

HEDONIC ANALYSIS OF LOBLOLLY PINE PLANTATION FIRST THINNING COSTS

T. Eric McConnell

ABSTRACT

Revenues from pine plantation harvests have increasingly struggled to adequately support the wood supply system. A model was developed to better understand how three timber tract characteristics—acreage, site index, and trees planted per acre—can affect loblolly pine plantation first thinning costs. A growth and yield model provided yield data when basal area reached 110 square feet per acre. The Auburn Harvest Analyzer determined harvest system costs for multiple tract sizes. Variable stand ages at thinning required converting costs to equivalent annual costs (EAC), \$/ton per year. The cost implicitly associated with each independent variable was calculated from the predicted EAC when holding all predictors at their mean levels, which was \$3.16/ton per year. Each 10-foot increment of site index added \$0.43 to system EAC. Planting 10 additional trees at stand establishment increased system EAC \$0.03. Conversely, EAC was reduced by \$0.76 for each additional 10 acres of tract size. Managers can use these findings to better gauge the relationship between physical attributes of timber stands and the prices payable for standing timber.

INTRODUCTION

Long-term cost reductions driven by increased productivity and technical efficiencies in the logging industry ended in the 1990s, with costs subsequently trending upward since that time (Baker and others 2014, Cubbage and others 1988, Dodson and others 2015). Harvest systems in the U.S. South generally consist of varying quantities of rubber-tired feller bunchers, grapple skidders, and trailer-mounted loaders. Tractor trucks and trailers hauling timber products to wood-using mills may be company owned or contracted for their services from independent firms. Each piece of in-woods equipment previously listed can easily eclipse \$100,000 each, and equipment investments exceeding \$1 million is a norm rather than an exception.

Logging costs ultimately impact the prices paid for standing timber. One logging cost estimation technique assesses a system's productivity via time and motion study, where a value is then placed on that productivity (Conrad IV and Dahlen 2019). Productivity studies alone, though, cannot reveal the latent values physical attributes possess to influence harvesting costs. Tree and tract sizes are two key factors impacting logger productivity and costs (Cubbage and others 1989). The former is linked to the typical increase in production, and the latter is related to economies of forest tract size in operations. An alternative perspective considers the values the market places on these and other timber sales characteristics because the timber market will consider

adjustments resulting from the levels of these factors (Munn and Palmquist 1997).

The hedonic function is well suited to discovering the characteristic values that comprise a forest-based product or service that themselves may not possess a market derived worth. Kennedy and others (2011) assessed north Louisiana timberland values, finding paved road access (+), distance from a city (-), and the potential for future development (+) played roles in determining sale values¹. Puttock and others (1990) found stumpage prices were influenced by segregating standing volumes further according to species, scale (+), quality (+), and tract distance to mill (-). Stand volume (+) and age (+) were significant determinants of Chinese fir (*Cunninghamia lanceolata*) stumpage price (Chen and others 2020). Wood quality declines in British Columbia softwood logs were disaggregated into two effects, species mix and grade mix, and how their proportional contributions to timber product output affected final product value (Constantino and Haley 1988). Alzamora and Apiolaza (2010) concluded log scaling diameter (+), taper (-), and length between branch internodes on the values of radiata pine (*Pinus radiata*) impacted butt and upper-log values, but branch-specific variables did not.

Even though the hedonic function has wide acceptance in the forest economic literature, a gap was identified regarding its application in harvesting economics. Loblolly pine plantation first thinnings are largely composed of smaller diameter pulpwood-sized stems, although some trees do

¹ The symbols (+) and (-) denote significant positive or negative effects observed in the cited studies.

Author Information: T. Eric McConnell, Assistant Professor, Mississippi State University, Mississippi State, MS 39762.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

reach small sawtimber “chip-n-saw” size. This type of operation typically removes all trees within every fourth or fifth row, and another 20 to 25 percent are selectively removed from between the rows due to poor size, form, etc. (Dickens and Moorhead 2015). Thus, most of the value received at the mill gate is paid to cover the logger’s costs, risk, and profit. For example, the harvest margin paid to loggers for pine pulpwood in Mississippi, on average, comprises 70 percent of the mill delivered product value versus 25 percent for pine sawtimber (Norris Foundation 2020).

Loggers as a tradeoff for the first thinning’s smaller average tree size require plantations of greater acreage that increase the tract’s total harvestable volume. This is because of the large, fixed costs tied to the equipment as well as transporting it to establish the harvest operation. Foresters typically time the thinning operation to coincide with the plantation’s reaching a designated stocking benchmark. When considered from the perspective of basal area (BA), this may range from 110 to 120 square feet per acre. Two physical characteristics that impact the time required to reach this level are a tract’s site index (SI) and its stand density. A higher site-indexed tract will, all else being equal, be more productive than a lower-indexed site. Consequently, production can be regulated within each of those sites by strategically planning the number of trees per acre to plant at establishment. This study’s goal was to apply hedonic modeling techniques to study timber tract characteristics—specifically acreage, SI, and trees per acre (TPA) planted at establishment—that can influence harvesting costs for loblolly pine plantation first thinnings.

METHODS

The Cutover Loblolly Growth and Yield Model (CoLob) (Matney 1996) provided timber yield data for the following tract variables and levels: SI (60, 65, 70, 75, and 80 feet at 25 years) and TPA (485, 585, and 685) at establishment. Thinning occurred only when stand BA surpassed 110 square feet per acre and yields of at least 25 tons per acre would result from harvesting every fifth row coupled with selective thinning of lower-sized classes between the harvested rows. Fifth row thinning was selected over more aggressive row removals because of the better quality that will result from selectively thinning over more TPA (Harrington 2001). Loblolly pine density outside bark was assumed as 63 pounds per cubic foot (Miles and Smith 2009). Remaining BA was set to 60 square feet per acre (Gallagher and others 2017). This was deemed the minimum to maintain full stocking for timber production (Dickens and Moorhead 2015). These were consistent across all possible treatment combinations. Results from CoLob were incorporated into a spreadsheet modeled on the Auburn Harvest Analyzer (Tufts and others 1985) that provided stump-to-mill costs for a balanced system.

The harvest system consisted of two rubber-tired feller bunchers, two grapple skidders, and two trailer-mounted loaders. One operator ran each machine along with one foreman on site. Machine rates were calculated using equipment costs obtained from a regional John Deere dealer of \$365,000 for the feller bunchers (John Deere 843L-II), \$365,000 for the skidders (John Deere 748L-II), and \$322,000 for the loaders (John Deere 437E). Operator wages were \$17 per hour (U.S. Department of Labor Bureau of Labor Statistics 2019) plus 45-percent fringe benefits. Machine availabilities were assumed to be a constant 90 percent as were operator efficiencies.

The feller bunchers were assumed to possess a capacity 5.2 square feet of area. Average skid distance was set to 400 feet. Average turn tonnage was set to center around 2.85 tons for the skidders, with variation around that value due to the treatment combinations’ mean tree weights by diameter class, which were determined at the time of thinning (Holtzschner and Lanford 1997). Four minutes of prep time was assumed for the loaders. Haul costs were based on the first quarter 2020 incremental haul rate published by Timber Mart-South for the U.S. South, \$0.15/ton per loaded mile (Norris Foundation 2020). Payload and distance were held constant at 27 tons and 50 miles, respectively. Moving time (4 hours) and distance (40 miles) were held constant. Unit costs, \$/ton, were calculated and recorded for each treatment combination.

Stand ages at the designated thinning times differed due to the variables analyzed (table 1). As SI and TPA increased, time to thinning decreased. A preliminary model that included age as a predictor returned high variance inflation factors for that variable, SI, and TPA. Therefore, costs at each factor and level combination were instead converted to their respective equivalent annual cost (EAC) at the time of thinning (years) so valid comparisons could be performed using equation 1

$$EAC = C_t * \frac{R(1+R)^t}{(1+R)^t - 1} \quad (1)$$

where

EAC is equivalent annual cost of the first thinning’s system costs (fell, skid, load, and haul); C_t is the first thinning’s system costs at thinning time; t is thinning time; and R is the real discount rate. The level of R was set to a constant 10-percent rate, which approximated the percent residual after subtracting historic logging costs and stumpage from pine pulpwood delivered price in Louisiana and Mississippi (McConnell 2020). Tract size was studied at six levels (P: 25, 50, 100, 250, 500, and 1,000 acres).

Table 1—Stand age at first thinning for the site index and trees planted per acre at establishment treatment combinations

Site index	Trees per acre	Age at first thinning years
60	485	28
60	585	22
60	685	19
65	485	22
65	585	19
65	685	17
70	485	19
70	585	16
70	685	15
75	485	17
75	585	14
75	685	13
80	485	15
80	585	13
80	685	12

The hedonic model's form was equation 2 (Hussain and others 2013, Kennedy and others 2011)

$$\ln EAC = \ln \beta_0 + \beta_1 \ln P + \beta_2 SI + \beta_3 TPA + \varepsilon \quad (2)$$

where

SI is modeled as a continuous variable, TPA is a discrete variable, ε is the error terms, and $\beta_0, \beta_1, \beta_2, \beta_3$ are model parameters. Tract size P was logged due to the intuitively nonlinear between P and EAC (Cubbage 1983). As P increased from the smallest tract size, average EAC decreased at a greater rate before leveling off at the highest levels of P , which was similar to results seen in land valuation studies (Hussain and others 2013, Kennedy and others 2011). Normality was tested using the Shapiro-Wilk test. Heteroskedasticity was examined using the Breusch-Pagan test.

Marginal implicit costs for each independent variable were determined at the predicted EAC from equation 2 when the independent variables were entered at their mean levels (Hussain and others 2013). The regression coefficients of tract size and SI (equations 3 and 4) represented their marginal costs and were multiplied by average EAC . The earlier transformation of the tract size to its natural logarithm required adjusting the model coefficient for tract size in equation 3 by one over the average tract size across all observations (Hussain and others 2013, Kennedy and others 2011). The discrete nature of TPA required an error adjustment per equation 5 (Hussain and others 2013), where the term was one-half of the standard error associated with the coefficient

$$ImpP_{EAC} = \widehat{\beta_1} / \bar{P} * \widehat{EAC} \quad (3)$$

$$ImpSI_{EAC} = \widehat{\beta_2} * \widehat{EAC} \quad (4)$$

$$ImpTPA_{EAC} = \left[e^{\left(\widehat{\beta_3} - \frac{S\beta_3}{2} \right)} - 1 \right] * \widehat{EAC} \quad (5)$$

RESULTS AND DISCUSSION

Average system costs at the time of thinning and their EAC s are provided in table 2 at each level of the independent variables. As mentioned previously, system costs decreased with tract size, therefore EAC decreased as well. A higher level of SI led to an increasing average EAC , but the trend was interestingly not consistent. This was due to improved site conditions that promoted tree growth, which allowed the stand to reach the target BA at an earlier age. Higher levels of TPA at establishment were associated with higher average EAC s. While the targeted stand BA was reached at earlier ages for increasing levels of SI and TPA in CoLob, the tree of average BA was smaller at higher levels of SI and TPA than at lower levels. However, total stand volume in those cases was greater.

Table 2—Average system costs, \$/ton, and equivalent annual costs, EAC \$/ton per year, at the various levels of independent variables

P	Average system costs \$/ton	Average EAC, \$/ton per year
25	\$34.34	\$4.36
50	\$28.01	\$3.56
100	\$24.70	\$3.14
250	\$22.61	\$2.87
500	\$21.80	\$2.77
1,000	\$21.35	\$2.71

SI	Average system costs \$/ton	Average EAC, \$/ton per year
60	\$24.39	\$2.78
65	\$24.99	\$2.99
70	\$25.80	\$3.26
75	\$26.57	\$3.56
80	\$25.59	\$3.58

TPA	Average system costs \$/ton	Average EAC, \$/ton per year
485	\$23.87	\$2.86
585	\$25.54	\$3.27
685	\$26.99	\$3.58

Equation 1 was applied to calculate EAC .

EAC = equivalent annual costs; P = logged tract size; SI = site index; TPA = trees per acre at establishment.

Table 3—Hedonic regression results, where the dependent variable was logged equivalent annual harvesting costs EAC, and marginal implicit costs associated with the independent variables

Independent variables	Coefficient	Standard error	t Statistic	p-value	Predicted EAC at mean P, SI, and TPA	Marginal implicit cost	10-unit incremental cost
Intercept	0.1416	0.0893	1.5849	0.1167			
P	-0.1220	0.0054	-22.5728	< 0.0001		-\$0.08	-\$0.76
SI	0.0138	0.0010	14.0309	< 0.0001	\$3.16/ton/year	\$0.04	\$0.43
TPA	0.0011	0.0001	13.3478	< 0.0001		< \$0.01	\$0.03

P = logged tract size; SI = site index; TPA = trees per acre.

Independent variables are logged tract size P, site index SI, and trees per acre at establishment TPA.

The marginal implicit cost represents the monetary value one unit of an independent variable carries at the predicted EAC when all predictors are at their mean levels.

The 10-unit incremental cost is the marginal implicit cost multiplied by 10.

Regression normality ($W = 0.9854$, $p = 0.4138$) was satisfied; the constant variance assumption ($F_{3,86} = 3.8288$, $p = 0.0126$) was not deemed extreme. The results are provided in table 3. The SI produced the greater positive influence statistically ($t = 14.0309$, $p < 0.0001$) followed by TPA ($t = 13.3478$, $p < 0.0001$). Tract size P was the lone variable to possess a negative effect on equivalent annual thinning costs ($t = -22.5728$, $p < 0.0001$). Additional findings included adjusted $R^2 = 0.9083$, Akaike Information Criterion = -485.9130 (lower is better), and variance inflation factors equal to 1.0000.

Marginal implicit costs were calculated based upon the predicted EAC when all independent variables are measured at their mean levels, which was \$3.16/ton per year². The marginal implicit cost is an estimate of how EAC changes, given a unit change in tract size, SI, or TPA per acre at establishment. A characteristic that exhibits a positive marginal implicit cost indicates that increasing that variable's level subsequently raises the per ton harvesting cost of loblolly pine plantation first thinnings. For example, increasing pine plantation acreage by a 1-acre lowered EAC by 8 cents, holding other factors constant. Marginal implicit costs ranged from -\$0.08/ton per year for P to \$0.04/ton per year for SI. Thought of another way, incremental implicit costs are provided in table 3 at 10-unit intervals. Each 10-foot increment of SI at 25 years thus increased average EAC by \$0.43/ton per year, while EAC rose \$0.03/ton per year due to planting 10 additional trees at stand establishment. Conversely, each additional 10 acres reduced EAC by -\$0.76/ton per year.

This study was a first step to differentiating the costs that timber stand characteristics carry for loggers. The reader should be aware these data were simulated; they were not obtained completely random. Therefore, the regression only provided indications of relationships. Similar type analyses will be conducted by studying other species and compositions, timber product and log-quality mixes, along with additional tract characteristics for different

types of forest operations. Perhaps by including additional characteristics, stand age can be incorporated into future analyses as well. Moreover, the challenging southern pine timber market in recent years has led some to consider greater thinning intensities that boost individual tree growth, so sawtimber size requirements are reached at earlier stand ages. Huang and Kronrad (2004) concluded a pine sawtimber price premium would be required in many of their hypothesized scenarios for an aggressive, low-density management regime to be financially feasible. This was due to the additional pruning operation required to maintain tree quality that impacted the net present value of the forest investment. A second stage bid function would be needed to understand this and other economic considerations. Future efforts intend to build on this concept.

Still, the results trended in expected directions as past logging cost studies (Cubbage and others 1989). As tree size, volume per acre, tract size, and total volume increased, EAC decreased. The contribution of this work to the literature went beyond hypothesis testing and system cost prediction by placing market derived costs on loblolly pine plantation characteristics. Like Branman and others (1981), this study demonstrated hedonic modeling can provide measures of change in harvesting cost due to the variability of a differentiated product's physical attributes, which in this case was a logging operation. Logging and forest managers can use this study to better gauge the relationship between timber stands' physical characteristics, the costs required to harvest and haul to market, and ultimately the prices payable for pine plantation first thinnings in their market regions.

² This equated to an actual cost of \$24.72/ton.

ACKNOWLEDGMENTS

This publication is a contribution of the Forest and Wildlife Research Center at Mississippi State University. This material is based upon work that is supported by the U.S. Department of Agriculture, National Institute of Food and Agriculture, McIntire-Stennis project under accession number 1025007. Bruno Kanieski da Silva, Brady Self, Shaun Tanger, and Curtis VanderSchaaf kindly reviewed earlier versions of this manuscript.

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