# The Impact of Cost and Price Fluctuations on U.S. Hardwood Sawmill Profit

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While public reports exist about hardwood log and lumber prices, sawmills' operating costs are proprietary, and few records are publicly available. Operating costs make up a considerable share of a sawmill's cost structure and are, therefore, crucial for understanding the fiscal health of a given operation. Using the assumption that today's depressed lumber and residue markets result in sawmills, on average, making no profit and incurring no loss, this study estimated operation costs of a hypothetical 4, 8, and 12 MMBF production hardwood sawmill in the eastern United States producing red oak lumber. Using this knowledge and the Log Recovery Analysis Tool (LORCAT), this study found that a sawmill's financial well-being is highly dependent on hardwood log and operating costs as well as lumber prices. A 0.1% change in any of these factors will lead to a statistically significant change in profit for a sawmill. For example, with a 12 MMBF/year production sawmill, a 0.1% increase in operating cost would reduce profit by $4,510 but would increase profit $4,536 with an operating cost decrease of 0.1%. Similar observations can be made for log cost while lumber prices contribute even more to the volatility of the financial well-being of a sawmill.

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## INTRODUCTION

With record low demand for graded lumber (HMRE 2024a,b) many eastern US hardwood sawmills struggle to be profitable (Kiernan 2024). A simple model of a sawmill's cost structure consists of log cost, *e.g.*, the raw material, and the operating cost, *e.g.*, the cost of operating the mill including the administration to manage and sell the resulting products. Those products, mainly lumber and residues, hopefully allow a hardwood sawmill to make a profit and sustain its business. However, the individual cost and revenue structure of a sawmill is, probably, the most guarded secret of the industry. It can also be argued that some mills only have sporadic knowledge of their costs.

In the past three years, operating costs for hardwood sawmills have increased 30 to 40% (HMR 2024a) and thus have become increasingly scrutinized by operators to ensure the long-term survival of the sawmill. Knowledge of operating costs helps determine the success of a sawmill business and can be used to improve the financial success of any given sawmill. Also, if a sawmill wants to know if a given combination of logs (diameter class, length, species, grades) breaks-even or makes a profit, (in industry parlance known as the break-even log problem), knowledge of operating costs is necessary (Thomas and

Buehlmann n.d.a). That is why an understanding of operating cost data is crucially important to industry practitioners.

Perkins *et al.* (2008), in their case study of the economic feasibility of a red oak small-diameter timber sawmill and pallet-part mill, used actual cost information based on the participating mill's 2005 operation data. These authors give a detailed accounting of the hypothetical sawmill cost components, with log costs being "*the single largest cost component for sawmills*" (Perkins *et al.* 2008, p. 259). Using break-even analysis, net present value (NPV) analysis, and internal rate of return (IRR) analysis, these authors found that using the sawmill and pallet-part mill was economically feasible, but a new sawmill (scragg mill) was not. Except for this publication (Perkins *et al.* 2008), publicly available cost data for eastern U.S. hardwood sawmills is hard to come by.

Operating costs refer to the maintenance and administration of a business on a day-to-day basis. Horngren *et al.* (1997, p. 36) define operating costs as "*all costs associated with generating revenues, other than cost of goods sold.*" However, this study takes a broader view of operating cost in that operating cost denotes all expenses incurred to make and sell the product.

This study was designed to find the operating cost of an eastern U.S. hardwood sawmill using publicly available information. To this end, information about prevailing log costs (Kentucky Division of Forestry 2024), lumber prices (Hardwood Market Report 2024b), and residues (Anonymous 2024; Weiss 2024) was collected.

## EXPERIMENTAL

### Cost Information

Using the LOg ReCovery Analysis Tool (LORCAT, Thomas *et al.* 2021 and 2024; Thomas and Buehlmann 2024 and n.d.b), this study investigated the cost structure of an eastern U.S. hardwood sawmill producing red oak lumber. Lacking access to mills' accounting information, this study used market data from various sources (Kentucky Division of Forestry 2024; Hardwood Market Report 2024; Anonymous 2024; Weiss 2024) and the assumption that, given the current depressed market for lumber (HMRE 2024a; 2024b), sawmills, on average, break even but make zero profits. Hence, the goal is to solve Eq. 1,

$$\textit{Operating Cost} = \textit{Revenue (Lumber + Residues)} - \textit{Log Cost} \quad (1)$$

where revenue from lumber can be obtained using price series reports such as the Hardwood Market Report (Hardwood Market Report 2024), while revenue from residues can be estimated using expert input (Anonymous 2024, Weiss 2024). The cost of logs for the operation can be obtained from price reports for logs (Kentucky Division of Forestry 2024). The unknown factor is the sawmill's operating cost, which was calculated using LORCAT (Thomas and Buehlmann 2024, Thomas *et al.* 2024). Once operating cost are known, profit can be calculated with Eq. 2,

$$\textit{Profit} = \textit{Revenue (Lumber + Residues)} - \textit{Log Cost} - \textit{Operating Cost} \quad (2)$$

where profit is the excess returns over expenditure over a given period (Horngren *et al.* 1997).

### Log Sample

A power analysis using R (R Core Team 2022) was performed to determine the log sample size necessary within the LORCAT analysis for a valid statistical comparison of the differences in profit due to a change in one or more of the factors shown in Eq. 1. Power analysis determines the power of a statistical analysis given a sample size and a required significance level (Frost 2020). The statistical power indicates the probability of not making a Type II error, *i.e.*, the failure to reject a null hypothesis that is false.

Using the R statistical package (R Core Team 2022), the pwr.t.test function of the pwr package (Champely *et al.* 2020) was used to determine that a sample size of 1,000 logs resulted in a statistical power of 0.832 with a significance level of 0.05. A statistical power of 0.832 means that 83.2% of the time, a statistically significant result will be observed when present, while 16.8% of the time, the analysis would fail to find a significant difference where one existed. Power values for statistical analyses typically range between 0.8 and 0.9 (Frost 2020). Based on the power analysis results, a 1,000 log sample consisting of 500 Factory 1 grade and 500 Factory 2 grade red oak (*Quercus rubra*) logs was created using the LORCAT log sample creation tool (Thomas and Buehlmann 2024; Thomas *et al.* 2024). All logs included in the sample are 12-feet long. Table 1 lists the specifications of the log sample. The average small end diameter (SED) and large end diameter (LED) values (Table 1) used to create the sample are based on a compendium of sawmill studies where red oak saw log diameters by grade were collected (Wood *et al.* 2020). Overall, the log sample consists of 8970.7 bdft (Doyle scale) of Factory 1 logs and 7937.5 bdft (Doyle scale) of Factory 2 logs. Hence, the total volume of the 1,000-log sample is 16,908.2 bdft (Doyle scale).

**Table 1.** Specifications of the 1,000 Red Oak Log Sample

| Log set | Average SED (inches) | Average LED (inches) | Average Doyle Volume (bdft) | Total Doyle Volume (bdft) |
|---|---|---|---|---|
| 500 logs, Factory 1 | 17.9 | 20.7 | 139.9 | 8970.7 |
| 500 logs, Factory 2 | 15.9 | 19.1 | 100.9 | 7937.5 |
| All 1,000 logs | 16.9 | 19.9 | 119.9 | 16908.2 |

**Table 2.** Sawing Settings Used

| Setting Description | Value (inches) |
|---|---|
| Cant height | 6 |
| Cant width | Random |
| Minimum opening face width | 5.5 |
| Minimum opening face length | 96 |
| Green allowance | 0.125 |
| Lumber thickness | 1 |
| Total sawing variation, headrig | 0.035 |
| Total sawing variation, resaw | 0.035 |
| Target thickness, headrig | 1.194 |
| Target thickness, resaw | 1.194 |
| Taper setting | Split |
| Sawing method | Grade |

## LORCAT Processing Setup

The Log Recovery Analysis Tool (LORCAT)LORCAT 4.0 (Thomas and Buehlmann 2024; Thomas *et al*. 2024) was configured to simulate the sawing practices of the typical eastern U.S. hardwood sawmill. Table 2 gives an overview of the sawing settings used in the LORCAT simulations conducted.

The minimum opening face width was 5.5-inches, with a minimum lumber length of 8-feet. A random-width, 6-inch-tall cant was sawn for all logs, which then was sawn into lumber using a gang-resaw, as specified in Table 2. The target thickness for the headrig and the gang-resaw was calculated using Brown’s equation (Brown 2000). LORCAT was instructed to simulate grade sawing, where the log is rotated and boards are sawn from the highest-grade face until a user-specified cant thickness is achieved. It was specified that the analyses simulate split-taper sawing, where the taper of the log is split between opposite faces and the log is sawn parallel to its central axis (Hallock *et al.* 1978).

## Mill Processing Volume

Luppold and Bumgardner (2017) estimated that the average hardwood sawmill across all size categories in the Northeastern and North Central regions of the United States produces approximately 4 million board feet (MMBF) lumber per year. Bergman and Bowe (2008) defined a large hardwood sawmill as one that produces 10 MMBF or more lumber per year. These authors also reported that the average large hardwood sawmill produced a mean volume of 15.25 MMBF per year. Similarly, Lang (2023) reported that the average hardwood sawmill produces 14 MMBF per year. However, Lang (2023) acknowledges that the mills included in their study also produced softwood lumber. NHLA (2023) data revealed that the average NHLA member produced approximately 11.75 MMBF of lumber per year. Based on this information, LORCAT was configured to simulate three mills that produced approximately 4, 8, and 12 MMBF per year.

LORCAT uses the log sawing time data collected by Adams (1972) and Adams and Dunmire (1977) to estimate the sawing time for each log based on log grade, scaling diameter, and length. In LORCAT, by scaling the simulated sawing time up or down, the sawing times can be adjusted to match a specified annual production volume. This is accomplished by the user specifying in LORCAT the hourly production volume. The hourly production volume is estimated by dividing the annual production volume by the total number of annual operating hours. The analyses specified that the mill operated 2,250 hours per year, based on the average annual production data from NHLA (2023). This equates to approximately 281 operating days per year, somewhat more than the 250 to 253 working days estimated by the production estimates of Hardwood Market Report (Caldwell 2024). Thus, for the annual mill production volumes of 4, 8, and 12 MMBF, the hourly production volumes are 1,778, 3,555, and 5,333 bdft, respectively.

## Log, Lumber and Residues Prices

To perform an accurate costing analysis that reflects current market conditions, accurate and current log and lumber prices are required. Average red oak log prices for the first half of 2024 were obtained from the Kentucky Division of Forestry (2024). These reports show delivered log prices to sawmills by region and by quality: high, medium, and low. Region 4, Eastern Kentucky, has the most complete data and reported the price of red oak logs per thousand board feet Doyle scale as $544, $402, and $133 for high, medium, and low-quality logs, respectively. Rogers (2024) states that the high, medium, and low-quality sorts are approximately equivalent to the USDA Forest Service Log Grades (Rast *et al.* 1973) Factory 1, Factory 2, and Factory 3, respectively.

Market prices for green red oak 4/4 thickness lumber in the Appalachian region are listed in Table 3 of Hardwood Market Report's weekly pricing report (HMR 2024b). HMR does not report prices for F1F or Selects. Johnson (2022), however states that FAS lumber prices can be used to estimate F1F and Selects prices at 0.98% and 0.95% of the FAS price, respectively.

**Table 3.** Green, Red Oak 4/4 Lumber Prices, per 1000 bdft (HMR 2024)

| NHLA Lumber Grade | Market Price (Dollars) |
|---|---|
| FAS | 1035.00 |
| F1F | 1014.30 |
| Selects | 983.25 |
| 1 Common | 680.00 |
| 2 Common | 515.00 |
| 3 Common | 470.00 |

SmurfitWestrock located in Covington, VA reported that the average price for hardwood chips, bark, and sawdust was $25, $17, and $17 per ton, respectively, delivered FOB to the mill (Anonymous 2024). To estimate shipping costs, a local trucking company was contacted for a quote to transport residue products to the SmurfitWestrock mill in Covington, VA from a hypothetical sawmill 50 miles away. The quoted price depends on the number of trailers required to be parked at the mill to collect the residues and the number of loads per day delivered to the mill (Weiss 2024). Weiss (2024) quoted a price of $17 per ton for the residues to be transported based on a mill volume of 12 MMBF. This example indicates that residue products are not currently a profitable aspect of sawmill operation. However, sawmills can at least be break-even with respect to residues and avoid tipping/disposal fees at landfills.

## Operating Cost Calculations

Given established current market prices (at the time of analysis) for logs, lumber, and residue products, and known annual production volumes and operating hours, a break-even hourly or annual operating cost can be calculated (Eq. 1). To calculate the operating cost, the 1,000-log sample was processed with LORCAT using the processing settings, log, lumber, and residue prices that were discussed earlier. For the 12 MMBF sawmill, five simulations were performed using hourly operating costs of $1900, $1950, $2000, $2050 and $2100. Based on the reported total profit for each analysis, linear regression was performed to determine the break-even operating cost, *e.g.*, the operating cost such that total profit was $0.00 (Equation 1). As shown in Table 4, the break-even operating cost for the 12 MMBF sawmill was found to be $2010 per hour.

**Table 4.** Break-even Operating Cost, Production Times, and Costs for 12, 8, and 4 MMBF Sawmills

| Statistic | Annual Production Volume | | |
|---|---|---|---|
| | 12 MMBF | 8 MMBF | 4 MMBF |
| Break-even operating cost (per hour) | $2,010 | $1,337 | $670 |
| Hours to process 1,000-log sample | 3.17 | 4.78 | 9.53 |
| Total operating cost for 1,000 log-sample | $6,389 | $6,390 | $6,386 |
| Simulated annual production capacity (MMBF) | 11.97 | 7.96 | 3.99 |
| Estimated annual operating cost | $4,522,928 | $3,007,305 | $1,506,870 |

This analysis was repeated for 4 MMBF and 8 MMBF annual sawmill production volumes. The break-even operating cost for the 4 MMBF and 8 MMBF sawmills was determined to be $670 and $1337, respectively (Table 4). Table 4 shows additional results from these operating cost examinations. Note the difference in processing times (hours to process 1000-log sample, Table 4) and estimated annual operating costs (Table 4) among the different annual production volumes. Based on Eq. 1, there is a linear relationship based on production volume (MMBF) between the values presented in Table 4.

### Statistical Methods

Using Levene's test (Brown and Forsythe 1974; Fox and Weisberg 2019), variances between operating cost, log cost, and lumber and residue value groupings were found not to be equal ($\alpha = 0.05$). Thus, a non-parametric approach was required to analyze the differences among the cost and price groupings. To determine what degree of change in one or more of the cost factors (operating cost, log cost, and lumber and residues price) resulted in a significantly different profit (loss or gain) with respect to the break-even point. The Aligned Rank Transform (ART) statistical test (Wobbrock *et al.* 2011) was used in conjunction with R (R Core Team 2022). ART allows for the analyses of multi-factor designs while traditional non-parametric tests permit the analysis of only one single factor. In this approach, the data are first rank transformed, then a factorial ANOVA is performed. Post-hoc pairwise comparisons were conducted using ART-C (Elkin *et al.* 2021; Kay *et al.* 2021). ART-C showed the instances where the profit differences attributable to any combination of factor changes were significant ($\alpha = 0.05$).

## RESULTS AND DISCUSSION

The 1,000-log sample was processed with LORCAT using the specifications and settings defined in the methods (Table 5). For a 12 MMBF sawmill, LORCAT estimated that it would take 3.17 hours to process the 1,000-log sample (Table 4).

**Table 5.** Base Costs and Values for the 12 MMBF Annual Capacity Analysis

| Parameter | Value |
|---|---|
| Annual production hours | 2250 |
| Annual operating cost | $4,522,928 |
| Annual log cost | $4,463,814 |
| Annual product value | $8,910,437 |

Given an average of 2,250 annual operating hours for hardwood sawmills (NHLA 2023), the sample results were multiplied by 709.8 (2,250 / 3.17) to approximate annual production costs and values based on the 1,000-log sample. In scaling the sample costs and values to annual production, the base annual operating cost for the 12 MMBF sawmill in the analysis is $4,522,928 (Table 5). In addition, the base annual log cost and product value for the same 12 MMBF sawmill are $4,463,814 and $8,940,437, respectively. To simplify the discussion about changes to the costs and price factors, they were examined from an annual perspective as shown in Table 5. The values shown in Tables 6, 7, and 8 are based on the calculations done for the 12 MMBF sawmill analysis results from which the associated costs, values, and profit were calculated for 8 and 4 MMBF sawmill capacities. This is possible because of the linear relationship among the sawmill capacities in the example. However, these linear relationships may not hold, as, for example, a small sawmill most likely will pay higher prices for their logs compared to a large mill and large mills might realize technical economies of scale.

## Operating Cost

The Aligned Rank Transform (ART) statistical test (Wobbrock *et al.* 2011) in conjunction with R (R Core Team 2022) showed that a 0.1% change in hourly operating cost caused a statistically significant difference in profit ($\alpha = 0.05$) for a sawmill with 12 MMBF capacity. The analysis was repeated for 8 and 4 MMBF sawmill capacities, and the same differences that were significant with the 12 MMBF sawmills were found to be significant ($\alpha = 0.05$) with the smaller capacity mills. Table 6 shows the changes in profit and total annual operating costs as operating costs increased or decreased by as much as 25%. For the 1,000-log sample (Table 1), LORCAT 4.0 (Thomas and Buehlmann 2024; Thomas *et al.* 2024) calculates a small profit of $0.11 for the break-even point, which translates into an annual profit of approximately $8 for the 12 MMBF capacity sawmill, and $6 and $3 annual profit for the 8 MMBF and 4 MMBF capacity sawmills, respectively (Table 6).

**Table 6.** Effect of Operating Cost Changes on Annual Profit and Annual Operating Cost for 12, 8, 4 MMBF Capacity Sawmills

| Operating Cost Change | 12 MMBF | | 8 MMBF | | 4 MMBF | |
|---|---|---|---|---|---|---|
| | Annual Profit | Annual Operating Cost | Annual Profit | Annual Operating Cost | Annual Profit | Annual Operating Cost |
| -25.00% | $1,130,745 | $3,345,878 | $751,775 | $2,224,505 | $376,699 | $1,114,654 |
| -20.00% | $904,611 | $3,572,012 | $601,430 | $2,374,850 | $301,364 | $1,189,988 |
| -15.00% | $678,450 | $3,798,173 | $451,067 | $2,525,213 | $226,020 | $1,265,332 |
| -10.00% | $452,310 | $4,024,313 | $300,718 | $2,675,562 | $150,684 | $1,340,669 |
| -5.00% | $226,174 | $4,250,449 | $150,372 | $2,825,908 | $75,348 | $1,416,004 |
| -2.50% | $113,076 | $4,363,547 | $75,178 | $2,901,102 | $37,670 | $1,453,682 |
| -1.00% | $45,239 | $4,431,384 | $30,077 | $2,946,203 | $15,071 | $1,476,281 |
| -0.50% | $22,632 | $4,453,991 | $15,047 | $2,961,233 | $7,540 | $1,483,813 |
| -0.25% | $11,301 | $4,465,322 | $7,514 | $2,968,766 | $3,765 | $1,487,588 |
| -0.10% | $4,536 | $4,472,087 | $3,015 | $2,973,265 | $1,511 | $1,489,842 |
| 0.00% | $8 | $4,476,614 | $6 | $2,976,274 | $3 | $1,491,350 |
| 0.10% | -$4,510 | $4,481,132 | -$2,998 | $2,979,278 | -$1,502 | $1,492,855 |
| 0.25% | -$11,301 | $4,487,924 | -$7,514 | $2,983,794 | -$3,765 | $1,495,117 |
| 0.50% | -$22,606 | $4,499,229 | -$15,030 | $2,991,310 | -$7,531 | $1,498,884 |
| 1.00% | -$45,225 | $4,521,847 | -$30,068 | $3,006,348 | -$15,066 | $1,506,419 |
| 2.50% | -$113,072 | $4,589,694 | -$75,176 | $3,051,456 | -$37,669 | $1,529,022 |
| 5.00% | -$226,124 | $4,702,747 | -$150,339 | $3,126,619 | -$75,332 | $1,566,684 |
| 10.00% | -$452,289 | $4,928,912 | -$300,704 | $3,276,984 | -$150,677 | $1,642,029 |
| 15.00% | -$678,419 | $5,155,042 | -$451,046 | $3,427,326 | -$226,010 | $1,717,363 |
| 20.00% | -$904,570 | $5,381,193 | -$601,403 | $3,577,683 | -$301,351 | $1,792,703 |
| 25.00% | -$1,130,724 | $5,607,347 | -$751,761 | $3,728,041 | -$376,692 | $1,868,045 |

For 12 MMBF sawmills, a 0.1% increase in operating cost results in an annual loss of $4,510 compared to the break-even point at 0.00% operating cost change (Table 6). For 8 and 4 MMBF sawmills, the same 0.1% increase in operating costs results in annual losses of $2998 and $1502, respectively (Table 6). However, a report in the Hardwood Market Report (HMR 2024a) explains that sawmills have experienced operating cost increases of 30% to 40% since 2020 alone. Examining Table 6, a 25% increase in operating cost reduces profit by $1,130,724, $751,761, and $376,692 for 12, 8, and 4 MMBF capacity sawmills, respectively, compared to the break-even operating cost (Table 6). Thus, simulation results show that operating cost increases of this magnitude have a severe impact on mill profitability regardless of annual capacity.

## Log Cost

The Aligned Rank Transform (ART) statistical test (Wobbrock *et al.* 2011) in conjunction with R (R Core Team 2022) showed that a 0.1% change in log cost caused a statistically significant difference in profit. The statistical analysis was repeated for 8 and 4 MMBF sawmills, with the result that a 0.1% change in log cost caused a statistically significant ($\alpha$ = 0.05) difference in profit for the smaller capacity sawmills as well. Table 7 reports the annual profit and log costs for the indicated percent changes in log costs ranging from -25% to +25%.

**Table 7.** Effect of Log Cost Changes on Annual Profit and Annual Log Cost for 12, 8, and 4 MMBF Capacity Sawmills

| | 12 MMBF | | 8 MMBF | | 4 MMBF | |
|---|---|---|---|---|---|---|
| Log Cost Change | Annual Profit | Annual Log Cost | Annual Profit | Annual Log Cost | Annual Profit | Annual Log Cost |
| -25.00% | 1,107,393 | 3,356,421 | 736,250 | 2,231,515 | 368,919 | 1,118,166 |
| -20.00% | 885,912 | 3,577,901 | 588,998 | 2,378,766 | 295,135 | 1,191,950 |
| -15.00% | 664,442 | 3,799,372 | 441,754 | 2,526,010 | 221,354 | 1,265,732 |
| -10.00% | 442,968 | 4,020,846 | 294,507 | 2,673,257 | 147,572 | 1,339,514 |
| -5.00% | 221,493 | 4,242,321 | 147,260 | 2,820,504 | 73,789 | 1,413,297 |
| -2.50% | 110,746 | 4,353,068 | 73,629 | 2,894,135 | 36,894 | 1,450,191 |
| -1.00% | 44,307 | 4,419,507 | 29,457 | 2,938,307 | 14,761 | 1,472,325 |
| -0.50% | 22,167 | 4,441,647 | 14,738 | 2,953,027 | 7,385 | 1,479,701 |
| -0.25% | 11,085 | 4,452,729 | 7,370 | 2,960,394 | 3,693 | 1,483,392 |
| -0.10% | 4,446 | 4,459,368 | 2,956 | 2,964,808 | 1,481 | 1,485,604 |
| 0.00% | 8 | 4,463,806 | 6 | 2,967,759 | 3 | 1,487,083 |
| 0.10% | -4,411 | 4,468,225 | -2,933 | 2,970,697 | -1,470 | 1,488,555 |
| 0.25% | -11,054 | 4,474,868 | -7,349 | 2,975,113 | -3,683 | 1,490,768 |
| 0.50% | -22,117 | 4,485,931 | -14,705 | 2,982,469 | -7,368 | 1,494,454 |
| 1.00% | -44,278 | 4,508,092 | -29,438 | 2,997,202 | -14,751 | 1,501,836 |
| 2.50% | -110,725 | 4,574,539 | -73,615 | 3,041,380 | -36,887 | 1,523,973 |
| 5.00% | -221,470 | 4,685,284 | -147,245 | 3,115,009 | -73,781 | 1,560,867 |
| 10.00% | -442,933 | 4,906,747 | -294,483 | 3,262,248 | -147,560 | 1,634,645 |
| 15.00% | -664,408 | 5,128,222 | -441,732 | 3,409,496 | -221,343 | 1,708,428 |
| 20.00% | -885,893 | 5,349,707 | -588,985 | 3,556,749 | -295,128 | 1,782,214 |
| 25.00% | -1,107,358 | 5,571,172 | -736,226 | 3,703,990 | -368,908 | 1,855,993 |

Simulation results showed that a 0.1% increase in log costs will reduce annual profit by $4,411 for 12 MMBF capacity sawmills (Table 7). For 8 and 4 MMBF annual capacity sawmills a 0.1% increase in log costs reduced annual profit by $2,933 and $1,470, respectively.

## Lumber Prices

The Aligned Rank Transform (ART) statistical test (Wobbrock *et al.* 2011) in conjunction with R (R Core Team 2022) showed that a 0.1% change in lumber prices caused a statistically significant difference in profit. The statistical analysis was repeated for 8 and 4 MMBF sawmills, with the result that a 0.1% change in lumber prices caused a statistically significant ($\alpha = 0.05$) difference in profit. Table 8 reports the annual profit and log costs for percent changes in log costs ranging from -25 to +25%. Simulation results showed that a 0.1% decrease in lumber prices will reduce annual profit by $3,419 for 12 MMBF capacity sawmills (Table 7). For 8 and 4 MMBF annual capacity sawmills, a 0.1% increase in log costs reduced annual profit by $2,273 and $1,139, respectively.

**Table 8.** Effect of Lumber Price Changes on Annual Profit and Value for 12, 8, and 4 MMBF Capacity Sawmills

| Lumber Price Change | 12 MMBF | | 8 MMBF | | 4 MMBF | |
|---|---|---|---|---|---|---|
| | Annual Profit | Annual Product Value | Annual Profit | Annual Product Value | Annual Profit | Annual Product Value |
| -25.00% | -$855,586 | $8,084,850 | -$568,836 | $5,375,208 | -$285,032 | $2,693,406 |
| -20.00% | -$684,471 | $8,255,965 | -$455,070 | $5,488,974 | -$228,026 | $2,750,412 |
| -15.00% | -$513,355 | $8,427,082 | -$341,304 | $5,602,740 | -$171,020 | $2,807,418 |
| -10.00% | -$342,230 | $8,598,207 | -$227,531 | $5,716,513 | -$114,011 | $2,864,427 |
| -5.00% | -$171,116 | $8,769,320 | -$113,767 | $5,830,278 | -$57,006 | $2,921,432 |
| -2.50% | -$85,554 | $8,854,883 | -$56,881 | $5,887,164 | -$28,502 | $2,949,936 |
| -1.00% | -$34,222 | $8,906,214 | -$22,753 | $5,921,291 | -$11,401 | $2,967,037 |
| -0.50% | -$17,106 | $8,923,330 | -$11,373 | $5,932,671 | -$5,699 | $2,972,739 |
| -0.25% | -$8,553 | $8,931,883 | -$5,687 | $5,938,357 | -$2,850 | $2,975,588 |
| -0.10% | -$3,419 | $8,937,018 | -$2,273 | $5,941,771 | -$1,139 | $2,977,299 |
| 0.00% | $3 | $8,940,440 | $2 | $5,944,046 | $1 | $2,978,439 |
| 0.10% | $3,428 | $8,943,865 | $2,279 | $5,946,323 | $1,142 | $2,979,580 |
| 0.25% | $8,559 | $8,948,996 | $5,691 | $5,949,735 | $2,851 | $2,981,289 |
| 0.50% | $17,118 | $8,957,554 | $11,381 | $5,955,425 | $5,703 | $2,984,141 |
| 1.00% | $34,230 | $8,974,667 | $22,758 | $5,966,802 | $11,404 | $2,989,842 |
| 2.50% | $85,561 | $9,025,998 | $56,885 | $6,000,930 | $28,504 | $3,006,942 |
| 5.00% | $171,125 | $9,111,561 | $113,772 | $6,057,816 | $57,009 | $3,035,447 |
| 10.00% | $342,244 | $9,282,681 | $227,541 | $6,171,585 | $114,016 | $3,092,454 |
| 15.00% | $513,361 | $9,453,798 | $341,308 | $6,285,352 | $171,022 | $3,149,460 |
| 20.00% | $684,483 | $9,624,920 | $455,078 | $6,399,122 | $228,030 | $3,206,468 |
| 25.00% | $855,602 | $9,796,039 | $568,847 | $6,512,891 | $285,037 | $3,263,475 |

## Combined Leverage

The increases/decreases in annual profits described in Tables 6, 7, and 8 show the volatility of the sawmill business. This volatility is amplified when changes in operating costs, log costs, and lumber prices are combined. In a worst-case scenario, operating cost and log costs increase while lumber prices decrease, a situation not far from what has happened over much of 2024. While the actual percentage increase/decrease will not be so simply distributed as in the example in Table 9, the Table shows the volatility with which sawmills have to cope. In the sawmill business, the downside potential is large, but so is the upside. Today, with a lackluster housing market, export markets not performing well, and operating costs increasing due to inflation, sawmills have a difficult time generating a profit. This is a different setting than during and after the “COVID” disruption of 2020, when people started buying new homes or remodeling existing homes, thereby increasing demand for hardwood lumber while only a limited supply reached the market.

**Table 9.** Best/Worse-case Scenario - Total Effect on Annual Sawmill Profitability if Log and Operating Cost Change Opposite of Lumber Prices

| Operating Cost Change | Annual Operating Cost | Log Cost Change | Annual Log Cost | Lumber Price Change | Annual Product Value | Annual Profit |
|---|---|---|---|---|---|---|
| -25.00% | $3,345,878 | -25.00% | $3,356,421 | 25.00% | $9,796,039 | $3,093,740 |
| -20.00% | $3,572,012 | -20.00% | $3,577,901 | 20.00% | $9,624,920 | $2,475,006 |
| -15.00% | $3,798,173 | -15.00% | $3,799,372 | 15.00% | $9,453,798 | $1,856,253 |
| -10.00% | $4,024,313 | -10.00% | $4,020,846 | 10.00% | $9,282,681 | $1,237,522 |
| -5.00% | $4,250,449 | -5.00% | $4,242,321 | 5.00% | $9,111,561 | $618,792 |
| -2.50% | $4,363,547 | -2.50% | $4,353,068 | 2.50% | $9,025,998 | $309,382 |
| -1.00% | $4,431,384 | -1.00% | $4,419,507 | 1.00% | $8,974,667 | $123,777 |
| -0.50% | $4,453,991 | -0.50% | $4,441,647 | 0.50% | $8,957,554 | $61,917 |
| -0.25% | $4,465,322 | -0.25% | $4,452,729 | 0.25% | $8,948,996 | $30,946 |
| -0.10% | $4,472,087 | -0.10% | $4,459,368 | 0.10% | $8,943,865 | $12,410 |
| 0.00% | $4,476,614 | 0.00% | $4,463,806 | 0.00% | $8,940,440 | $20 |
| 0.10% | $4,481,132 | 0.10% | $4,468,225 | -0.10% | $8,937,018 | -$12,340 |
| 0.25% | $4,487,924 | 0.25% | $4,474,868 | -0.25% | $8,931,883 | -$30,909 |
| 0.50% | $4,499,229 | 0.50% | $4,485,931 | -0.50% | $8,923,330 | -$61,830 |
| 1.00% | $4,521,847 | 1.00% | $4,508,092 | -1.00% | $8,906,214 | -$123,725 |
| 2.50% | $4,589,694 | 2.50% | $4,574,539 | -2.50% | $8,854,883 | -$309,351 |
| 5.00% | $4,702,747 | 5.00% | $4,685,284 | -5.00% | $8,769,320 | -$618,711 |
| 10.00% | $4,928,912 | 10.00% | $4,906,747 | -10.00% | $8,598,207 | -$1,237,452 |
| 15.00% | $5,155,042 | 15.00% | $5,128,222 | -15.00% | $8,427,082 | -$1,856,182 |
| 20.00% | $5,381,193 | 20.00% | $5,349,707 | -20.00% | $8,255,965 | -$2,474,934 |
| 25.00% | $5,607,347 | 25.00% | $5,571,172 | -25.00% | $8,084,850 | -$3,093,668 |

While interesting to consider, a situation as described in Table 9 is unlikely to happen (with the same percentage changes to operating cost, log cost, and lumber prices occurring simultaneously). In addition, while a 25% cost/price change is quite a large swing in costs/price, even small changes, such as +/- 0.25%, can change the profit/loss of a sawmill considerably as can be seen in Table 10. In the best case, with a decrease of 0.25% for operating and log cost (highlighted green in Table 10) and an increase of the lumber price of 0.25% (highlighted green), the profit of the mill increases by $30,946, as shown in Table 10 (second row). The reverse, where operating cost and log cost increase by 0.25% (highlighted red) and lumber prices (highlighted red) decrease by 0.25%, yields a $30,909 loss (last row in Table 10).

Losing nearly $31,000 due to a combined 0.25% increase in operating and log costs and a 0.25% decrease in lumber prices shows the volatility with which sawmills must cope. However, the reader must keep in mind that a) the model employed builds on the assumption that a sawmill is not making a loss or a profit due to current market conditions and b) costs and prices rarely, if ever, increase/decrease by the same percentage overall. In addition, economies of scale lead to costs and price changes on the size of each transaction. Hence, our theoretical model shows the volatility of the sawmill business. However, reality is far more complex than what can be represented in a model.

**Table 10.** The Combined Effects of +/- Changes of 0.25% in Operating Cost, Log Cost, and Product Value on Annual Profit for a 12 MMBF Sawmill

| Operating Cost Change | Annual Operating Cost | Log Cost Change | Annual Log Cost | Lumber Price Change | Annual Product Value | Annual Profit |
|---|---|---|---|---|---|---|
| -0.25% | $4,465,322 | -0.25% | $4,452,729 | 0.25% | 8,948,996 | 30,946 |
| -0.25% | $4,465,322 | -0.25% | $4,452,729 | 0.00% | 8,940,440 | 22,390 |
| -0.25% | $4,465,322 | -0.25% | $4,452,729 | -0.25% | 8,931,883 | 13,833 |
| -0.25% | $4,465,322 | 0.00% | $4,463,806 | 0.25% | 8,948,996 | 19,869 |
| -0.25% | $4,465,322 | 0.00% | $4,463,806 | 0.00% | 8,940,440 | 11,313 |
| -0.25% | $4,465,322 | 0.00% | $4,463,806 | -0.25% | 8,931,883 | 2,756 |
| -0.25% | $4,465,322 | 0.25% | $4,474,868 | 0.25% | 8,948,996 | 8,807 |
| -0.25% | $4,465,322 | 0.25% | $4,474,868 | 0.00% | 8,940,440 | 250 |
| -0.25% | $4,465,322 | 0.25% | $4,474,868 | -0.25% | 8,854,883 | -85,307 |
| 0.00% | $4,476,614 | -0.25% | $4,452,729 | 0.25% | 8,948,996 | 19,653 |
| 0.00% | $4,476,614 | -0.25% | $4,452,729 | 0.00% | 8,940,440 | 11,097 |
| 0.00% | $4,476,614 | -0.25% | $4,452,729 | -0.25% | 8,931,883 | 2,540 |
| 0.00% | $4,476,614 | 0.00% | $4,463,806 | 0.25% | 8,948,996 | 8,576 |
| 0.00% | $4,476,614 | 0.00% | $4,463,806 | 0.00% | 8,940,440 | 20 |
| 0.00% | $4,476,614 | 0.00% | $4,463,806 | -0.25% | 8,931,883 | -8,537 |
| 0.00% | $4,476,614 | 0.25% | $4,474,868 | 0.25% | 8,948,996 | -2,486 |
| 0.00% | $4,476,614 | 0.25% | $4,474,868 | 0.00% | 8,940,440 | -11,042 |
| 0.00% | $4,476,614 | 0.25% | $4,474,868 | -0.25% | 8,931,883 | -19,599 |
| 0.25% | $4,487,924 | -0.25% | $4,452,729 | 0.25% | 8,948,996 | 8,343 |
| 0.25% | $4,487,924 | -0.25% | $4,452,729 | 0.00% | 8,940,440 | -213 |
| 0.25% | $4,487,924 | -0.25% | $4,452,729 | -0.25% | 8,931,883 | -8,769 |
| 0.25% | $4,487,924 | 0.00% | $4,463,806 | 0.25% | 8,948,996 | -2,733 |
| 0.25% | $4,487,924 | 0.00% | $4,463,806 | 0.00% | 8,940,440 | -11,290 |
| 0.25% | $4,487,924 | 0.00% | $4,463,806 | -0.25% | 8,931,883 | -19,846 |
| 0.25% | $4,487,924 | 0.25% | $4,474,868 | 0.25% | 8,948,996 | -13,796 |
| 0.25% | $4,487,924 | 0.25% | $4,474,868 | 0.00% | 8,940,440 | -22,352 |
| 0.25% | $4,487,924 | 0.25% | $4,474,868 | -0.25% | 8,931,883 | -30,909 |

## Limitations and Future Work

This work does not include the effects of economy of scale and size, which a larger sawmill might benefit from. Examples of this would be where a larger production volume sawmill, with greater purchasing volume, may be able to negotiate better prices with respect to logs, lumber, or aspects of operating cost compared to a sawmill with smaller volume. However, other cost factors may be higher for a larger sawmill. For example, larger sawmills might have to pay higher wages to attract a larger pool of employees, may have to do elaborate environmental studies to satisfy laws and regulations, or be more affected by increases in fuel costs given larger procurement areas.

This study also did not consider transportation costs and residues market prices, mainly because there is little profit potential for a sawmill. Including transportation costs and residues market prices into the present study would have increased the complexity of the statistical analysis, as it would have necessitated a 5-factor analysis instead of the 3-factor analysis used to explore the interactions of operating cost, log cost, and product value. However, both transportation costs and residues pricing can impact the profit potential of a sawmill and hence future work should take account of this.

This research determined that a change of 0.1% in any of the costs (log or operating costs) or value factors (lumber) had a statistically significant ($\alpha = 0.05$) impact on profit. One immediate question becomes whether a change of this magnitude in any of these cost or value factors will also change what constitutes the break-even log for a sawmill. That is, does the profit of a diameter class and/or grade of log that was once profitable, become a zero profit or a loss due to minor cost or value fluctuations?

While this research looked at sawmills with 4, 8, and 12 MMBF production volume, it did not take account of economies of scale or other factors that are different for different-sized mills. For example, based on earlier research (Bumgardner *et al.* 2011), small secondary woodworking firms are more likely to want to increase revenue in a downturn, while large firms tend to try to cut costs in a downturn. Future research could look at different-sized sawmills to investigate which factor of Equation 1 they would focus on to improve their profitability.

Furthermore, future research could also investigate the effect of the degree of utilization a given sawmill as typically operating costs/unit output increasing with reduced utilization.

## CONCLUSIONS

While reports document prevailing log and lumber prices, operating costs are non-public information and are not commonly available. To better understand the sawmill business, and for the industry to be able to address the break-even log problem (where operating costs must be known), this study used LORCAT to estimate average sawmills' operating cost for a 4, 8, and 12 MMBF production volume mill producing Red Oak lumber. Operating costs were estimated under the assumption that sawmills operating in today's depressed markets make zero profit.

1. This study found that even miniscule changes in in either log costs, operating cost, or in lumber prices influence the profit of a sawmill for all mill sizes (4/8/12 MMBF). Using the ART statistical test, a 0.1% change in either log costs, operating cost, or in lumber prices were found to be statistically significant ($\alpha = 0.05$) for all mill sizes (4/8/12 MMBF).
2. A 12 MMBF production sawmill, based on this study, would lose $4,510 if operating cost increased by 0.1% and would gain $4,536 if operating cost decreased by 0.1% per year. For log costs, the same sawmill would lose $4,411 if log costs increase by 0.1% and would gain $4,446 if log costs decrease by 0.1% per year. For lumber prices, the same sawmill would gain $3,428 if lumber prices increased by 0.1% and would lose

$3,419 if lumber prices decrease by 0.1% per year. Hence, changes in operating cost have a slightly more pronounce influence on profits compared to log cost and lumber prices.

3. For a 12 MMBF sawmill, a 25% increase in operating and log costs the sawmill would lose $1,130,724 and $1,107,358, respectively. A 25% decrease in operating and log costs would cause gains of $1,130,743 and $1,107,393, respectively. With a 25% lumber price increase, the sawmill would gain $855,602 and would lose $855,586 if lumber prices would decrease by 25%. In a best case/worst case scenario, where log cost and operating cost increase/decrease by 25% and lumber prices decrease/increase by 25%, a 12 MMBF sawmill can lose or gain over $3 million per year. Even in the case of a more moderate 0.25% change for all three factors, the sawmill can lose $31,909 in the worst case or profit $30,946 in the best case showing the volatility of the sawmill business.

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