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Assessing market power in the U.S. pulp and paper industry

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ABSTRACT

This paper assesses the market power of pulpwood mills in different regions of the U.S. We estimated the conjectural elasticity, elasticities of substitution and price elasticities for the delivered price at the mill in Southeast and North U.S. and the stumpage in the Southeast. We assembled data composed of price and quantity of Labor, Energy, Chemical Products and Wood at firms' level from Q4/2016 to Q4/2017, and applied a variety of econometric models that measure the influence of firms and resource characteristics on market competition. The results indicate moderate levels of oligopsony power in all markets, with the highest effect at the mill in the North, and lowest in the stumpage market in the South. Market power in the pulpwood market is strongly driven by industry concentration and local company size, and decreases as the estimated wood procurement radius from a mill increases in size.

1. Introduction

Economists usually assume that classical markets with perfect atomistic competition between many producers and many consumers produce the best social welfare and most efficient production. However, the market of natural resources and many agriculture products are commonly imperfect competitive. These markets often have a structure where the prices of the factors of production (inputs) are formed from the interaction between a large number of sellers and few buyers. The high concentration of buyers can lead to oligopsony, where buyers of inputs pay lower prices than in a perfectly competitive environment, leading to poor resources allocation and less income to producers of input goods. The pulp and paper industry (PPI) sector has been one area where market power has been identified in the past. We re-examine this question with improved data sets and econometric methods.

The share of the total output production of the four and eight largest PPI (CR4 and CR8) in the United States are respectively 61% and 84.5% respectively (United States Census Bureau, 2018). Even with the expansion of the wood pellet production and the consequent increase in competition for pulpwood (Abt et al., 2014), pulpmills have by far the most significant share of pulpwood consumption.[1] In the Southeast U.S., pulpmills shared 83% of the softwood pulpwood, while pellet mills had 4% and OSB 13% in 2014. The hardwood pulpwood market is even more concentrated; 93% of the total volume feeds pulpmills, and 7% went to OSB during the same period (Forest2Market, 2014).

Transportation costs and the suppliers' price elasticities have a substantial impact on the pulpwood market in addition to the industry concentration. Pulpmills expand or contract their procurement area according to the ratio between transportation costs and pulpwood prices. The higher the transportation costs, the more significant is the influence of the pulpmills in local markets. Also, the timber supply curve is inelastic (Parajuli and Chang, 2015; Polyakov et al., 2005), increasing the likelihood of suppressing local prices without substantially affecting the total amount of timber supplied.

A systematic lack of competition in the timber market could lead to (i) misallocation of resources, such as less production of pulpwood, due to low prices (ii) incentives for landowners to merge or to unify (Khajuria et al., 2005), and (iii) harmful effects on social welfare as defined as reductions in maximum efficiency in perfect competition (Brown et al., 2012; Niquidet and Cornelis Van Kooten, 2006). However, it is not clear to which extent a pulpmill can influence pulpwood prices and what factors might determine it.

In this paper, we investigated the oligopsony power and cost structure of three different datasets: (i) U.S. Southeast delivered pulpwood at the firm level, (ii) U.S. Southeast stumpage prices (with regional market data) and (iii) U.S. Northeast delivered pulpwood at the firm level. Our contribution to prior research consists of (i) the assessment of the market power for purchased wood at the plant level (U.S. South and North) and stumpage micromarket (only U.S. South); previous studies have used nationwide data (Mei and Sun, 2008;

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[1] Pulpwood is not actually consumed in the strict sense but used as a production factor.

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Murray, 1995b; Murray, 1995a) and; (ii) estimation of price elasticities for all regions and aggregate levels. Our data are composed of quantity and prices of labor, chemical, energy, and wood for 74 pulpmills; 55 are located in the Southeast U.S. and 19 in the Northeast. We assess the market competitiveness deriving the Conjectural Elasticity (CE) from a translog cost function as described next.

2. Literature review

Earlier studies on oligopsony markets in the forest sector have shown mixed results. Using aggregate data, Murray (1995a) and Mei and Sun (2008) found evidence of market power in the pulpwood and sawlog market in the U.S. According to both studies, there was a substantial increase in the market power over the past decades, mainly by the pulpmills. However, Murray (1995b) did not find significant welfare or price distortion that could have justified any government intervention. Mead (1966) also detected the prevalence of non-competitive practices in the supply of Douglas Fir from the national forests. Finding from other studies in North America suggested a competitive market in the U.S. – Pacific North Region (Campbell, 1996) and Canada (Bernstein, 1992).

In Europe, the presence of market power is not very clear either. Most of the research in Scandinavia indicates at least a moderate level of oligopsony. Results from Brannlund (1989) show evidence of monopsony power in the Swedish pulpwood market. However, Bergman and Bränlunnd (1995) highlight that the competitiveness in the Swedish pulpwood market varied over time, with high competition levels between the 1960s and 1970s and almost full monopsony in the 1990s. Different periods and tests suggest opposite conclusions in the Finnish pulpwood market. While parametric tests indicate a competitive market between 1965 and 1994 (Ronnila and Toppinen, 2000), a non-parametric analysis suggests monopsony levels in 1990, 1992 and 1993 (Kallio, 2001; Kallio and Kallio, 2002). In Norway, the monopsony structure is also dominant in the sawlog market (Stordal and Baardsen, 2002; Kumbhakar et al., 2012).

The variety of results in the topic can be related to the assessment methods and data characteristics. Aggregate data for a region assumes a certain level of homogeneity among firms, which is often not realistic since firms have different strategies and cost structure. So, why aren't there many publications with firm-level data? Costs and sales information are confidential and hard to have access by academics. To our knowledge, in the agricultural and forest sector, only Paul (2001), Perekhozhuk et al. (2013), Stordal and Baardsen (2002) and Kumbhakar et al. (2012) studied market power using plant-level data; the first in the U.S. meat packing, the second on dairy industries in Hungary, and the last two papers with sawlogs in Norway.

3. Theoretical framework

The New Empirical Industrial Organization (NEIO) has been the most common approach adopted to study market power. The advantage of the NEIO is that it measures the market power directly through the conjectural variation (the reaction of a competitor as one company varies its output or input) grounded on the production economics. An enormous number of studies applied the NEIO approach, including in agriculture and forestry (see Perekhozhuk et al. (2016) for a detailed survey). They commonly rely on the calculation of Conjectural Elasticity (CE) to determine the degree of market power, as shown in Eq. (1).

$$\theta_j = \left(\frac{\partial Q}{\partial q_j}\right)\frac{q_j}{Q} \tag{1}$$

where Q denotes the industry output (input) and q_j is the output (input) of firm j, θ_j measures the market response to a change in the quantity produced of output (or used of input) by firm j; the value of θ_j (CE) ranges from 0 to 1, which zero indicates perfect competition (the marginal cost of a product equals the market price) and one suggests a monopoly or monopsony market (marginal factor cost is equated to the value marginal product). Eq. (1) has been used to assess either oligopoly (e.g., Appelbaum, 1982) and oligopsony (e.g., Murray, 1995a).

The CE and the optimal quantity of the input market are derived from a profit function. Consider the profit function of a representative firm j:

$$\pi_j = P_j q_j - w_j^{nw} x_j^{nw} - w_j^{w}\, x_j^{w} \tag{2}$$

where P_j is a vector of output prices and q_j their respective quantities, w_j^{nw} and x_j^{nw} are the price and quantity vectors of nonwood inputs, $w_j^{w} = g^{-1}(x_j^{w})$ is the inverse wood supply function, and x_j^{w} is the quantity of wood used. Assuming price-taking in the outputs and all the inputs except for wood5F,[2] the first order conditions of Eq. (2) are:

$$P_j \frac{\partial q_j}{\partial x_j^{nw}} = w_j^{nw} \tag{3.1}$$

$$P_j \frac{\partial q_j}{\partial x_j^{w}} = w_j^{w} + \frac{\partial w_j^{w}}{\partial x_j^{w}} x_j^{w} \tag{3.2}$$

In an analogy to the markup, Eq. (3.2) can be manipulated to its markdown representation7FF[3] (Paul, 2001):

$$VMP_j^{w} = P_j \frac{\partial q_j}{\partial x_j^{w}} = w_j^{w}\left(1 + \frac{\theta_j}{E}\right) = -\frac{\partial C_j}{\partial x_j^{w}} = Z_j^{w} = MFC_j^{w} \tag{4}$$

where j stands for each pulpmill and w for the wood prices, VMP_j^{w} is the Value Marginal Product, MFC_j^{w} is the Marginal Factor Cost. $E = \left(\frac{\partial x}{\partial w}\right)\left(\frac{w^{w}}{x^{w}}\right)$ is the own price elasticity of the pulpwood supply, θ_j is the Conjectural Elasticity defined in Eq. (1). $-\frac{\partial C_j}{\partial x_j^{w}} = Z_j^{w}$ is the shadow value of wood for pulpmill j (Lau, 1978).

Eq. (4) gathers the revenue and cost of the profit maximization condition in an input market subject to market power; its derivatives represent therefore any change from the maximum input allocation, revealing also the amount of deviation from perfect competition. Two main approaches estimate the Conjectural Elasticity (CE): (i) the primal production function (e.g., Azzam and Pagoulatos, 1990; Mei and Sun, 2008) and, (ii) the dual cost function (e.g., Paul, 2001; Stordal and Baardsen, 2002). The primal approach estimates the production function and the uncompensated input demand functions, whereas the dual approach is based on a cost function and its respective compensated input demand functions. Here, we adopted the dual approach because (1) it facilitates the estimation of the elasticity of substitution and price elasticities and (2) our data are more suitable for cost function estimation.

3.1. Cost equations

We estimated a translog cost function because it is flexible, twice-differentiable, and has no prior restriction on partial elasticities.[4] The

[2] Assuming pulpmills are price takers in the inputs market (labor, capital and materials) is reasonable since the input markets are not as sensitive as pulpwood to spatial location. For the output market on the other hand, we acknowledge that pulp and paper industry have little oligopoly power (Mei and Sun, 2008). However, since our output data are not disaggregated by the type of paper or pulp, it is very difficult to measure the oligopoly and oligopsony power simultaneously.

[3] $P_j \frac{\partial q_j}{\partial x_j^{w}} = w_j^{w} + \frac{\partial w_j^{w}}{\partial x_j^{w}} x_j^{w} = w_j^{w} + \frac{\partial w_j^{w}}{\partial x_j^{w}} x_j^{w} \frac{w_j^{w}}{w_j^{w}} = w_j^{w}\left(1 + \frac{1}{E_j}\right) = w_j^{w}\left(1 + \frac{\theta_j}{E}\right)$ where $E_j = \left(\frac{\partial x_j^{w}}{\partial w_j^{w}}\right)\left(\frac{w_j^{w}}{x_j^{w}}\right) = \frac{E}{\theta_j}$ is the derived price elasticity of mill j (Murray, 1992).

[4] Generalized Leontief and Generalized Cobb-Douglas also have these properties (see details in Griffin et al., 1987, and Thompson, 1988). However, while attempting to use these functions we encountered serious singularity problems.

price representation is also crucial to estimate market power. For instance, Paul (2001) derived the inverse of Shepard's Lemma optimization condition, where input prices are functions of the CE and input demand. On the other hand, Stordal and Baardsen (2002) employed the traditional Shepard's Lemma where the input demand is a function of the CE and input prices. We opted to use the latter price representation because it facilitated the convergence of the coefficient estimation and minimized the problems with collinearity.

Let j be a representative pulpmill, t be time, i and p be the inputs Labor, Energy, and Chemical Products, q_{jt} the output quantity, K_{jt} is the capital, defined as the number of machinery per mill j and period t,[5] w_{jt}^{w} the pulpwood prices and $w_{jt}^{i(p)}$the input prices $i(p)$ other than wood. The empirical translog cost function is represented as:

$$\begin{aligned}\ln(TC_{jt}) = {} & \beta_0 + \beta_Q \ln(q_{jt}) + \frac{1}{2}\beta_{QQ}\ln(q_{jt})\ln(q_{jt}) \\ & + \frac{1}{2}\sum_{i}^{3}\sum_{p}^{3}\beta_{ip}\ln(w_{jt}^{i})\ln(w_{jt}^{p}) \\ & + \sum\nolimits_{i}^{3}\beta_{iW}\ln(w_{jt}^{i})\ln\left(w_{jt}^{w}\left(1+\frac{\theta}{E}\right)\right) \\ & + \frac{1}{2}\beta_{WW}\ln\left(w_{jt}^{w}\left(1+\frac{\theta}{E}\right)\right)\ln\left(w_{jt}^{w}\left(1+\frac{\theta}{E}\right)\right) \\ & \frac{1}{2}\beta_{KK}\ln(K_{jt})\ln(K_{jt}) + \sum\nolimits_{i}^{3}\beta_{iK}\ln(w_{jt}^{i})\ln(K_{jt})\Big) \\ & + \quad + \beta_{QK}\ln(q_{jt})\ln(K_{jt}) + \\ & \beta_{KW}\ln(K_{jt})\ln\left(w_{jt}^{w}\left(1+\frac{\theta}{E}\right)\right) + \beta_{QW}\ln(q_{jt})\ln\left(w_{jt}^{w}\left(1+\frac{\theta}{E}\right)\right)\end{aligned} \tag{5}$$

Following the Shepard's Lemma $\frac{\partial \ln(TC_{jt})}{\partial \ln(w_{jt}^{i})} = \frac{w_{jt}^{i}Q_{jt}}{TC_{jt}} = S_{jt}^{i}$ and $\frac{\partial \ln(TC_{jt})}{\partial \ln\left(w_{jt}^{w}\left(1+\frac{\theta}{E}\right)\right)} = \frac{w_{jt}^{w}\left(1+\frac{\theta}{E}\right)Q_{jt}}{TC_{jt}} = S_{jt}^{w} = \frac{\partial \ln(TC_{jt})}{\partial \ln\left(w_{jt}^{w}\left(1+\frac{\theta}{E}\right)\right)} / \left(1+\frac{\theta}{E}\right)$ for the wood prices, we derived from Eq. (5) the share functions:

$$S_{jt}^{i} = \beta_i + \sum\nolimits_{p}^{3}\beta_{ip}\ln(w_{jt}^{p}) + \beta_{iw}\ln\left(w_{jt}^{w}\left(1+\frac{\theta}{E}\right)\right) + \beta_{iQ}\ln(Q_{jt}) + \beta_{iK}\ln(K_{jt}) \tag{6.1}$$

$$S_{jt}^{w} = \frac{1}{\left(1+\frac{\theta}{E}\right)}\left[\beta_W + \sum\nolimits_{i}^{3}\beta_{iW}\ln(w_{jt}^{k}) + \sum\nolimits_{i}^{3}\beta_{iW}\ln(w_{jt}^{i})\ln\left(w_{jt}^{w}\left(1+\frac{\theta}{E}\right)\right) + \beta_{WQ}\ln(Q_{jt}) + \beta_{WK}\ln(K_{jt})\right] \tag{6.2}$$

Where, symmetry ($\beta_{ij} = \beta_{ji}$) and homogeneity ($\Sigma_i^3\beta_i = 1$ *and* $\Sigma_i^3\beta_i = \Sigma_i^3\beta_{Xi} = \Sigma_i^3\beta_{qi} = 0$) in input prices are imposed. The symmetry of the parameters guarantees the symmetry of the Hessian matrix and, the linear homogeneous form assures costs will change in the same proportion when all input price change.

3.2. Parameter-varying oligopsony model

The above model specification estimates the static CE ($\hat{\theta} = \theta$); it does not consider its spatial-temporal variation. In order to capture the timber harvest seasonality and the particularity of each market, we calculate the CE as a function of the Herfindahl – Hirschmand Index (HHI_{jt}) represented as:

$$\theta_{jt} = \delta_0 HHI_{jt} \tag{7}$$

[5] We decided to use the number of machinery as a proxy for capital because of there was no other variable available and the correlation between number of companies and production is 56%.

HHI is a well-known measure of market concentration. In a market with n firms, the market share of firm j is defined as $s_j = x_j / \sum_{i=1}^{n} x_i$, then *HHI* is

$$HHI_{jt} = \sum_{i=1}^{n} s_{it}^{2} \text{ and } \sum_{i=1}^{n} s_{it} = 1 \tag{8}$$

Under monopoly, $n = 1$, $s_{it} = 1$ and $HHI_{jt} = 1$. As $n \to \infty$, markets are perfectly competitive and $HHI_{jt} \to 0$. We thus replaced θ by θ_{jt} (Eq. (7)) on the system of Eqs. (5), (6.1) and (6.2), giving the flexibility to calculate the CE for each pulpmill j and period t. This approach was also adopted by similar studies like Mei and Sun (2008), Murray (1995a) and Paul (2001).

In sum, we analyzed the market structure using three models for three different dataset (South – by pulpmill and microregions - and North U.S. – by pulpmill): (i) Perfect competition, imposing perfect competition ($\hat{\theta} = 0$); (ii) Static, where θ is constant ($\hat{\theta} = \theta$) and (ii) Parameter Varying, where θ varies according to *HHI* of company j's market at time t (Eq. (7)).

3.2.1. Computing the Herfindahl – Hirschman Index (HHI)

We estimated the *HHI* for every pulpmill based on their market size and the local demand. The definition of market size surrounding the pulpmills varies according to their capacity and location. Hahn (2015) found that wood procurement in North Carolina averaged 50 miles from the plant, while Forest2Market (2015) suggested 75 miles for the U.S. South. Here we performed sensitivity analyses using 50, 75 and 100 miles to evaluate the impacts of procurement area on market power estimation. Beyond 100 miles, the transportation costs of pulpwood would usually become too high (Conrad IV et al., 2017).

After defining the market size, we calculated the local demand and the *HHI*. For instance, if the market size of firm j does not overlap with any other mill, the local *HHI* equals one (monopsony). On the other hand, if it overlaps with mill i, the local demand would be therefore $X_{jt} = x_{jt} + x_{it} * AI_{ij}$, where *AI* is the overlaped area between the two mills and $x_{j(i)t}$ is the demand for wood of mill $j(i)$ at period t. The local *HHI* is then $(x_{jt}/X_{jt})^2 + \left({}^{x_{it}}/_{X_{jt}} * AI_{ij}\right)^2$. Generalizing for $n > 2$ these steps are represented as:

$$X_{jt} = x_{jt} + x_{it} * AI_{ij} \ \forall \ AI_{ij} > 0 \tag{9.1}$$

$$X_{jt} = x_{jt} \ \forall \ AI_{ij} = 0 \tag{9.2}$$

$$HHI = \left(\frac{x_{jt}}{X_{jt}}\right)^2 + \sum_{i=1}^{n}\left({}^{x_{it}}/_{X_{jt}} * AI_{ij}\right)^2 \ \forall \ AI_{ij} > 0 \tag{9.3}$$

$$HHI = 1 \ \forall \ AI_{ij} = 0 \tag{9.4}$$

3.2.2. Stumpage Herfindahl – Hirschman Index (HHI)

The market share (s_{jt}) of each company located in the micromarket m at time t is the ratio of the total volume of softwood timber demanded by company j (x_{jt}) times the area (in percentage) of its circle located in the market m (A_{im}) divided by total volume demanded ($\sum_{i=1}^{n} x_{it} * A_{im}$). The *HHI* is thus represented as follows:

$$s_j = \frac{x_j * A_{jm}}{\sum_{i=1}^{n} x_i * A_{im}} \text{ and } HHI_m = \sum_{i=1}^{n} s_i^2 \tag{10}$$

3.2.3. Model estimation

The system of Eqs. (5), (6.1) and (6.2) was estimated jointly since the error terms of each equation are correlated. We dropped the share cost equation of chemical products to avoid singularity of the covariance matrix (Bernt and Wood, 1975). In addition, we imposed linear homogeneity by dividing labor, wood and energy prices by the chemical prices to reduce the number of parameters and collinearity. The coefficients of the chemical equation are obtained from the linear

Table 1
Non-Linear Iterated Three Steps Least Square (IT3SLS) - Instrumental Variables.

Model	Instrumental variables
Static	$ln(w_{it}^{L})$, $ln(w_{it}^{E})$, $ln(w_{it}^{W})$, $ln(K_{it})$, $ln(Q_{it})$, $ln(x_{it}^{L})$, $ln(x_{it}^{E})$, $ln(x_{it}^{W})$
Parameter-varying	$ln(w_{ij}^{L})$, $ln(w_{ij}^{E})$, $ln(w_{ij}^{W})$, $ln(K_{ij})$, $ln(Q_{it})$, $ln(x_{it}^{L})$, $ln(x_{it}^{E})$, $ln(x_{it}^{W})$, $ln(R_{it})$

Note: i = pulpmill or micromarket, t = time, L = labor, E = energy, W = pulpwood, K = capital, R = company revenue, w = input price, x = input quantity, Q = output quantity.

homogeneity restriction.

$$\beta_C = 1 - \beta_L - \beta_E - \beta_W$$

$$\beta_{CE} = 0 - \beta_{LE} + \beta_{EE} + \beta_{WE}$$

$$\beta_{CL} = 0 - \beta_{LL} - \beta_{EL} - \beta_{WL}$$

$$\beta_{CW} = 0 - \beta_{LW} - \beta_{EW} - \beta_{WW} \tag{11}$$

We addressed the endogeneity between the cost functions equations by adopting the Non-Linear Iterated Three Steps Least Square (IT3SLS) version of Zellner (1962). The iterated methods compute the cross-equation covariance matrix recursively until their estimates converge into an optimum solution. For each model (Static and Parameter-Varying), we defined a set of instruments (Table 1).

A problem faced in the practical implementation of forest products oligopsony models is the identification of θ and E; their estimation needs additional information about the timber supply relationship. A possible solution is to add a timber supply function to the system of Eqs. (5), (6.1) and (6.2). However, if this supply function is not well specified, it will lead to a specification problem in the overall system (Paul, 2001). Paul and others (e.g., Azzam and Pagoulatos, 1990; Mei and Sun, 2008; Murray, 1995a) suggest that E could be determined a priori to side-step this problem. Because our data suffers from multicollinearity, adding one more equation to the system would just aggravate the problem as we could observed in the first estimation attempts. Therefore, we opted to impose a scalar value $E = 0.3$ as suggested by Polyakov et al. (2005) and Newman (1987) instead of risking a misspecification in the supply function. We show the sensitivity analysis with different elasticities of supply in the Appendix A.

3.3. Elasticities of substitution and price elasticities

Since the coefficients in the system of equations are difficult to interpret, a common practice is to estimate the elasticities of substitution and price elasticities to help understand price responses. To determine the level of substitution of inputs, we calculated the elasticities of substitution using Allen – Hicks partial elasticities of Substitution (AES), Morishima Partial Elasticities of Substitution (MOS) and Cross – Price Elasticities. AES between input i and j is then defined as

$$\sigma_{ik} = \frac{\beta_{ik} + S^iS^k - S^i}{S^iS^k}\ \forall\ i = k \tag{12.1}$$

$$\sigma_{ik} = \frac{\beta_{ik} + S^iS^k}{S^iS^k}\ \forall\ i \neq k \tag{12.2}$$

Where i and k are the Labor, Chemical, Energy and Wood. If $\sigma_{ik} > 0$, the increasing in the *jth* price increases the quantity of input i, and they are Allen – Hicks substitutes. If $\sigma_{ik} < 0$, they are net complements.

Even though AES is a traditional measure of substitution, it does not effectively calculate the elasticities under more than two inputs. The relationship among many inputs becomes complicated, and the results from AES might be meaningless (Blackorby and Russel, 1989)[6]. The Morishima Partial Elasticities of Substitution (MOS) (Morishima, 1967) overcomes this limitation and has the additional advantage of not imposing symmetry between the inputs. Mathematically, MOS is expressed as:

$$\eta_{ik} = S^k(\sigma_{ik} - \sigma_{kk}) \tag{13}$$

where S^k is the share of input k.

Finally, the own and cross-price conditional elasticities of demand can be calculated as follows

$$\epsilon_{ik} = S^k\sigma_{ii} \tag{14}$$

We then calculated the standard errors of these elasticities by bootstrapping the distribution of their respective coefficients β_{ik}.

3.4. Welfare effects

The welfare effects of the potential loss of perfect competition are measured by estimating the net change in producer and consumer surplus. These changes use the estimated Value Marginal Revenue of Pulpwood (VMP_j^{w}). The subtraction of Eq. (4)$\left(VMP_j^w = w_j^w\left(1 + \frac{\theta_j}{E}\right)\right)$ by w_j^w from both sides lead to the marginal social loss:

$$VMP_j^w - w_j^w = \left(\frac{\theta_j}{E}\right)w_j^w \tag{15}$$

where $\frac{\theta_j}{E}$ is analogous to the Lerner Index of Monopoly ($(P - MC)/P$).

The total loss is then the integral of the left-hand side of Eq. (15) between the quantity of wood demanded/supplied in perfect competition and oligopsony condition. We followed Murray (1995b) to estimate changes in the social welfare.

The change on the pulpwood supply (Eq. (16.1)) and demand (Eq. (16.2)) curve can be approximated by their linearization around the relatively small changes from the baseline value.

$$\Delta x_{jt}^{(s)w} = E\left(\frac{w_{jt}^w}{x_{jt}^w}\right)\Delta w_{jt}^w \tag{16.1}$$

$$\Delta x_{jt}^{(d)w} = \epsilon_{ww}\left(\frac{x_{jt}^w}{w_{jt}^w\left(1 + \frac{\theta_j}{E}\right)}\right)\left(\Delta w_{jt}^w + \frac{\theta_j}{E}w_{jt}^w\right) \tag{16.2}$$

where E is the own-price elasticity of the supply curve, ϵ_{ww} is the own-price elasticity of the demand curve, w_{jt}^{w} and x_{jt}^{w} are the reference value. Eqs. (16.1) and (16.2) must be equal in equilibrium ($\Delta x_{jt}^{(d)w} = \Delta x_{jt}^{(s)w} = \Delta x_{jt}^{w}$).

The change in the producer and consumer surplus are defined as:

$$\Delta PS_{jt}^w = \Delta w_{jt}^w\, x_{jt}^w - 0.5\Delta w_{jt}^w \Delta x_{jt}^w \tag{17.1}$$

$$\Delta CS_{jt}^w = -\Delta w_{jt}^w\, x_{jt}^w + 0.5\Delta w_{jt}^{wi} \Delta x_{jt}^w \tag{17.2}$$

where $\Delta w_{jt}^{wi} = \left(\frac{\theta_j}{E}\right)w_j^w$. Finally, the net welfare effect (Dead Weight Losses - DWL) is:

$$DWL_{jt}^w = \Delta CS_{jt}^w + \Delta PS_{jt}^w \tag{18}$$

Using x_{jt}^{w}, w_{jt}^{w} and E, and the estimated values of ϵ_{ww} and θ_j from Eqs. (5) to (6.1), and Eqs. (12.1, 12.2) to (14), we can solve Eqs. (16.1, 16.2) to (18) algebraically by imposing economical equilibrium ($\Delta x_{jt}^{(d)w} = \Delta x_{jt}^{(s)w} = \Delta x_{jt}^{w}$) and solving for Δw_{jt}^{w} *and* Δx_{jt}^{w}, then for ΔPS_{jt}^{w}, ΔCS_{jt}^{w} and DWL_{jt}^{w}.

[6] However, we still present the results of AES because others elasticities, like Morishima, can be derived from it (Stern, 2011).

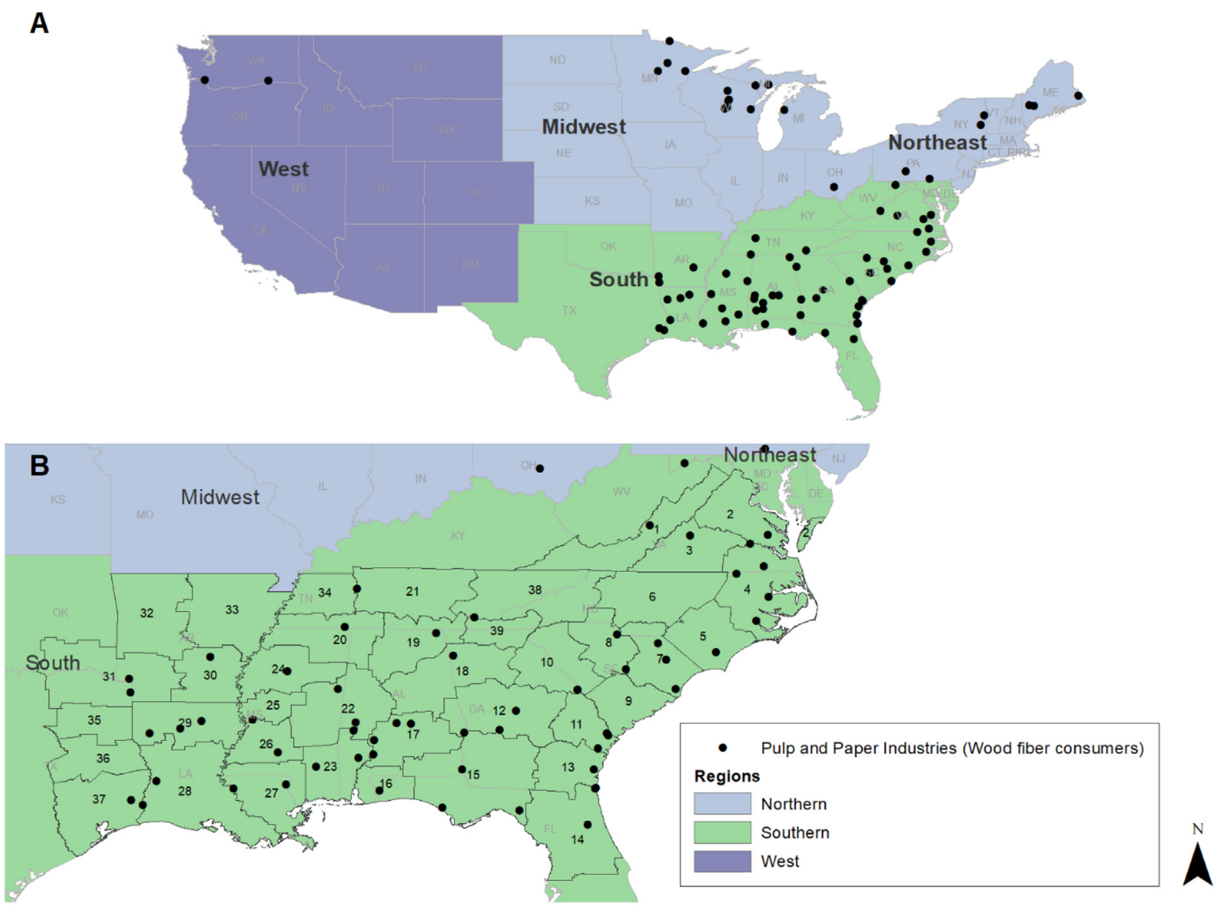

Fig. 1. (A) Pulp and Paper Industries (PPI) – Wood fiber Consumers – location in the U.S. (B) Micromarkets of timber defined by Forest2Market for the U.S. South.

4. Data

We investigated the pulpwood market structure of the US using three different datasets: In the Southeast, we analyzed (1) delivered wood and (2) stumpage prices of softwood and, in the North we investigated only the (3) delivered wood prices of hardwoods. The data is composed of quarterly input (Labor, Chemical materials, Energy, and Wood) and, output prices and quantities between Q4/2016 and Q4/2017 for 74 pulpmills in the U.S. (Fig. 1 – A and B) (FisherSolve, 2018). Fifty-five mills are in the South and 19 in the Northeast (Midwest and Northeast of the U.S.). The mills in the West were excluded because of the small sample size (two pulpmills), but their descriptive statistics are presented for comparison.

In 2017 – Q4 the total capacity share of softwood and hardwood in the U.S. South was 80.4% (45.3 million of 56.3 million Bone Dry Short Tons - BDST), while the Northeast represents 7.9% (4.4 million BDST), Midwest and West consume 11.2% (6.3 million BSDT) and 0.5% (306 thousand BDSDT) respectively.

Pulpwood production in the Southern and Western States is mostly composed of softwood timber. The annual average softwood used by pulpmills in the Southeast and the West were 78% (3.6 million of 4.6 million BDST) and 85% (2.6 million of 3.1 million BDST) respectively. On the other hand, hardwood represents 77% (4.7 million of 6.1 million BDST) and 71% (2.3 million of 3.3 million BDST) of the total in the Midwest and the Northeast States. There is no significant difference between the quarters analyzed in the volume of wood or cost shares (Fig. 2 – A and B).

Energy and Labor together account for > 50% of the total costs in every region analyzed; the southern states have the lowest cost allocation on labor with approximately 25% of the total cost. In comparison, costs of wood are 40% of the total cost in the Midwest, Northeast and Southeast state, while in the West it is around 10% of the total cost (Fig. 2 – B).

As a measure of capital, we used the number of machines per mill. The average number of machines per mill in the U.S. South was 145, while in the West was 114 machines and, in the Midwest and Northeast were 132 and 153 respectively. As expected though, the U.S. South has the most variety of sizes, from 52 to 344 machines per pulpmill. The pulpmills in the U.S. South produce a variety of products that require different sizes and types of machines.

4.1. Stumpage markets

While our data allowed direct estimation of CE for individual pulpmills, we needed to aggregate the data for stumpage market estimates. This aggregation was necessary because stumpage price data for producers are only available at a broad market level, not by pulpmill regions. We aggregated the pulpmill data (Labor, Chemical, Energy and quantity of Wood) for every period into 26 micromarkets to match the stumpage data provided by the consultant company Forest2Market (F2M, 2016)[7] (Fig. 1 - B). We focused on softwood because it has the largest market share, has a density that is relatively homogenous in comparison to hardwood, and could be converted from BDST (2000 pounds of wood material at zero percent moisture content) to tons with more accuracy.

Prices of Labor, Chemicals, and Energy were averaged for each market respecting the pulpwood location, whereas their respective quantities were summed. To estimate the amount of wood used in each

[7] Forest2Market is a consulting firm located in the U.S. South - https://www.forest2market.com/.

Fig. 2. (A) Consumption share of hardwood and softwood in the pulpwood market. (B) Average share costs of pulpmills in different regions in the U.S. South between 2016 and 2017. FisherSolve (2018).

micromarket, we assumed a radius varying 50, 75, and 100 miles around every mill and all timber supplied would come from inside this area. If a pulpmill is in between more than one region, the volume of wood was spread over the share of the areas in each region.

5. Results and discussion

This paper assesses the oligopsony power in the pulpwood market of the (1) U.S. Southeast delivered pulpwood - softwood, (2) U.S. Northeast delivered prices – hardwood, and (3) U.S. Southeast stumpage – softwood. For every market, we estimated a translog cost function and, price elasticity and elasticity of substitution. Descriptive data are presented in Tables 2 and 3.

5.1. Conjectural elasticities (CE)

In Tables 4 and 5 we present the Non-Linear IT3SLS estimates of the translog cost function for the Southeast mills, Northeast mills, and Southeast Stumpage with symmetry and homogeneity imposed. The coefficients β_{ij}, where i and j are the combination of the production factors Chemicals (C), Labor (L), Energy (E), Pulpwood (W) and Capital (K), are later used to estimate the elasticity of substitution and price elasticities. The last row in the table presents the conjectural elasticity (CE) or θ; its value varies from 0 (perfect competition) to 1 (monopsony). For every market analyzed, we ran three models: (i) imposing a perfect market ($\widehat{\theta} = 0$), (ii) static oligopsony model ($\widehat{\theta} = \theta$), which has no variation in either space or time (Table 2), and (iii) Parameter-Varying oligopsony model ($\widehat{\theta}_{jt} = \delta_0 HHI_{jt}$), which varies according to region/mill j and period t (Table 3). The results at the mill level show that the pulpwood market in the Northeast and Southeast exhibited some degree of oligopsony in both static and parameter-varying model. There was no evidence of market power over pulpwood stumpage prices either in the static or in the parameter-varying model.

The estimated R^2 ranges from 0.29 and 0.89 in the Southeast Stumpage static (Table 2) and parameter-varying models respectively. Normality of the residuals was rejected at 10% of significance in all equations.

5.2. Perfect competition and static model

The difference between the coefficients on the perfectly competitive model ($\widehat{\theta} = 0$) and static oligopsony model ($\widehat{\theta} = \theta$) was not very large (Table 2). In terms of magnitude, there was not much variance between the parameters, except the variables that are directly affected by θ like the estimates of the cost share of wood. For instance, in the Southeast, β_{KK} was negative in the oligopsony model and not significant in the perfect competition (though also negative). The Northeast model, on the other hand, presented clear differences between oligopsony and perfect competition in five coefficients,β_0, β_Q, β_{QQ} and β_{WW}. They were significantly different from zero at 10% level only in the oligopsony model, while β_{KW} and β_{EK} were significant only in the static model. The coefficients in the Southeast Stumpage were similar between the two models, with the same sign and similar magnitude. The difference between regions is partially explained by the market power, which was greater in the Northeast than in the Southeast and not significant in the Southeast Stumpage.

Table 2
Pulpwood production - annual descriptive statistics - southeast (Softwood).

Statistic	Unit	Mean	SD	Min	Max
Revenue	$	488,173,169	181,048,597	110,255,990	934,471,948
Production	Ton	694,550	271,801	171,150	1,612,765
Labor wages	$/unity	101,044	2959.712	85,880	103,723
Labor quantity	N	503	187	154	1250
Energy price	$/Mwh	101.48	39.25	24.87	238.19
Energy quantity	Mwh	670,657	411,889	94,784	2,345,137
Chemical price	$/Ton	720.15	386.51	327.14	1689.66
Chemical quantity	Ton	15,824	12,750	2305	57,132
Softwood price - delivered	$/BDST[a]	75.83	4.23	67.15	83.49
Softwood price - stumpage	$/Ton	7.64	3.33	2.64	20.22
Softwood quantity	BDST	657,321	386,008	25,107	1,846,437
Capital	N	148	58	52	344
Total costs	$	174,761,809	67,813,629	46,183,030	364,938,977
HHI - 50 miles[b]		0.49	0.22	0.19	1
HHI - 75 miles[b]		0.26	0.17	0.12	1
HHI - 100 miles[b]		0.18	0.10	0.09	0.93

Note: SD = Standard Deviation.
[a] BDST = Bone Dry Short Ton.
[b] Herfindahl - Hirschman Index (HHI): the highest the more concentrated is the market.

The CE indicate significant market power in the Southeast (θ = 0.34, ± 0.071), Northeast (θ = 0.76, ± 0.216) but not significant in the Southeast Stumpage pulpwood market (θ = 0.13, ± 0.14). The stronger market power in the Northeast may be explained by the mills' costs and the difference in the structure of the land ownership. Pulpmills in the U.S. Northeast and Midwest have the highest manufacturing costs per output in the country (Greenleaf, 2014). According to the authors, the costs per finished short ton (FST) in the South is approximately $400, whereas in the Northeast and Midwest are around $550 and $620 per FST. The higher costs lead to lower profit, pressuring mill managers to reduce costs on the input market, like pulpwood.

Also, forest ownership concentration in the Southern states is higher than in the North of the U.S. The share of properties > 100 acres owned by families is 34% of the total forest area in the Southern states (74.2 of 216.2 million acres) and 22% in the U.S. North (37.6 of 170 million acres) (Butler and Leatherberry, 2004). The different management goals of forest landowners might also influence the price negotiation. According to Butler and Leatherberry, Northern landowners do not consider timber production as an essential priority, while in the South, land investment is among their top three goals. Since family landowners in the Northern and Southern states account for 32% and 23% of the total forestland owned by private entities in the U.S. (127.6 and 93.9 of 393 million acres respectively), their behavior could have a more significant impact in the North. If timber production is not a primary goal, landowners may be less concerned about timber market opportunities and more likely to be price takers. These decisions, however, might vary according to the share of forest profits in the landowner income and/or liquidity constraints. A forest owner who depends on forest investments could be less sensitive to prices than the ones with large non-forest incomes. Also, restricted liquidity can make price negotiation less favorable, since there are not many opportunities to sell timber. In addition, most of the industrial forests in the U.S. South were bought by Timberland Investment Management Organizations (TIMOs) or spun off into Real Estate Investment Funds (REITs) in the 1990s and 2000s. Altogether they owned 10% of the timberland and approximately 26% of planted forest in the U.S. South in 2010 (Zhang et al., 2012); these areas are mostly located near industrial clusters. TIMOs and REITs have therefore a certain degree of oligopoly power as sellers in these areas which might offset some of the oligopsony power of pulpmills, forcing market prices closer to perfect competition.

In the Northeast, between 2005 and 2007, TIMOs and REITs purchased 2.6 million acres of publicly-announced northern timberland (James W. Sewall Company, 2007). However, the region does not seem to offer higher returns from forest investments than in the South. Results from Wan et al. (2015) indicate that under a mixed portfolio

Table 3
Pulpwood production - annual descriptive statistic - northern (hardwood).

Statistic	Unit	Mean	SD	Min	Max
Revenue	$	298,885,021	163,919,101	98,633,357	619,224
Production	Ton	394,879	205,358	116,147	797,410
Labor waves	$/Unity	94,450	1399	90,810	96,405
Labor quantity	N	478	147	292	926
Energy price	$/Mwh	98.13	34.97	15.38	165.12
Energy quantity	Mwh	478,659	195,533	128,872	828,409
Chemical price	$/Ton	1241.20	423.50	423.44	2093.01
Chemical quantity	Ton	8864	8843	707	33,011
Hardwood prices - delivered	$/BDST[a]	97.70	5.19	85.30	103.40
Hardwood quantity	$/BDST	366,089	323,125	38,051	1,316,066
Capital	N	136	49	63	244
Total costs	$	135,504,149	57,686,018	52,343,892	270,102,595
HHI - 50 miles[b]		0.54	0.29	0.18	1
HHI - 75 miles[b]		0.43	0.23	0.15	1
HHI - 100 miles[b]		0.34	0.19	0.15	1

Note: SD = Standard Deviation.
[a] BDST = Bone Dry Short Ton.
[b] Herfindahl - Hirschman Index (HHI): the highest the more concentrated is the market.

Table 4
Estimates of the parameters and conjectural elasticity at the pulp and paper industry for different regions in the U.S.: static model.

	Southeast at the mill (softwood)				Northern at the mill (hardwood)				Southeast stumpage (softwood)			
	$\hat{\theta} = \theta$		$\hat{\theta} = 0$		$\hat{\theta} = \theta$		$\hat{\theta} = \theta$		$\hat{\theta} = \theta$		$\hat{\theta} = 0$	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
β_0	−44.348	(34.802)	−68.347**	(30.573)	144.085***	(48.697)	2.407	(29.761)	290.897	(179.2)	262.12	(161.8)
β_Q	19.374***	(5.065)	21.446***	(4.387)	−28.905***	(4.833)	−1.618	(2.857)	−39.626	(37.423)	−35.062	(33.816)
β_{QQ}	−2.385***	(0.383)	−2.317***	(0.332)	2.07***	(0.394)	−0.089	(0.227)	1.980	(3.929)	1.616	(3.551)
β_L	0.020	(0.362)	−0.163	(0.464)	1.376***	(0.439)	2.172**	(0.882)	−0.52	(0.435)	−0.419	(0.425)
β_{LL}	0.157***	(0.049)	0.178***	(0.063)	0.084	(0.051)	−0.033	(0.105)	0.315***	(0.036)	0.304***	(0.035)
β_{LE}	−0.067***	(0.013)	−0.08***	(0.013)	−0.049***	(0.015)	−0.075***	(0.017)	−0.14***	(0.028)	−0.14***	(0.028)
β_{LQ}	−0.078***	(0.016)	−0.083***	(0.016)	−0.170***	(0.019)	−0.184***	(0.02)	−0.128***	(0.029)	−0.130***	(0.029)
β_E	−0.518**	(0.219)	−0.46**	(0.218)	0.217	(0.285)	0.590**	(0.276)	0.074	(0.398)	0.070	(0.398)
β_{EE}	0.098***	(0.012)	0.09***	(0.014)	0.064***	(0.014)	0.101***	(0.017)	0.052*	(0.031)	0.051*	(0.030)
β_{EQ}	0.073***	(0.016)	0.073***	(0.017)	0.044**	(0.019)	0.018	(0.017)	0.130***	(0.029)	0.131***	(0.029)
β_W	2.861***	(0.637)	1.707***	(0.475)	−2.015*	(1.17)	−1.68*	(0.976)	1.486***	(0.391)	1.163***	(0.189)
β_{WL}	−0.128***	(0.048)	−0.107*	(0.06)	−0.104*	(0.057)	0.092	(0.111)	−0.062***	(0.015)	−0.053***	(0.012)
β_{WE}	−0.057***	(0.019)	−0.010	(0.018)	−0.086**	(0.034)	−0.041*	(0.024)	0.024*	(0.013)	0.024**	(0.012)
β_{WW}	0.382***	(0.075)	0.151**	(0.063)	0.672***	(0.209)	−0.05	(0.122)	0.084***	(0.024)	0.06***	(0.008)
β_{WQ}	−0.004	(0.043)	0.005	(0.021)	0.359***	(0.092)	0.15***	(0.027)	−0.056**	(0.027)	−0.042***	(0.015)
β_K	−31.121***	(4.094)	−26.966***	(3.628)	17.466	(11.115)	3.932	(5.879)	2.759	(30.888)	1.221	(27.907)
β_{KL}	0.047***	(0.016)	0.06***	(0.016)	0.112***	(0.028)	0.149***	(0.027)	0.105***	(0.027)	0.104***	(0.027)
β_{KE}	0.067***	(0.017)	0.077***	(0.017)	−0.037	(0.031)	−0.003	(0.027)	−0.101***	(0.026)	−0.101***	(0.026)
β_{KW}	−0.229***	(0.049)	−0.130***	(0.022)	−0.142	(0.142)	−0.128***	(0.039)	0.021	(0.022)	0.015	(0.015)
β_{KK}	−0.952*	(0.514)	−0.336	(0.419)	−6.109***	(1.687)	−3.491***	(0.855)	−4.934*	(2.845)	−4.985*	(2.57)
β_{KQ}	2.728***	(0.284)	2.164***	(0.238)	0.928**	(0.458)	0.944***	(0.254)	1.932	(3.288)	2.054	(2.97)
θ	0.347***	(0.071)	–	–	0.763***	(0.216)	–	–	0.131	(0.145)	–	–

Equation	Southeast R-Square	Southeast SW-Test	Southeast DF	Northern R-Square	Northern SW-Test	Northern DF	Southeast Aggregate R-Square	Southeast Aggregate SW-Test	Southeast Aggregate DF
$lnTC_{jt}$	0.42	***	261	0.49	***	82	0.78	***	93
S_{jt}^{L}	0.40	***	271	0.76	**	92	0.53	**	104
S_{jt}^{E}	0.45	***	271	0.30	*	92	0.29	***	104
S_{jt}^{W}	0.42	***	271	0.42	***	92	0.40	**	104

Note: $\hat{\theta} = \theta$ (Oligopsony model), $\hat{\theta} = 0$ (perfect competition), Q = output quantity, L = labor, E = energy, W = pulpwood, K = capital, θ = conjectural elasticity, $lnTC_{jt}$ = total cost, S_{jt}^{L} = labor share costs, S_{jt}^{E} = energy share costs, S_{jt}^{W} = pulpwood share costs.
* $p < .1$.
** $p < .05$.
*** $p < .01$.

optimization, the allocation of investment in timberland in the Northeast U.S. is almost zero, whereas there is a consistent allocation in the U.S. South and Pacific Northwest.

5.3. Parameter – varying model

The parameter varying model has the advantage of assessing the market power per mill (Southeast and North of U.S.) or micromarket in the stumpage model (Southeast). In addition, we tested its sensitivity to different distances from the mill (50, 75 and 100 miles) (Table 5).

The estimated CE at 75 miles were on average $\widehat{\overline{\theta}}_{75} = 0.19$ (± 0.11) in the Southeast for pulpmills, $\widehat{\overline{\theta}}_{75} = 0.261$ (± 0.140) in the Northeast for pulpmills and not significant in the Southern Stumpage market. As the distance from the mills increase, the value of CE, or the influence of a single pulpmill on pulpwood prices, reduces, and vice versa. This reduction is not constant over the different regions. Since there are more pulpmills in the U.S. South than in the Northeast, the expansion of market from 50 to 75 miles, and 75 to 100 miles cause the CE to decrease faster in the U.S. South. On average, the CE goes from 0.321 to 0.118 (or 63%) in the U.S. South and it goes from 0.332 to 0.210 (or 36.7%) in the Northeast.

The positive effect of *HHI* is also observed in stumpage prices. Market power seems to be stronger in the West part of the U.S. South than in the eastern states, except in Alabama where pulpwood market is the most competitive among the pulpmills analyzed. Mississippi, on the other hand, is where the industries have the highest market power. In the North of the U.S., there are many more pulpmills in Wisconsin and New York, and less competition in Pennsylvania and Minnesota (Table 6).

Market power does not necessarily translate into higher prices; it indicates that prices are not in the perfect competition equilibrium. Other factors also can cause deviation from the competitive market equilibrium, like natural disasters (Prestemon and Holmes, 2000) and external economic shocks. The specific regional characteristics can lead buyers or sellers to exercise different levels of market power. For instance, the sensitivity analysis with respect to supply elasticity indicates that more elastic curves (0.4) could result in different conjectural elasticities, 0.25 in the US South and 0.23 in the Northeast (Table A.1).

There was a significant difference in terms of data structure — we could use individual firm data rather than aggregate regional data — and the period modeled in our study compared to previous research, which helps explain our somewhat different results. Our findings are similar to the results in the U.S. from Mei and Sun (2008) and Murray (1995a). Mei and Sun estimated CE for pulpwood market in the United States using a nationally aggregated data between 1955 and 2003. The average CE found was 0.59 with the highest peak at 0.79 in 1997 and the lowest one at 0.52 in the 1950s and 1960s. On the other hand, Murray found a smaller CE with the lowest at 0.06 between 1973 and 1977 and highest at 0.41 between 1958 and 1962.

The period and market structure analyzed by other researchers is entirely different from our study. Before the 1980s the market structure was dominated by vertically integrated pulpmills that owned a large part of the timberland. The number of pulpwood transactions and data then was much smaller, and therefore it is hard to make similar comparisons. Also, the data for our period is from after the great recession in 2008; there was a dramatic drop in the timber prices since then and

Table 5
Estimates of the parameters and conjectural elasticity at the pulp and paper industry for different regions in the U.S.: Parameter-Varying Model.

	Southeast at the mill (softwood)		Northern at the mill (hardwood)		Southeast stumpage (softwood)	
	Coef.	SE	Coef.	SE	Coef.	SE
β_0	3.643	(28.802)	−13.128	(40.493)	−315.551***	(50.809)
β_Q	11.389***	(4.29)	−6.21	(4.368)	68.621***	(11.236)
β_{QQ}	−1.669***	(0.326)	0.246	(0.374)	−7.371***	(1.264)
β_L	−0.471	(0.599)	1.194***	(0.322)	0.646***	(0.228)
β_{LL}	0.203***	(0.071)	0.12***	(0.04)	0.128***	(0.026)
β_{LE}	−0.07***	(0.015)	−0.027*	(0.015)	−0.069***	(0.019)
β_{LQ}	−0.073***	(0.018)	−0.177***	(0.016)	−0.144***	(0.012)
β_E	−0.715***	(0.221)	0.183	(0.267)	−0.065	(0.185)
β_{EE}	0.096***	(0.012)	0.112***	(0.017)	−0.002	(0.018)
β_{EQ}	0.086***	(0.016)	0.038**	(0.017)	0.109***	(0.012)
β_W	2.328***	(0.619)	0.098	(0.548)	0.575	(0.098)
β_{WL}	−0.154**	(0.065)	−0.126***	(0.036)	−0.041***	(0.008)
β_{WE}	−0.07***	(0.019)	−0.138***	(0.023)	0.028***	(0.008)
β_{WW}	0.362***	(0.067)	0.638***	(0.065)	0.061*	(0.032)
β_{WQ}	0.022	(0.032)	0.139***	(0.039)	0.006	(0.015)
β_K	−28.717***	(3.726)	23.969**	(9.617)	−58.057***	(10.434)
β_{KL}	0.069***	(0.017)	0.125***	(0.023)	0.144***	(0.013)
β_{KE}	0.067***	(0.016)	−0.038	(0.027)	−0.093***	(0.012)
β_{KW}	−0.188***	(0.035)	−0.005	(0.063)	−0.015	(0.015)
β_{KK}	−0.716	(0.441)	−7.574***	(1.363)	−6.326***	(1.19)
β_{KQ}	2.44***	(0.247)	0.977**	(0.401)	6.602***	(1.195)
δ_0	0.649***	(0.148)	0.606***	(0.165)	0.325	(0.621)
$\bar{\hat{\theta}}_{50}$	0.321	(0.143)	0.332	(0.178)	–	–
$\bar{\hat{\theta}}_{75}$	0.194	(0.110)	0.261	(0.140)	–	–
$\bar{\hat{\theta}}_{100}$	0.118	(0.065)	0.210	(0.115)	–	–
Equation$^{(1)}$	R-Square	SW-Test	R-Square	SW-Test	R-Square	SW-Test
$lnTC_{jt}$	0.59	***	0.52	***	0.89	*
S_{jt}^{L}	0.16	***	0.79	***	0.59	***
S_{jt}^{E}	0.38	***	0.40	**	0.44	**
S_{jt}^{W}	0.24	***	0.42	***	0.61	***

Note: $^{(1)}$Estimation IT3SLS, Q = output quantity, L = labor, E = energy, W = pulpwood, K = capital, θ = conjectural elasticity, $lnTC_{jt}$ = total cost, S_{jt}^{L} = labor share costs, S_{jt}^{E} = energy share costs, S_{jt}^{W} = pulpwood share costs.
* p < .1.
** p < .05.
*** p < .01.

Table 6
Southeast aggregated conjectural elasticities: state average - Q1/2016 to Q4/2017.

Southeast at the mill (softwood)			Northern at the mill (hardwood)		
State	CE	SE	State	CE	SE
Alabama	0.109	(0.019)	Wisconsin	0.110	(0.021)
Florida	0.144	(0.032)	Michigan	0.312	(0.032)
South Carolina	0.157	(0.055)	New York	0.319	(0.012)
North Carolina	0.169	(0.023)	Maine	0.332	(0.082)
Missisipi	0.181	(0.011)	Minnesota	0.337	(0.082)
Georgia	0.189	(0.116)	Pennsylvania	0.605	(0.000)
Louisiana	0.195	(0.014)			
Virginia	0.252	(0.189)			
Texas	0.268	(0.061)			
Arkansas	0.368	(0.090)			
Tennessee	0.466	(0.120)			

Note: CE = conjectural elasticity and SE = Standard Error.

the biomass market also became much stronger. Between 2011 and 2016 the quantity of pulpwood used by pellet mills increased from 877 thousand to 13.16 million green short tons (Forisk Consulting in Abt et al., 2014). The impact of pellet production on pulpwood market is unclear, but the projection of timber supply indicates an increase in competition between pellet facilities and pulpmills (Abt et al., 2014).

Our results suggest that the inherently oligopolistic pulpwood stumpage market in the South has become more competitive than found previously. Our individual firm CEs in the Southeast (0.118 to 0.321) are similar to those found by Murray in the 1960s (0.26) and, higher than his results in the 1970s (0.06) and 1980s (0.13).

Comparing our results to other countries is interesting, if a bit academic. Our results do conform with the non-competitive hypothesis found in Sweden (Bergman and Bränlunnd, 1995) and Finland (Ronnila and Toppinen, 2000). Bergman and Bränlunnd found a CE from 0 to 0.9 in the pulpwood market in Sweden between 1960 and 1987, while the Ronnila and Toppinen just tested whether pulpmills have market power in Finland ($\hat{\theta} = 0$). None of them, however, examined models with data at the firm level.

5.4. Partial elasticities of substitution

Tables 7 and 8 present the Allen-Hicks and Morishima Partial Elasticities of Substitution (hereafter names AES and MOS for short, respectively). Both measures change in a relative factor for a change in price. Positive values indicate the input factors are net substitutes and negative indicate they are net complements.

Every elasticity calculated was statistically significant, rejecting the null hypothesis at 1% level. Interpreting AES and MOS is straightforward. For instance, all else constant, a 1% increase in the price of wood (labor) would lead to an increase of 0.17% in the quantity of labor (wood) (σ_{LW} in Table 4). Of six input studied, only wood/chemicals (σ_{WC}) and, wood/labor (σ_{LW}) are complements in the Southeast mill data according to the AES. The Southeast stumpage data, on the other hand, show complementarity between labor/chemicals (σ_{LC}),labor/wood (σ_{LW}) and wood/chemicals (σ_{WC}). In the Northeast, every input pair for pulpwood mill markets are net substitutes.

Table 7
Allen - Hicks partial elasticities of substitution (AES).

	Southeast at the mill (softwood)		Northern at the mill (hardwood)		Southeast stumpage (softwood)	
	Mean	SE	Mean	SE	Mean	SE
σ_{EE}	−1.15	(0.007)	−1.143	(0.016)	−1.005	(0.013)
σ_{EL}	1.009	(0.016)	1.736	(0.037)	2.07	(0.018)
σ_{EC}	0.897	(0.011)	0.493	(0.035)	1.859	(0.036)
σ_{EW}	0.251	(0.008)	0.39	(0.015)	0.114	(0.015)
σ_{LL}	−0.388	(0.039)	−1.894	(0.082)	0.605	(0.024)
σ_{LC}	1.499	(0.033)	1.809	(0.103)	−1.286	(0.029)
σ_{LW}	−0.176	(0.04)	2.001	(0.134)	−1.359	(0.056)
σ_{CC}	−12.118	(1.828)	−19.007	(3.241)	−4.227	(0.372)
σ_{WC}	−1.119	(0.04)	0.669	(0.207)	−2.47	(0.071)
σ_{WW}	−0.65	(0.045)	−4.098	(0.228)	−0.166	(0.186)

Note: SE = Standard Error, L = labor, E = energy and W = pulpwood. Monotonicity held for each observation and the estimated matrix of substitution elasticities is non-negative semi-definite.

Table 8
Morishima partial elasticities of substitution (MOS).

	Southeast at the mill (softwood)		Northern at the mill (hardwood)		Southeast stumpage (softwood)	
	Mean	SE	Mean	SE	Mean	SE
η_{EL}	0.199	(0.013)	0.859	(0.034)	−0.172	(0.013)
η_{EC}	0.763	(0.105)	1.306	(0.204)	0.865	(0.051)
η_{EW}	0.447	(0.014)	1.072	(0.051)	0.138	(0.013)
η_{LE}	0.481	(0.004)	0.5	(0.008)	0.497	(0.012)
η_{LC}	0.791	(0.105)	1.309	(0.203)	0.407	(0.052)
η_{LW}	0.137	(0.024)	1.426	(0.084)	−0.073	(0.014)
η_{CE}	0.741	(0.005)	0.939	(0.011)	1.367	(0.01)
η_{CL}	0.587	(0.019)	1.395	(0.031)	−0.663	(0.016)
η_{CW}	−0.135	(0.017)	1.121	(0.094)	−0.148	(0.013)
η_{WE}	0.702	(0.006)	0.534	(0.015)	1.273	(0.019)
η_{WL}	0.067	(0.025)	1.463	(0.08)	−0.688	(0.023)
η_{WC}	0.64	(0.105)	1.239	(0.205)	0.246	(0.052)

Note: SE = Standard Error, L = labor, E = energy and W = pulpwood. Monotonicity held for each observation and the estimated matrix of substitution elasticities is non-negative semi-definite.

MOS had similar findings. In the Southeast, wood/chemicals (η_{CW}) are complements only in one direction; chemical prices would increase the quantity share of wood, but an increase in wood prices will decrease the quantity share of chemical products. Asymmetry between inputs is also observed in the Southeast stumpage. The impact of wood prices on chemical usage ($\eta_{WC} = 0.64, \pm 0.10$) is inverse and more than two times the impact of chemical prices on wood costs ($\eta_{CW} = -0.13, \pm 0.01$). Chemical products and labor, and energy and labor are also asymmetric; chemical products have a greater impact over labor ($\eta_{CL} = 0.58, \pm 0.01$) in absolute value and labor on energy ($\eta_{LE} = 0.48, \pm 0.004$). The inputs in the Northeast are all substitutes with no exception; few of them have MOS less than one (η_{EL}, η_{LE} and η_{WE}), indicating a strong substitutability relation. The greater elasticities of substitution in the Northeast indicates that the regional input prices are less rigid than in the other regions and have more possibilities of substitution.

These results are similar to the literature in some aspects. McCarthy and Urmanbetova (2011) estimated the MOS for labor, energy, and material using aggregate data of the U.S. Paper and Paperboard industry between 1965 and 1996. Their MOS of labor/energy were 0.25 and 0.21 for energy/labor; it was smaller than in the Southeast ($\eta_{LE} = 0.48$ *and* $\eta_{EL} = 0.19$), the Northeast ($\eta_{LE} = 0.5$ *and* $\eta_{EL} = 0.85$) and, labor/energy in the Southeast stumpage ($\eta_{LE} = 0.49$) and it had the opposite sign for energy/labor ($\eta_{EL} = -0.17$). Lundmark and Olsson (2015) found wood/energy might be complements if calculated with AES (−0.13) and substitutes if estimated with MOS (0.061) in the Swedish Pulp and Paper Industry. This outcome had the opposite sign found in the AES and smaller than MOS in every region analyzed here. The authors also found labor and energy are complements (AES = 0.24, MOS = 0.14), as are energy and labor (MOS = 0.12).

Table 9
Price elasticities of conditional input demand.

	Southeast at the mill (softwood)		Northern at the mill (hardwood)		Southeast stumpage (softwood)	
	Mean	SE	Mean	SE	Mean	SE
ε_{EE}	−0.395	(0.002)	−0.373	(0.005)	−0.447	(0.006)
ε_{EL}	0.078	(0.002)	0.147	(0.006)	0.04	(0.005)
ε_{EC}	0.058	(0.001)	0.11	(0.002)	0.283	(0.002)
ε_{EW}	0.259	(0.003)	0.115	(0.008)	0.123	(0.002)
ε_{LE}	0.086	(0.003)	0.128	(0.005)	0.051	(0.007)
ε_{LL}	−0.121	(0.012)	−0.711	(0.03)	0.212	(0.008)
ε_{LC}	0.086	(0.002)	0.114	(0.006)	−0.175	(0.004)
ε_{LW}	−0.051	(0.012)	0.469	(0.032)	−0.089	(0.003)
ε_{CE}	0.346	(0.005)	0.567	(0.012)	0.92	(0.008)
ε_{CL}	0.466	(0.01)	0.684	(0.04)	−0.451	(0.01)
ε_{CC}	−0.705	(0.105)	−1.196	(0.203)	−0.582	(0.051)
ε_{CW}	−0.323	(0.011)	0.164	(0.048)	−0.163	(0.005)
ε_{WE}	0.308	(0.004)	0.161	(0.012)	0.826	(0.016)
ε_{WL}	−0.054	(0.013)	0.752	(0.051)	−0.476	(0.019)
ε_{WC}	−0.064	(0.002)	0.043	(0.013)	−0.336	(0.009)
ε_{WW}	−0.188	(0.013)	−0.957	(0.053)	−0.015	(0.012)

Note: SE = Standard Error, L = labor, E = energy and W = pulpwood. Monotonicity held for each observation and the estimated matrix of substitution elasticities is non-negative semi-definite.

5.5. Own and cross-price elasticities

Own-price elasticities are rather small (less than one) in the Southeast at the mill and Southeast stumpage, indicating an inelastic demand curve for all inputs analyzed (Table 9). In the Northeast, the conditional demand curve of the chemical products and wood are rather elastic. It indicates pulpmills in this region are more sensitive to changes in price, which might prompt pressure on reducing the demand for input factors.

Previous research in the region found a similar own-price elasticity of wood (Newman, 1987) and less elastic than in Polyakov et al. (2005). Hussain and Bernard (2017) showed less elastic values for labor. Our values are more elastic than other studies using national aggregate levels like McCarthy and Urmanbetova (2011).

The labor own-price elasticity in the Southeast stumpage has a counter-intuitive sign. This result is most likely related to the issue of the data aggregation. However, it would not be unusual that wages have positive effect on the quantity of labor during the period of this study. Between Q1/2016 and Q4/2017, the U.S. achieved the lowest level of unemployment, approximately 5% according to the Bureau of Labor Statistic Data, practically full employment. The counter-intuitive results in the in the labor variable might indicate a shortage of employees during the period analyzed.

Following the same trend as AES and MO, only wood and chemical are substitute inputs of the 12 cross-price elasticities estimated in the Southeast, a 1% increase in prices of wood (chemicals) would decrease chemical prices in 0.06% (0.32%). In the Northern states, cross-price elasticities are all complimentary as well. In the Southeast stumpage labor and wood, labor and chemical, chemical and wood are substitutes while the other estimates are complements.

5.6. Welfare effects

Results from the economic welfare of oligopsony are shown in Table 10; the columns are the average change of quantity (pulpmills)

Table 10
Estimated market distortions and welfare effects of pulpwood market structure.

	Southeast at the mill (softwood)				
	Δx^w	Δw^w	ΔPS	ΔCS	DWL
	Thousand tons	$/ton	Million $	Million $	Million $
Q4/2016	−50.14 (−7%)	−19.01 (−24%)	−755.96	627.27	−128.68
Q1/2017	−50.13 (−7%)	−18.29 (−24%)	−727.61	604.70	−122.90
Q2/2017	−48.66 (−7%)	−17.71 (−24%)	−687.89	575.82	−112.06
Q3/2017	−47.84 (−7%)	−17.71 (−23%)	−681.19	571.65	−109.53
Q4/2017	−50.59 (−7%)	−18.66 (−25%)	−725.30	595.45	−129.84
	Northern at the Mill (Hardwood)				
	Δx^w	Δw^w	ΔPS	ΔCS	DWL
	Thousand tons	$/ton	Million $	Million $	Million $
Q4/2016	−90.63 (−19%)	−63.89 (−65%)	−645.59	472.29	−173.30
Q1/2017	−89.36 (−19%)	−64.71 (−66%)	−631.81	459.24	−172.57
Q2/2017	−88.66 (−19%)	−63.64 (−66%)	−616.94	448.43	−168.51
Q3/2017	−88.58 (−19%)	−63.32 (−66%)	−612.93	455.43	−167.49
Q4/2017	−86.19 (−19%)	−63.50 (−66%)	−596.93	431.71	−165.21

Proportional change are in parenthesis. Δx^w = change in quantity of pulpwood demanded and supplied, Δw^w = change in pulpwood prices, ΔPS = change in Producer Surplus, ΔCS = change in Consumer Surplus, DWL = Dead Weight Losses.

(Δx^w) and prices (Δw^w), the total change in Producer Surplus (ΔPS), Consumer Surplus (ΔCS) and Dead Weight Losses (ΔDWL) as the sum of the two changes.

There was an economically minor effect of market power on the changes in quantity and prices of delivered pulpwood over the period analyzed. Pulpwood prices decreased 24% (Southeast delivered to the Mill), 36% (Northern delivered to the Mill) compared to the perfect competition market equilibrium levels[8]. The quantity of wood produced and used at equilibrium prices was 7% (Southeast at Mill) and 11% (Northern at Mill) less than the perfect competition quantities. This means that while mills do exercise some market power, and thus prices are lower than in the case of perfect competition, there also is less output than would occur in the perfect competition case.

The imperfect competition in pulpwood markets is expected to reduce the Producer Surplus (PS) on average $710 million per year in the Southeast at Mill; this is greater than the value of the surplus lost in the Northern at Mill ($610 million per year). The impact of the market distortion on PS decreased over time, in all regions analyzed. In the Southeast (at Mill and Stumpage), PS increased between Q3/2017 and Q4/2017, but it did not reach similar values found in Q4/2016. The same behavior can be observed in the change in Consumer Surplus (CS). In the Northern at Mill, the largest impact on CS was in Q4/2016 with $627.27 million per year; it reduced to $595.45 million per year in Q4/2017.

Although Southeast and Northern at Mill have different wood markets, they experienced similar net welfare losses. Overall the periods analyzed, the welfare losses were on average $110 million per year in the Southeast and $165 million per year in the Northern States. Our results are not much higher than previous studies; Murray (1995b) found that oligopsony structure in the Southern U.S. decreased prices in 12%; its final welfare loss was minus $7.8 million (1982 dollars, $17.7 million in 2017). In Sweden, the effect on welfare was minus $484 million1[9](1.9 billion Swedish Krona) (Brannlund, 1989).

Even though there are evidences of welfare losses, pulpmills employed on average 500 employees in the Southeast and 470 employees in the Northeast, spending $50 and $45 million on salaries. In comparison, the average Dead Weight Loss per mill in Q4/2017 was $2.4 million ($137million/55 pulpmills) and $5.3 million per mill ($102.61/19 pulpmills) in the Southeast and Northeast respectively. Thus, the potential costs of the oligopsony of mills are somewhat offset by potential benefits.

The welfare effect is also sensitive to elasticities of supply, adopting a more inelastic curve (0.2) would reduce the DWL in ~50% (from ~$110 to ~$67 million per year) in the US South and almost 100% (from ~$170 million to $50 million) in the Northeast. The opposite effect, but less intense, is observed with a more elastic supply curve. If supply elasticity is assumed to be 0.4, the DWL stays similar in the US South (~$120 million) and grows from ~$170 to $200 million per year. Markets with elastic supply curves tend to suffer higher impact due to market power, but it tends to diminish as elasticity increases.

6. Conclusion

This paper investigated the oligopsony power in the pulpwood market of two regions in the U.S. using plant-level data for the first time. We studied the softwood market in the U.S. South and the hardwood market in the Northern States. The analysis also included an aggregate analysis of the stumpage prices in the Southeast. We estimated a translog cost function and four cost share equations (Energy, Labor, Chemicals, and Pulpwood) and derived the conjectural elasticities (CE), static and parameter varying, of the pulpwood prices and the input demand variables. We also estimated input demand price elasticities and elasticities of substitution (Allen – Hickens and Morishima elasticities). We used exceptionally detailed and robust data assembled at the firm level, at the mill, extending the aggregate approach used by almost all forestry researchers previously. However, we had only regional micromarket data for stumpage prices, which was less powerful and discerning than the individual mill data for pulpmills. Quantifying market power using aggregate stumpage data in the Southeast might mask local particularities that we could detect with the pulpwood mill data and analyses.

Similar to most previous research, our findings indicate a statistically significant market power for delivered pulpwood in every model, but not for just the Southeast Stumpage market. We found that there is a significant difference between regions. Northern pulpmills had higher market power in comparison to the ones located in the Southeast. This difference is probably a consequence of more industry concentration in the Northeast, while the Southern industry has more mills, spread over the U.S. South. Smaller clusters of pulpmills comprise the market in the North. We did not find statistical evidence of market power in the pulpwood stumpage market, perhaps partially due to the lack of precise, robust mill level data set available when we examined those

[8] Stumpage prices are not reported because the coefficients of market power were not significant.

[9] The original value is 1937 SEK millions, converting to 2017 dollars (divided by 8 and correcting for inflation) results in $484 million.

markets. Our estimates of price elasticities also were generally consistent with expectations, supporting the merits of our approach.

The results of some market power for pulpmills aligned with previous research findings. However, we consistently found that the pulp and paper sector exhibited less oligopsony than previous studies indicated. Furthermore, market power diminished as the assumed mill procurement zones expanded. Despite some market power, there are little opportunities for government action that will improve social welfare given the high transaction costs of intervention. While perfect competition is always theoretically superior for maximizing social welfare, pulp industries have a high investment cost, which is a natural entry barrier. The spatial characteristics of the wood market lead to a natural oligopsony. Wood producers located near pulpmills might have advantages in transportation costs, but they cannot negotiate prices well because of the lack of other options. Also, wood transactions are often negotiated by a third party, a wood procurement company. The sources of market power become then an intricate web with different players and goals in the wood supply chain. This finding of modest oligopsony—but less than in previous studies—is not likely to be improved enough by government actions that could outweigh the high costs of interventions in these markets, not to mention the challenges of making imprecise estimates of how much any presumed adjustment to an imperfect market should be on a mill by mill basis.

This paper covers only the oligopsony side of the story; unfortunately, we could not estimate the oligopoly of pulpmill suppliers because the output data had many different aggregate products. Estimating both oligopoly and oligopsony would give a greater insight into market behavior and dynamics. In reality, however, it is virtually impossible to find any data on timber supply market concentration, so this ideal market power research is apt to be unachievable in the U.S. at least. Nevertheless, our detailed input data at the pulpmill level allowed a broader and more detailed understanding of pulpwood competitiveness and finance decisions than previous studies. This research also accounted for major changes in the forest land ownership structure of TIMOs and REITs rather than the vertically integrated forest products firms from studies from a couple of decades ago. Future research could investigate the role of international trade to capture the integration between regional and global forest markets, although data and structural issues would again materialize.

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Appendix A. Supply elasticity

Table A.1 shows the conjectural elasticity (static and dynamic) under different elasticities of supply. In our sensitive analysis, elasticity of supply and conjectural elasticity have a positive correlation; in other words, as pulpwood producers become more sensible to changes in price, the pulpwood demand from a single pulpmill seems to gain greater capacity to change overall market demand. However, even not demonstrated here, in theory we expect a diminishing increment of market power as supply curve become more elastic because landowners could not accept to supply enough wood under certain price level to feed a pulpmill. Under this condition, the marginal cost of not operating under full capacity is greater than the cost with pulpwood.

Table A.1
Conjectural elasticities under different supply elasticities (0.2 and 0.4).

	Supply elasticity	$\hat{\theta}$	$\overline{\overline{\theta}}_{75}$
Southeast at the mill (softwood)	0.2*	0.207***	0.129**
	0.4	0.414***	0.258
Northeast at the mill (hardwood)	0.2	0.65***	0.11
	0.4	1.29***	0.23
Southeast stumpage (softwood)	0.2	0.10	-
	0.4	0.26	-

Note: $\hat{\theta}$ = conjectural elasticity, $\overline{\overline{\theta}}_{75}$ = average conjectural elasticity estimated assuming 75 miles radius around the pulpmills.
* $p < .1$.
** $p < .05$.
*** $p < .01$.

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