighted, in dollars of 2000) are scaled to obtain monthly estimates. (E.g., Feb. value = ((April value − Jan. value)/3) + Jan. value. For PP, the BLS price index for plastic materials and resin is used as a second demand-shift variable; demand for PP has weakened significantly in recent decades as consumers substitute plastic bags for paper bags made of unbleached kraft packaging paper (Ince 2001) [5].

Each of the four empirical models regress (in stage two) output quantity as a function of market price (predictions from the first stage), eleven monthly dummy variables (eliminating the need for seasonally adjusted data), output quantity lagged one period, and five factor costs: capital, wood fiber, labor, energy, and wastepaper. All variables in all four models are expressed as natural logarithms (ln). Time periods covered by each model vary based on data availability: NP (1981–2001), PWP (1981–2001), TP (1982–1998), and PP (1987–2001). In the presence of a lagged dependent variable, the usual test for first-order autocorrelation (Durbin–Watson test) is not appropriate (Greene 2000). The recommended test in such cases is instead the "Durbin h" test (Pindyck and Rubinfeld 1998, who note that the Durbin h statistic requires an alternative calculation when $1 - T[\mathrm{Var}\ (\beta)]$ is negative, such as in the present analysis [see Durbin 1970]). Where indicated by this test, corrections for autocorrelation follow the Newey–West procedure in Green (2000).

Results

Final regression results for each 2SLS distributed-lag model using monthly data are presented in Table 4. Three of the four models (NP, PWP, and PP) required corrections for autocorrelation judging from Durbin h and Durbin–Watson test statistics. These corrections followed the Newey–West procedure (Greene 2000). Each model appears to do a modest-to-excellent job explaining the data; adjusted-R^2 values are 0.92 (NP), 0.95 (PWP), 0.80 (TP), and 0.83 (PP). Long-run elasticity estimates are presented in Table 5. To compare results for more aggregate product groups (e.g., paper except newsprint), short-run and long-run estimates from the present study are weighted by production shares from Table 1 and then summed.

In general, the estimated factor demand and supply elasticity estimates have the expected sign and are statistically significant at the 1% level. Elasticities are not homogeneous for all paper types as might be inferred from earlier studies but, instead, vary quite dramatically. Short-run supply elasticities range from 0.2 for PP to 1.8 for TP with NP (0.7) and PWP (1.1) being closer to unitary. In the long-run, NP (2.8) and PWP (2.5) have much more elastic supply responses whereas the TP (1.8) estimate remains unchanged, and PP (0.4) is still quite inelastic.

Variations in elasticity may be attributable to differences in output substitution, capacity utilization, growth trends, retail orientation, and price volatility as noted previously.

Table 4. Supply model for newsprint (NP), printing/writing paper (PWP), tissue paper (TP), and packaging paper (PP) in the United States.

	NP	PWP	TP	PP
Constant	1.997* (0.599)	1.618* (0.476)	7.448* (0.849)	6.851* (0.933)
Market Price	0.693* (0.227)	1.067* (0.302)	1.770* (0.178)	0.243* (0.100)
Lag-Quantity	0.748* (0.072)	0.565* (0.096)	not applicable	0.413* (0.073)
Capital	−0.188* (0.055)	−0.187* (0.049)	−0.100* (0.035)	−0.114* (0.027)
Softwood pulpwood	−0.273* (0.116)			
Woodpulp		−0.322* (0.094)		
Mixed pulpwood			−0.288* (0.083)	−0.354* (0.118)
Labor	−0.494* (0.160)	−0.395* (0.115)	0.998* (0.167)	−0.007 (0.194)
Energy	−0.630* (0.232)	−0.552* (0.198)	−1.356* (0.265)	−0.593* (0.171)
Wastepaper	−0.025* (0.009)	0.040* (0.011)	0.052* (0.015)	0.019* (0.008)
No. of observations	239	250	204	143
Durbin h or DW statistic	Dh = −4.64	Dh = −4.86	DW = 2.00	Dh = −3.26
(critical value)	(1.97)	(1.97)	(d_u = 2.05)	(1.98)
Adjusted-R^2	0.92	0.95	0.80	0.83

* indicates coefficient estimate is significant at 1% level. Standard errors given in parentheses under coefficient estimates. Dummy variable estimates not shown. As indicated by Durbin h statistic (Pindyck and Rubinfeld 1998), corrections for autocorrelation follow Newey-West procedure (Greene 2000). DW statistic is Durbin–Watson statistic (Greene 2000).

Table 5. Output supply and input demand elasticity estimates from different studies of the United States pulp and paper industry.

Industry	Output Supply	Input Demand				
		Capital	Fiber	Labor	Energy	Waste-paper
Paper						
Buongiorno et al., 1983		−0.5	−0.8	−0.8	−0.9	−1.0
De Borger and Buongiorno, 1985				−0.3	−0.4	
Quicke et al., 1990				−0.3	−0.3	
This study, weighted sum, SR	1.0	−0.2	−0.3	−0.2	−0.7	−0.0
This study, weighted sum, LR	2.2	−0.4	−0.7	−0.7	−1.5	0.1
Paper and allied products						
Stier, 1985		−0.1		−0.1		
Pulp and paper						
Hseu and Buongiorno, 1997		−2.0	−1.1	−1.3	−0.9	−2.2
Paper except newsprint						
Buongiorno et al., 1983		−0.4	−0.8	−0.9	−1.0	−1.0
Hseu and Buongiorno, 1997	1.2					
This study, weighted sum, SR	1.1	−0.2	−0.3	−0.1	−0.7	0.0
This study, weighted sum, LR	2.0	−0.3	−0.6	−0.4	−1.3	0.1
Newsprint						
Hseu and Buongiorno, 1997	1.9					
Buongiorno et al., 1983		−0.6	−0.8	−0.8	−0.8	−1.0
This study, SR	0.7	−0.2	−0.3	−0.5	−0.6	−0.0
This study, LR	2.8	−0.7	−1.0	−2.0	−2.5	−0.1
Printing and writing paper						
This study, SR	1.1	−0.2	−0.3	−0.4	−0.6	0.0
This study, LR	2.5	−0.4	−0.7	−0.9	−1.3	0.1
Tissue paper						
This study, SR	1.8	−0.1	−0.3	1.0	−1.4	0.1
This study, LR	1.8	−0.1	−0.3	1.0	−1.4	0.1
Packaging paper						
This study, SR	0.2	−0.1	−0.4	−0.0	−0.6	0.0
This study, LR	0.4	−0.2	−0.6	−0.0	−1.0	0.0

SR and LR indicate short-run and long-run respectively. Weighted sum calculations are based on production shares from Table 1.

For instance, the relatively inelastic price responses observed in the case of PP may, in part, be due to low output substitution possibilities, industry decline, or relatively high price volatility. In the case of NP, capacity utilization is very high (95%) and may contribute to a relatively low short-run price elasticity (0.7). The relatively high short- and long-run elasticities for PWP may be explained by the high output substitution opportunities and growth trend for this paper type. As noted previously, higher competition and a more retail-oriented marketing approach may explain why TP has relatively large and similar elasticites both in the long- and short-run.

On the input side, producers of all types of paper are apparently most sensitive to changes in energy prices and least sensitive to changes in wastepaper prices. Energy elasticities may be higher, in part, due to power cogeneration that uses papermaking by-products and typically uses independent, add-on technologies, making it unnecessary to retool entire mills. In addition to wastepaper, capital and fiber are generally inelastic both in the short-run and long-run whereas labor and energy tend to be relatively more elastic.

Elasticity estimates in the present analysis may also be compared, albeit cautiously, with estimates from earlier published studies. Such comparisons can be difficult because of differences in maintained assumptions, definitions of inputs and outputs, estimation procedures, and time periods. When compared to existing studies, the present results generally have higher long-term price elasticities and lower input demand elasticities (Table 5). For example, earlier studies show that aggregate paper supply in the United States is generally elastic with respect to price whereas the present study finds that the same is true only for NP (2.8), PWP (2.5), and TP (1.8) in the long-run. In the short-run, only TP and possibly PWP appear to have elastic supply responses using the present analysis. On the input side, the wastepaper demand elasticity estimates from the current study are sharply lower than those obtained from earlier published works. Generally, however, the present input demand elasticity estimates reinforce previous results that show energy and labor to be relatively more elastic than fiber and capital inputs [6].

Two anomalies in the models, however, are worth noting. First, in three of the four models (PWP, TP, and PP), wastepaper is statistically significant with an unexpected positive sign, whereas in the NP model this coefficient is negative (Plaut [1978] similarly finds positive wastepaper demand elasticities ranging from 0.00 to 0.21). Wastepaper demand in the United States, as noted earlier, is motivated in part by the increasing tendency for governments to mandate minimum secondary fiber content levels and for firms to do public relation works. Positive signs on the wastepaper coefficients may be explained if required content levels have risen along with, but slightly faster than, wastepaper prices, ceteris paribus. In any case, wastepaper input demand elasticity estimates are extremely small (e.g., −0.025 for NP) suggesting that tax incentives that focus on increasing the supply of wastepaper do little to increase wastepaper utilization by paper mills and reduce wastepaper loadings at landfills.

Second, the labor cost variable is insignificant in the PP model and significant with the wrong sign in the TP model. As noted previously, PP capacity in the United States has been in decline in recent decades. Nonprice factors such as labor union pressures may have forced uncompetitive PP mills to operate with incomplete regard for changing labor costs. The unexpected TP result, in contrast, may be due to regional shifts in TP production from the Northeast to the South where labor costs have risen more slowly than national averages. Since 1970, the share of TP production in the South has grown steadily from 17% to 37% in 2000.

Concluding Remarks

An analysis of paper supply in the United States reveals that elasticity responses vary by specific paper types (e.g., newsprint, printing/writing paper, tissue paper, and packaging paper). This can be attributed to differences in capacity utilization, growth trends, output substitution, and market structure across a subsegment of the paper industry. Furthermore, elasticities for specific paper types tend to differ from estimates derived by previous studies that examined more aggregate product groups (e.g., "paper" or "paper excluding newsprint").

This finding has implications on various modeling exercises and/or forecast efforts and public policy. Industry executives and public policymakers who use forecasts based on models for the whole industry need to be aware that subsegments of the industry respond differently to changes in prices and policies than the whole industry and thus distort existing forecasts. Government policymakers, for instance, are increasingly concerned for environmental reasons about industrial consumption of natural resources (e.g., trees, water, electricity, landfill space, etc.). Consider the economic impacts of a hypothetical environmental tax on industrial electricity used to make "paper except newsprint". Buongiorno et al. (1983) estimate the input demand elasticity for electricity to be −1.0, implying that a 1% increase in the cost of electricity due to a tax would yield a 1% decrease in the quantity of paper except newsprint produced. The current study, however, predicts that tissue paper output would fall 40% *more* than expected whereas printing/writing paper and packaging paper production would (in the short-run) fall 40% *less* than expected. Environmental policy objectives may be more efficiently achieved if decision-makers recognize that elasticity estimates for aggregated products may differ from more product-specific estimates.

Endnotes

[1] Døhl (2002) supports this intuition, showing that, in Norway, elasticity estimates for aggregated outputs—e.g., paper + paper products—are statistically inferior to estimates based on disaggregated output data.

[2] We have also considered and tried to identify potential cross-equation bias (i.e., cross-equation correlation in errors) using three-stage least squares (3SLS). Full use of 3SLS is constrained by a lack of data because different paper types have data covering different time periods. However, two paper types—NP and PWP—have data covering similar periods (n = 239 and n = 250, respectively). We tried 3SLS for these two types of paper. We used gross domestic product (GDP) as the instrumental variables for both products because our econometric software does not allow us to use newspaper price as the instrumental variable for NP and GDP for PWP at the same time, because these two variables are highly correlated (r = 0.9878). Still, the 3SLS results are almost the same as those reported here. Coefficient estimates for PWP differ by no more than 3% between the two methods. Coefficient estimates for NP vary somewhat more (as much as 10% in the case of labor), which is likely due to the absence of a better instrumental variable. Adjusted-R^2 between the two models is nearly identical. Thus, cross-equation correlation in errors, if it exists, apparently has very little impact on our estimates.

[3] The lag variable in the TP model may be insignificant because the TP market in the United States is relatively profitable, highly competitive, and provides products directly to retail consumers. It may be that, as a result of these factors, TP mills have a relatively attuned sense of near-term price changes without reference to output choices made during previous periods.

[4] Because technological change may be an important factor in the paper industry, we have included a time-trend variable in each of the four models and found it to be statistically insignificant in all models with an inconsistent sign. Subsequently we excluded it from each model.

[5] Instrument choices appear well chosen. Instruments should be highly correlated with the independent variables and, at the same time, uncorrelated with the error term. Using Hausman's specification test (outlined by Griffiths et al. 1993), we accepted the null hypothesis that there is no regressor–error correlation for each paper supply model. Furthermore, simple correlations show PWP and TP prices are, respectively, 90% and 93% correlated with the selected demand-side variable (GDP). The price of newspapers and NP prices are similarly correlated at 69%. GDP and the price of plastics jointly explain 96% of price variations for PP. Adjusted-R^2 from first stage regressions, Equation 5, are 0.62 (NP), 0.96 (PWP), 0.94 (TP), and 0.98 (PP).

[6] Estimates from Hseu and Buongiorno (1997) for the aggregate category "pulp and paper" is a notable exception. This aberrant finding may, in part, be due to the absence of any consideration of pulp supply in the present analysis.

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