Journal of Forestry (2026) 124:579–601
https://doi.org/10.1007/s44392-026-00074-z

ORIGINAL PAPER

An Analysis of the Process and Attributes Used in the Transaction Evidence Appraisal Method for USDA Forest Service Timber Sales in the US Southwest

Charles Tucker Herbert[1] · Han-Sup Han[1] · Mathew Smidt[2] · Jaechoul Lee[3] · Carlos Diniz[2,4]

Received: 16 July 2025 / Accepted: 5 January 2026 / Published online: 30 January 2026

Abstract

Evaluating the cost of fuel treatment operations is an essential aspect for mitigating elevated wildfire risks across western US landscapes. The USDA Forest Service (Forest Service) currently uses a Transaction Evidence Appraisal (TEA) method to appraise stumpage, incorporating key factors such as stump-to-truck processing, slash disposal, transportation, timber markets, and bidder competition. This study aims to improve our understanding of the total costs involved and final advertised rates in fuel treatment operations in Forest Service Regions 2 and 3. Stump-to-truck processing and timber transportation to mills represented the greatest share of TEA costs, comprising 96% of sale estimates in Region 2 and 94% in Region 3. TEA costs are significantly influenced by factors such as volume per acre, skidding distance, and proximity to processing facilities. Additionally, regression analysis examining bids identified total sawtimber sale volumes and travel time as key factors influencing high bid amounts. Refining TEA cost estimation methods and strategically structuring future sales could enhance the effectiveness and scalability of mechanical thinning treatments on national forests.

Keywords Mechanical thinning treatment · Forest restoration · Timber appraisal · Bidding behavior · Stumpage prices

✉ Han-Sup Han

Charles Tucker Herbert
Tucker.Herbert@nau.edu

1 Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ, USA

2 Southern Research Station, USDA Forest Service, Auburn, AL, USA

3 Department of Mathematics and Statistics, Northern Arizona University, Flagstaff, AZ, USA

4 Department of Forest Engineering and Technology, Universidade Federal do Paraná, Curitiba, Brazil

Introduction

Multiple key factors have altered fire regimes and created conditions in western United States (US) forests conducive to increasing the spread of frequent, large-scale high-severity catastrophic wildfires (Wasserman and Mueller 2023; Reinhardt et al. 2008). This increasing scale and intensity is predominantly a result of years of effective fire suppression policies (Dombeck et al. 2004; Rummer 2008), climate-driven fuel aridity (Abatzoglou and Williams 2016), and expansion of the wildland-urban interface (WUI) (Schoennagel et al. 2017). Together, these conditions increase the risk of larger, more destructive fires that threaten both ecological and human communities (Allen et al. 2002).

In response, forest managers are increasingly using mechanical forest thinning treatments to restore western forests to more natural conditions and reduce the risk of stand-replacing crown fires. Treatment planning and implementation must address spatial and logistical complexities, including acreage, location, site access (e.g., temporary roads), boundaries, WUI proximity, funding, and operational constraints like slope or skid distance (Stephens et al. 2021). It is important to consider that a large proportion of the extracted products from treatments available to regional markets consist of small-diameter, low-grade, and low-value timber (Townsend et al. 2019). Because timber removal and transport pose a financial barrier, understanding how these treatment costs are assessed is essential for large-scale implementation in the western US (Rummer 2008). To support this effort, the USDA Forest Service (Forest Service) launched the Wildfire Crisis Strategy (WCS) in 2022, aiming to treat approximately 50 million acres across 10 western states over the next decade (Woolsey et al. 2024).

Rummer (2008) identifies four main approaches for evaluating forest restoration treatment costs: expert opinion, transaction evidence, accounting, and engineering cost analysis. The result of the transaction evidence method, which reflects the stumpage price paid by contractors, provides insight into the total bid cost for proposed thinning treatments while also reflecting the impact of competition and local market fluctuations. In some cases, a combination of treatment cost analysis approaches can be utilized to determine the estimated cost for a particular treatment (Rummer 2008). Understanding how timber sales and thinning treatments are appraised on public lands in the western US requires examining the Forest Service approach to sale valuation.

Since 1902, the US Secretary of the Interior recognized the need to appraise Forest Service timber based on quality, logging difficulty, and proximity to mills (Craig 1983). Today, the Forest Service's Transaction Evidence Appraisal (TEA) method, used in all regions except Alaska (Region 10), estimates fair market value for timber sales through recent sale data and engineering cost analysis. A Base Period Price (BPP) is established from prior sale high bid prices, while an engineering cost analysis estimates skid-yard (stump-to-truck), slash management, road maintenance, and haul costs. The TEA method aims to reflect current market conditions, encourage competitive bidding, and reduce the gap between bid values and advertised rates (Haynes et al. 2016).

In Regions 2 and 3, where operational and market conditions vary widely, the TEA method is particularly sensitive to limited competition and sale offerings. This may result in declining advertised rates even amid rising market prices. Prior studies note several risks in using average high bids to establish BPPs, including intentional underpricing in competitive markets, preclusive bidding, no-bid outcomes, and the practice of intentionally skewing bids on species believed to be overestimated, that can distort value estimates and make it difficult for operators to develop feasible bids for multi-year contracts (Rummer 2008; Brown et al. 2012; Athey and Levin 2001).

Bid behavior is influenced by sale characteristics that span operational factors, site conditions, regional and seasonal considerations, and management objectives. Silvicultural prescriptions, forest management plans, and fuel treatment goals shape the timing, volume, quality, and species of timber offered (Soman et al. 2019). However, forest managers can still design sales to attract stronger competition and higher bids while aligning with ecological and management goals (Brown et al. 2012). By analyzing bidding behavior trends, managers can identify optimal sale characteristics that not only attract higher stumpage bids and help potential bidders predict operational costs (Kilgore and Blinn 2005), while also accounting for potential impacts on the long-term sustainability of the logging industry and timber markets (Brown et al. 2012).

Accurately and consistently estimating mechanical thinning treatment costs using TEA is crucial to the success of the WCS. Inconsistent or inaccurate cost estimations threaten the economic viability of sales, hinder project planning and contractor bid preparation, and create inefficiencies when sales fail to receive any bids, ultimately constraining efforts to expand the pace and scale of treatments across western US priority landscapes. Although the TEA method has been in use for nearly 40 years, its ability to estimate accurate treatment costs reliably warrants reassessment given evolving timber markets and cost estimation techniques.

This study provides one of the first comparative analyses of TEA application across Regions 2 and 3, evaluating the current appraisal process for sale cost centers and examining how various sale characteristics and competition influence bid behavior. Specifically, trends in TEA cost center estimates and stumpage bidding habits were analyzed to address the following three study objectives: (1) examine the influence of operational variables (e.g., tree size, volume per acre, skid distance) on harvest productivity, and explore how these factors could be more effectively integrated into TEA skid-yard calculations to improve cost estimation, with attention to regional differences between Regions 2 and 3; (2) analyze trends in TEA stumpage bids to understand how competition, stand characteristics, and operational variables shape high bid amounts, including regional differences and potential effects of sale design or appraisal adjustments on bid outcomes; (3) identify opportunities to increase consistency and accuracy of TEA procedures across regions so that appraisals better reflect current market and operational realities, especially where transportation costs and limited market availability are concerns.

Data and Methods

TEA Method

Establishment of a BPP for each appraisal group (i.e., product, species, and condition) is the starting point for all TEA sales. Subsequent adjustments—accounting for market conditions, sale-specific costs, timber quality, and competition—are applied to the BPP following Forest Service appraisal procedures to determine the final advertised rate. Table 1 summarizes the key definitions and variables used in the

Table 1 Primary variables used in the Forest Service TEA method

TEA Attribute	Description
Base Period Price (BPP)	The value representing the appraisal group's volume-weighted average winning bid price of competitively sold timber sales from the previous base period. Starting point for the TEA process prior to adjustments
Base Rates	The lowest rates of payment for timber authorized within a federal contract. Usually the same as minimum rates but can be raised if the collection of essential K-V and/or timber property requires the additional funds
Market Adjustment	An adjustment that reflects changes in the lumber market between the base period and the most recent quarter within that period
Cost Centers	The primary estimation of sale specific costs adjusted against the average base period costs from prior sales. Adjustments can be positive or negative
Haul Cost	The cost to transport sale timber products to the nearest estimated processing facility
Road Maintenance Cost	The cost to operate and maintain existing roads to access the timber sale cutting unit(s)
Temporary Road Cost	The cost of constructing a road for timber removal from sale units, used only for initial access and not needed thereafter
Slash	The cost associated with burning landing slash piles or any other extraordinary logging operation slash management
Skid-Yard	The stump-to-truck (felling, skidding, processing) operational logging cost for removal of sale material
Unusual Adjustments	Made for special sale characteristics not reflected in other market, quality, risk or cost adjustments (e.g., seasonal restrictions, sorting and handling)
Quality Adjustments	An appraisal adjustment to reflect differences in timber quality (e.g., excessive taper) between the base period and current sale
Predicted Bid Rate	The highest anticipated bid if the timber sale attracts average competition
Competition Factor	A rollback factor (either 10% or 5%) applied to account for market changes, risk, and slack in bidding
Adjustment to Base Rate	Adjustment made to raise timber rates when they fall below the required minimum authorized "base" rate during the appraisal process
Advertised Rate	The final step in the TEA process. Designates the final rate at which each product and species in the sale will be advertised
Timber Property Value	The total cost of manufacture from the standing tree to its sale-ready form, including felling, bucking, skidding, decking, overhead, and depreciation
Specified Road Cost	The estimated cost of constructing permanent roads for future which are included in the timber sale contract

TEA method, while Fig. 1 illustrates the TEA process flow and decision steps from the initial BPP to the final advertised rate.

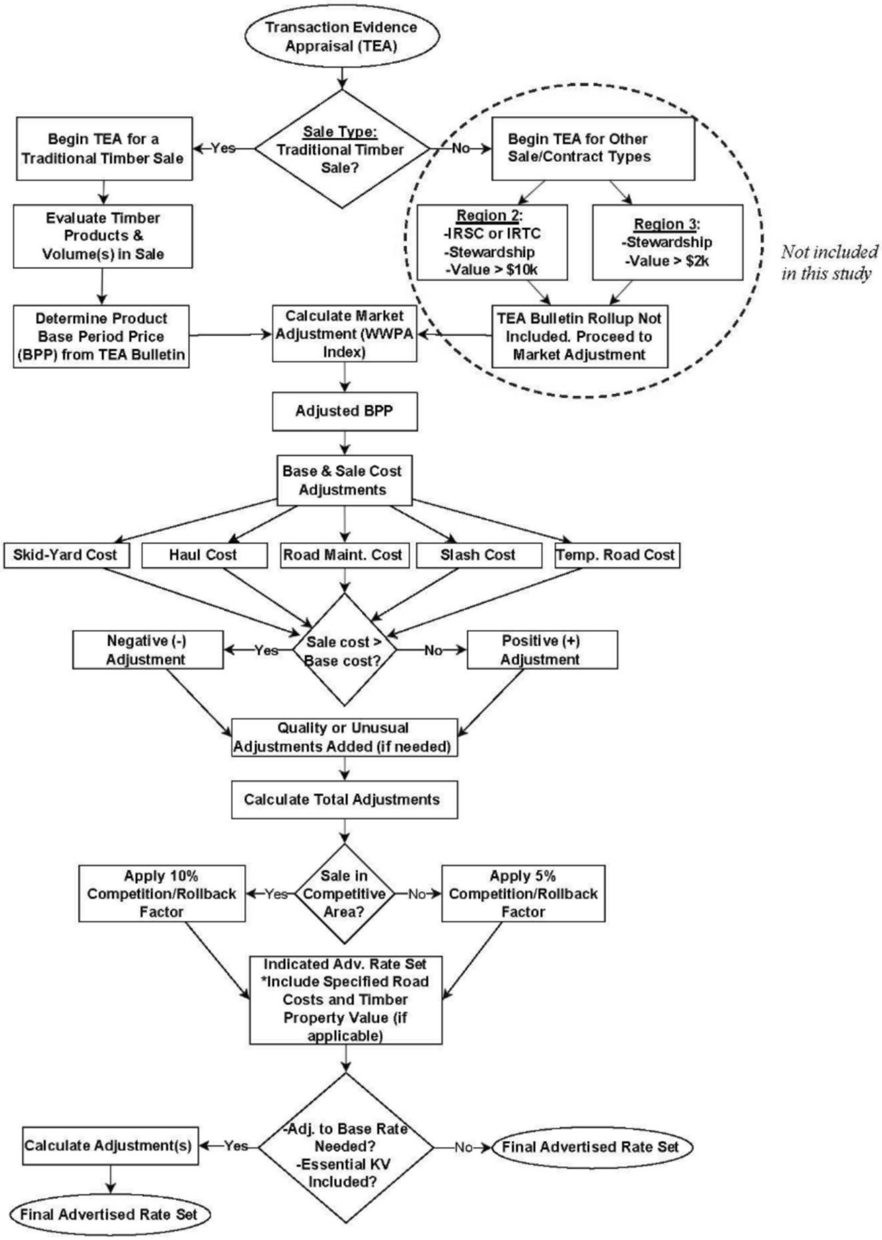

Fig. 1 Flowchart illustrating the Forest Service TEA process, from establishing the BPP to determining the final advertised rate. Key abbreviations: Western Woods Product Association (WWPA) Index, Integrated Resource Timber Contract (IRTC), and Integrated Resource Service Contract (IRSC)

TEA Forest Service Regions and Timber Sale Data Collection

Forest Service WCS priority landscapes analyzed in this study include the Four Forest Restoration Initiative (4FRI) in Arizona, the Enchanted Circle in New Mexico, and the Colorado Front Range. The study included TEA data from four western states (AZ, NM, CO, WY) and twelve different National Forests (NFs) across the Forest Service's Region 2 (Rocky Mountain) and 3 (Southwestern) from 2020 to 2024 to capture recent sale characteristics and market conditions. Data from seven Region 2 NFs, including some within the Colorado Front Range landscape, were analyzed. Region 3 timber sales came from six NFs. Table 2 lists the forests, TEA products, and timber species.

In the TEA process, appraisal zones typically define geographic areas with similarities in timber sale characteristics, such as haul distances, species composition, timber quality, or market competition. An appraisal zone could encompass an entire Forest Service Region, multiple NFs within a particular region, or several Ranger Districts.

Region 2, encompassing 17 NFs across Wyoming, Colorado, South Dakota, Nebraska, and Kansas, is divided into three distinct appraisal zones. For this study, TEA data from Appraisal Zone 1 (NW Intermountain) and Zone 3 (SW Intermountain) was analyzed. TEA data from Zone 2 (Black Hills) was excluded because it included sales from Wyoming, outside the study region. Region 3, covering 11 NFs across New Mexico and Arizona, is currently one continuous appraisal zone.

A total of 63 Region 2 and 28 Region 3 timber sales were analyzed. TEA sales associated with stewardship or service contracts, and simple, small, or deck sales

Table 2 Forest Service TEA regions, NFs, products (TEA code in parentheses), and timber species analyzed

Region 2 (Rocky Mountain)			
National Forests	Products	Species	Scientific Name
Arapaho.Roosevelt	(01) Sawtimber	Ponderosa pine	*Pinus ponderosa*
Grand Mesa.Uncompahgre.Gunnison	(03) Poles (0–4.9")	Douglas-fir	*Pseudotsuga menziesii*
Medicine Bow.Routt		White fir	*Abies concolor*
Pike.San Isabel		Lodgepole pine	*Pinus contorta*
San Juan		Engelmann spruce	*Picea engelmannii*
Rio Grande		True fir	*Abies*
White River		Quaking aspen	*Populus tremuloides*
Region 3 (Southwestern)			
National Forests	Products	Species	Scientific Name
Apache-Sitgreaves	(01) Sawtimber	Ponderosa pine	*Pinus ponderosa*
Carson	(07) Fuelwood	Douglas-fir	*Pseudotsuga menziesii*
Coconino	(08) Non-sawtimber	White fir	*Abies concolor*
Gila	(20) Biomass		
Kaibab			
Santa Fe			

were excluded. Although still part of the TEA process, these contract types are awarded on best value (past performance, work quality, benefit to local community) rather than highest bid, making them unsuitable for generating base period prices from TEA bulletin rollup reports.

Access and permission to utilize data from the TEA Microsoft Access Database was provided in collaboration with Forest Service Appraisal Specialists from Regions 2 and 3. An Access database query extracted key data variables to Excel for sorting and organizing by individual NF within the two regions. Variables not included in the initial query (e.g., volume per acre, species, average diameter at breast height) were identified and manually added to spreadsheets.

TEA Cost Attributes and Bid Analysis

Summary statistics were computed in Microsoft Excel to determine the percentage breakdown of cost characteristics for timber sales across Region 2 and Region 3. Mean and standard error values were calculated for haul and skid-yard costs by product type and region. To evaluate cost center trends over the past 3–4 years, analysis focused on Product 01 (Sawtimber), the only product consistently appraised across both regions. For each sale, the percentage of total cost attributed to each sawtimber cost center was calculated, averaged by NF, and then summed to yield regional totals.

To analyze timber sale competition and sale characteristics influencing bids, statistical analyses designed to identify regional trends and differences within the TEA dataset were conducted in R v4.4.2 (R Core Team 2024). A one-way analysis of covariance (ANCOVA) was used to assess how the number of bids per sale (1–5) affected the log-transformed, volume-weighted percentage increase from advertised rate to high bid for sawtimber, non-sawtimber, and biomass products. The log-transformation was applied to address right-skewness and to ensure the normality assumption was satisfied.

The ANCOVA analysis used the total number of bids as the covariate and the percentage increase in payment from the advertised rate to the high bid as the dependent variable. To prevent infinite values in the log-transformed percentage increase when a bid for a sale product equaled the advertised rate, 0.01 was added. The percentage increase in payment was based on the total volume-weighted appraised sale value, calculated as follows:

$$TSV = \left(AR_1 \cdot V_1\right) + \left(AR_2 \cdot V_2\right)$$

where

TSV Total Sale Value ($/CCF),

AR_i Advertised rate for product i, i = 1, 2,

V_i Volume (CCF) for product i, i = 1, 2.

Next, the volume-weighted total bid value for each timber sale is calculated using the following equation based on the dataset:

$$TBV = \left(B_1 \cdot V_1\right) + \left(B_2 \cdot V_2\right)$$

where

TBV Total Bid Value (\$/CCF),

B_i High Bid for product i, i = 1, 2,

V_i Volume (CCF) for product i, i = 1, 2.

Finally, the percentage increase in payment (ΔP) between the total bid value and total sale value was calculated. The equation is expressed as:

$$\Delta P = (TBV - TSV)/TSV$$

Additionally, a multiple linear regression with backward variable selection was performed to evaluate how sale characteristics such as, volume, skid distance, number of bids, average sale diameter at breast height (DBH), round-trip minutes (RTM), and advertised rate, affected the log-transformed high bid for sawtimber. To avoid duplication, sales involving multiple species with varying advertised rates and high bids were aggregated into a single, volume-weighted data point. Data from both regions were combined for analysis. Multicollinearity was assessed using a correlation matrix with variance inflation factors (VIFs), and final model performance was evaluated based on the adjusted coefficient of determination (R^2) and root mean squared error (RMSE).

Results

TEA Cost Attributes and their Effect on a Final Advertised Rate

TEA data for the sawtimber product (01), based on sale-specific cost adjustments from 63 timber sales in the Rocky Mountain region (R2) and 28 timber sales in the Southwestern region (R3), was analyzed to identify which estimated cost center (e.g., skid-yard, slash, temporary road, haul, road maintenance, quality, and unusual adjustments) constituted the largest percentage of a completed appraisal. As shown in Fig. 2, skid-yard and haul cost expenditure estimates represent the largest portion (> 90%) of sale cost centers appraisals across both regions over the past 3–4 years.

Skid-yard cost, a calculation of the stump-to-truck harvest operating cost for felling, skidding, and processing the sawtimber (sawlog) product, represents the highest proportion of sale cost center appraisals, comprising 67.2% of the total estimate in Region 2 and 56.3% in Region 3. Haul cost, a transportation-based calculation,

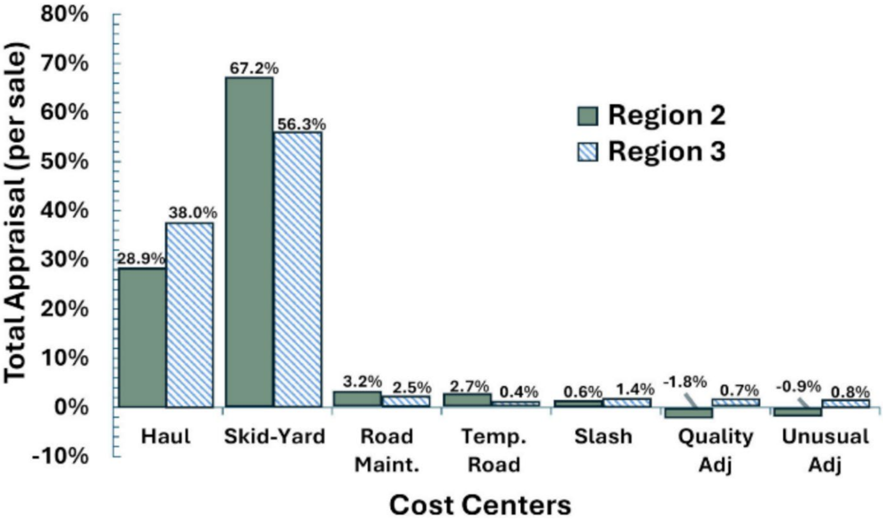

Fig. 2 Percentage breakdown of TEA sale cost centers for timber sales in Regions 2 and 3 from 2020–2024. Primary cost centers, including quality and unusual adjustments, are shown

is determined from a RTM estimate derived from local studies or data measuring minutes per mile on various road segments classified by class and grade for delivering sawlogs to the mill. It was the second-largest component of the TEA process in Region 2 (28.9%) and Region 3 (38%). A RTM factor (e.g., 0.1130) used to calculate haul costs varies slightly between regions. The remaining sale cost centers, including estimates for road maintenance, slash management, temporary road construction, and quality or unusual adjustments, made up a small fraction (< 6%) of the total appraisals, with similar percentages across both regions.

The Pike-San Isabel and San Juan-Rio Grande NFs in Colorado (CO) had the highest average haul costs for sawtimber in Region 2, at $63.05/CCF and $65.17/CCF respectively (Table 3). The Medicine Bow-Routt NF, with the largest number (26) of timber sales analyzed over the past 3–4 years, appears to be closest to several nearby lumber processing facilities (i.e., appraisal points) with an average of 48 miles and 219 RTM. In comparison, the San Juan-Rio Grande NF in southwest CO has an average haul estimate of 574 RTM and 135 miles. To calculate skid-yard timber processing costs in Region 2, the sale cruise report estimates for sawtimber, including average DBH and volume per acre (CCF/acre), are balanced against averages from a TEA bulletin to determine the adjustment. As the sale DBH increases, the estimated skid-yard cost decreases with the same correlation holding true for increases in volume per acre. With the lowest estimated average sawtimber DBH (9.3 in), the Arapaho-Roosevelt NF had the highest average skid-yard cost at $136.35/CCF (Table 4). Due to higher volume and average DBH estimates for their timber sales, the San Juan-Rio Grande and White River NFs had the lowest estimated skid-yard cost at $89.24/CCF and $88.85/CCF, respectively.

Table 3 Means and standard errors (in parentheses) of Regions 2 and 3 haul cost, miles, and round-trip minutes (RTM) for sawtimber, non-sawtimber, biomass, and poles TEA products

Region 2 (Rocky Mountain)					
Product	National Forest	n	Haul Cost ($/CCF)	Miles (mi)	RTM (min)
Sawtimber	Arapaho.Roosevelt	5	33.29	65	294
	Grand Mesa.Uncompahgre.Gunnison	15	37.55	85	347
	Medicine Bow.Routt	26	24.70	48	219
	Pike.San Isabel	1	63.05	129	558
	San Juan.Rio Grande	9	65.17	135	574
	White River	5	61.84	125	535
	Sub-Total	61	38.21 (2.5)	79 (5.6)	340 (21.1)
Poles	Arapaho.Roosevelt	2	−4.17	28	187
	Grand Mesa.Uncompahgre.Gunnison	2	7.23	95	285
	Medicine Bow.Routt	16	2.94	69	220
	San Juan.Rio Grande	6	9.59	108	547
	Sub-Total	26	4.26 (1.5)	77 (8.5)	288 (42.8)
	Total	87			
Region 3 (Southwestern)					
Product	National Forest	n	Haul Cost ($/CCF)	Miles (mi)	RTM (min)
Sawtimber	Apache-Sitgreaves	6	38.46	37	173
	Carson	2	66.16	87	304
	Coconino	6	88.56	159	373
	Gila	3	84.62	127	370
	Kaibab	8	87.13	192	426
	Sub-Total	25	73.81 (5.7)	128 (14.7)	332 (25.0)
Non-sawtimber	Apache-Sitgreaves	5	41.57	44	184
	Carson	2	66.16	87	304
	Coconino	9	51.31	109	241
	Gila	3	41.33	49	198
	Kaibab	6	70.73	158	360
	Santa Fe	1	61.42	56	240
	Sub-Total	26	54.30 (3.8)	94 (12.4)	254 (20.1)
Biomass	Apache-Sitgreaves	4	40.93	42	183
	Coconino	6	87.78	144	370
	Kaibab	4	74.02	170	364
	Sub-Total	14	70.46 (5.8)	122 (14.8)	315 (25.0)
	Total	65			

n = number of timber sale transactions analyzed for individual products

In Region 3, the sawtimber product accounted for the highest average estimated haul cost ($78.81/CCF), while biomass was slightly lower at $70.46/CCF. Of the five NFs analyzed, the Kaibab NF in northern Arizona (AZ), located farthest from lumber processing facilities, estimated an average transport distance

Table 4 Means and standard errors (in parenthesis) of Region 2 skid-yard cost, volume, and the timber sale average DBH for sawtimber, and poles TEA products

Product	National Forest	n	Skid-Yard Cost ($/CCF)	Volume (CCF)	Avg. dbh (in.)
Sawtimber	Arapaho.Roosevelt	5	136.35	5225	9.3
	Grand Mesa Uncompahgre.Gunnison	15	89.38	5492	13.1
	Medicine Bow.Routt	26	130.46	6337	9.7
	Pike.San Isabel	1	106.81	4740	11.6
	San Juan.Rio Grande	9	89.24	7019	12.9
	White River	5	88.85	7874	12.8
Sub-Total		61	110.96 (3.4)	6239 (533.5)	11.3 (0.27)
Poles	Arapaho.Roosevelt	2	128.20	1917	9.1
	Grand Mesa Uncompahgre.Gunnison	2	89.23	631	12.6
	Medicine Bow.Routt	16	129.82	857	9.3
	San Juan.Rio Grande	3	103.33	405	11.6
Sub-Total		23	122.69 (3.5)	871 (112.9)	9.9 (0.29)
Total		84			

n = number of timber sale transactions analyzed for individual products

Table 5 Means and standard errors (in parenthesis) of Region 3 skid-yard cost, volume, and average skid distance for sawtimber, non-sawtimber, and biomass TEA products

Product	National Forest	n	Skid-Yard Cost ($/CCF)	Volume (CCF)	Skid Distance (ft)
Sawtimber	Apache-Sitgreaves	6	115.35	3036	660
	Carson	2	74.10	317	131
	Coconino	6	101.86	8040	573
	Gila	3	95.28	1235	467
	Kaibab	8	92.59	5197	576
Sub-Total		25	99.12 (2.8)	4495 (771.7)	547 (41.9)
Non-sawtimber	Apache-Sitgreaves	5	114.34	1790	585
	Carson	2	74.10	142	131
	Coconino	8	100.29	11030	555
	Gila	3	95.28	1008	467
	Kaibab	6	97.30	2625	627
	Santa Fe	1	95.66	1512	400
Sub-Total		25	99.50 (2.4)	4710 (1232.4)	527 (36.9)
Biomass	Apache-Sitgreaves	4	118.85	1703	655
	Coconino	6	101.86	2910	573
	Kaibab	4	97.08	783	721
Sub-Total		14	105.35 (2.9)	1957 (438.3)	639 (30.5)
Total		64			

n = number of timber sale transactions analyzed for individual products of 192 miles and 426 RTM to deliver sawtimber to mills (Table 3). As part of an engineering cost analysis, skid-yard cost estimates in Region 3 use volume per acre (CCF/acre), volume per tree (CF/tree), and average skid distance as the key operational variables. As skid distance increases, skid-yard cost estimates rise accordingly. However, as CCF/acre and CF/tree estimates-compiled from cruise reports-increase, skid-yard costs decrease. The Apache-Sitgreaves NF in Arizona had the lowest estimated average total sale volume (3,036 CCF) and the highest average skid distances (660 ft) among NFs with similar timber sale sample sizes, such as the Coconino and Kaibab NFs, resulting in the highest estimated average skid-yard cost at $115.35/CCF (Table 5).

TEA Bidding

Competition for timber sale offerings on TEA sales from Regions 2 and 3 can be measured by evaluating the bids from timber purchasers. This study analyzed the bids of timber purchasers on Forest Service TEA sales in Regions 2 ($n=63$ sales) and 3 ($n=28$ sales) from 2020 to 2024 to understand how sale-specific factors and regional competition influenced the additional payments bidders made above advertised rates to secure timber sale contracts.

To gain a more comprehensive understanding of recent bids, we analyzed the total number of bids received per sale (ranging from 1–5) and compared the results between the two regions, as shown in Fig. 3. In Region 2, a large proportion (65%) of the 63 total timber sales received only one bid. Of the 15 sales from the Grand Mesa, Uncompahgre, and Gunnison NFs in Colorado, 86.7% received just one bid.

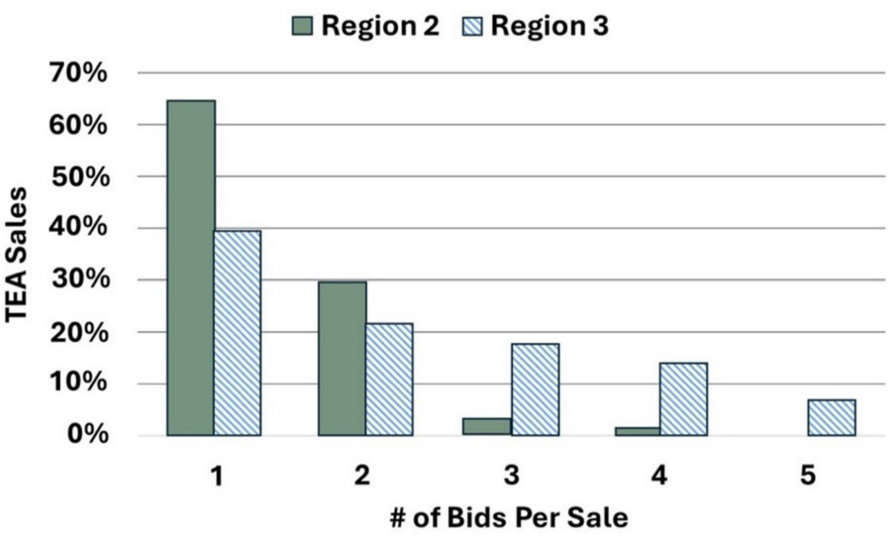

Fig. 3 General TEA bidding attributes showing the percentage of sales receiving between 1 to 5 bids from Forest Service Regions 2 (Rocky Mountain) and 3 (Southwestern)

In comparison, approximately 40% of the 28 timber sales analyzed from the Southwestern Region (R3) received one bid. In Region 2, only 5% of the 63 sales received three to five bids. By contrast, 40% of Region 3 sales fell into that range, indicating more potential purchasers and potentially more competition for sales. Additionally, none of the sales across six NFs in Region 2 received five bids, while 7% of Region 3 sales reached that number.

To further assess competition and the effect of an increase in the total number of bids received per sale (across all products and volumes) on the percentage increase in payment above advertised rates, a one-way analysis of covariance (ANCOVA) was conducted. The estimated mean difference in the log-transformed volume-adjusted percentage increase in payment above the advertised rate was not statistically significant with a p-value of 0.43. The estimated slope parameter in the

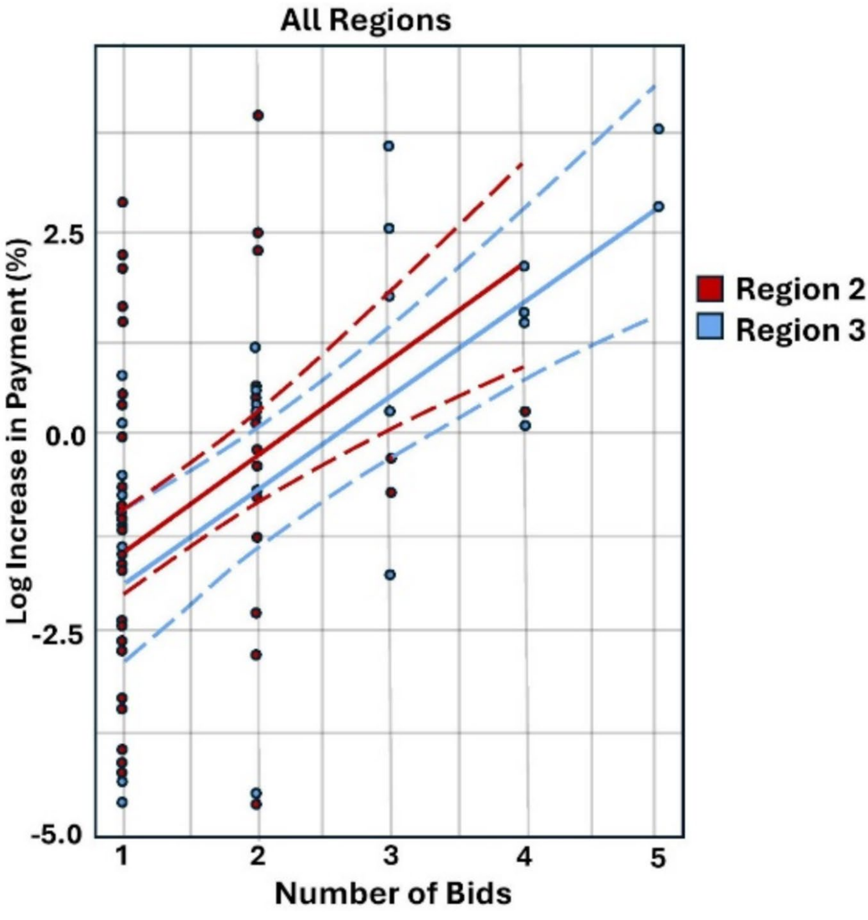

Fig. 4 Log-transformed percentage increase in payment above the TEA advertised rate versus total number of bids received per sale, based on ANCOVA analysis. Solid lines represent the estimated means of the log-transformed percentage increase for each region

ANCOVA was 1.22, indicating that for every additional bid per sale, the percentage increase in payment above the advertised rate tended to increase by an average of 238% (i.e., $e^{1.2181} - 1 = 2.38$) across both regions (Fig. 4). With a p-value close to 0 ($p < 0.0001$), this result suggests that the number of bids received per timber sale is significantly associated with the percentage by which the winning bid exceeds the advertised rate.

To gain a deeper understanding of trends in TEA bids based on the influence of various timber sale characteristics, specifically those affecting sawtimber product high bid amounts, we fitted a multiple regression model to the combined data from Regions 2 and 3 as illustrated in Section "TEA Cost Attributes and Bid Analysis". After backward variable selection, the fitted model produced an adjusted R^2 of 0.78 and a residual standard error (RSE) of 0.55. Five sawtimber product sale characteristics were assessed for their impact on log-transformed high bid amounts for sales in Regions 2 and 3. The regression results, presented in Table 6, illustrate the relationship between high bid amounts (the response variable) and predictor variables (sale characteristics). A correlation matrix revealed strong correlations between RTM and

Table 6 Sale characteristics, parameter estimates[a], and p-values from TEA sawtimber high bid amount model, displayed by USDA Forest Service Region. $n = 75$ (56, Region 2; 19, Region 3)

Region 2 (Rocky Mountain)		
Sale Characteristic (Variable)	Parameter estimates	*p*-value
Intercept	0.6924	0.0913
Log-transformed sawtimber TEA advertised rate	0.7204	< 0.0001
Number of bids per timber sale	0.1622	0.1581
Sawtimber volume (in 100 CCF)	−0.0056	0.0029
Round-trip transportation of product to mill (in hours)	0.1154	0.0018
Estimated timber sale average skid distance (in 100 feet)	−0.0165	0.7888
Region 3 (Southwestern)		
Sale Characteristic (Variable)	Parameter estimates	*p*-value
Intercept	0.5808	0.3529
Log-transformed sawtimber TEA advertised rate	0.7204	< 0.0001
Number of bids per timber sale	0.6555	< 0.0001
Sawtimber volume (in 100 CCF)	0.0130	0.0069
Round-trip transportation of product to mill (in hours)	−0.0040	0.9604
Estimated timber sale average skid distance (in 100 feet)	−0.2112	0.0037
Difference: Region 3—Region 2		
Sale Characteristic (Variable)	Parameter estimates	*p*-value
Number of bids per timber sale	0.4934	0.0033
Sawtimber volume (in 100 CCF)	0.0186	0.0005
Round-trip transportation of product to mill (in hours)	−0.1194	0.1786
Estimated timber sale average skid distance (in 100 feet)	−0.1947	0.0399

[a]The coefficient estimates from the log-transformed high bid amount model were exponentiated and adjusted by subtracting 1 to calculate the percentage change in the high bid amount, e.g., $e^{0.1154} - 1 = 0.122$ (12.2%)

haul miles (0.92 in Region 2 and 0.95 in Regions 3, respectively), with RTM providing a slightly better model fit. Volume (in CCF) and harvest acres also showed strong correlations (0.64 in Region 2 and 0.83 in Region 3, respectively), which led to the inclusion of volume over harvest acres in the backward variable selection. Variables with high p-values were removed through backward selection, resulting in a simplified model that retained *volume, number of bids, RTM,* and *skid distance* without significantly compromising model fit. Although important in other harvest productivity models (Louis et al. 2022), the *average sale DBH* did not significantly affect high bid amounts when accounting for other variables and was thus removed during the backward selection process.

In Region 2, sawtimber volume (in 100 CCF) and RTM significantly influenced contractors' high bid submissions for Forest Service TEA timber sale offerings. The average skid distance estimates ($p = 0.7888$) and total number of bids submitted per sale ($p = 0.1581$) did not significantly influence high bid amounts in Region 2. For every additional 100 CCF of sawtimber volume estimated for timber sales across Region 2, the high bid amount is expected to decrease by 0.56% (i.e., $e^{-0.0056} - 1 = -0.0056$) if other timber sale characteristics and the number of bids remain the same.

As a key factor in TEA haul-cost calculations, RTM determines the estimated travel time required to deliver sawtimber from the cutting site to the nearest appraised sawmill or processing facility. In Region 2, an additional hour of round-trip travel time (in RTM) is associated with a 12.2% increase in high bid amount (i.e., $e^{0.1154} - 1 = 0.122$). However, RTM is also negatively correlated with log-transformed advertised rates (correlation $= -0.559$ in Region 2). To quantify the effect of travel time on advertised rates, we fitted an auxiliary regression model identical to the TEA model but with log-transformed advertised rates as the response while retaining the same predictors. In this model, the same one-hour increase in travel time corresponds to a 27% decrease in advertised rates (i.e., $e^{-0.3153} - 1 = -0.270$ with p-value < 0.0001). To assess the overall influence of RTM on high bids, we combined its direct effect (coefficient $= 0.1154$) with its indirect effect through advertised rates (the product of the effect of RTM on advertised rates, -0.3153, and the effect of advertised rates on high bids, 0.7204). The resulting total effect of an additional hour of RTM is a 10.6% reduction in the high bid (i.e., $0.1154 + (-0.3153)(0.7204) = -0.1118$, and $e^{-0.1118} - 1 = -0.106$).

For Region 3, which includes NFs in Arizona and New Mexico, sawtimber volume estimates significantly influenced high bid amounts. An additional 100 CCF of sawtimber volume in the appraisal estimate is predicted to increase the high bid amount by 1.31% (i.e., $e^{0.013} - 1 = 0.013$) on average. Unlike Region 2, average skid distance ($p = 0.0037$) and total number of bids submitted per sale ($p < 0.0001$) significantly impacted high bids in Region 3. For each additional bid submitted, the high bid amount is predicted to increase by 92.6%. As an indicator of stump-to-truck operational processing costs, an increase of 100 feet in estimated skid distance is anticipated to lower the high bid amount by 19.1%. However, the RTM estimate for haul cost did not significantly influence bids in Region 3.

The model also demonstrated how key variables influenced high bid amounts between the two regions. In the TEA method, the high bid amount refers to the winning bid for each product in a timber sale. Statistically significant differences between the regions were found in how three variables influenced high bid amounts: the number of bids, sawtimber volume, and average skid distance. In Region 3, each additional bid per sale is associated with a 63.8% higher high bid amount compared to Region 2 ($p = 0.0033$). For every 100 CCF increase in sawtimber volume per sale, the high bid amount in Region 3 is expected to increase by 1.9% more than in Region 2 ($p = 0.0005$). Additionally, a 100-foot increase in the average skid distance is expected to reduce the high bid amount in Region 3 by 17.7% less than in Region 2 ($p = 0.0399$).

Discussion

TEA Design Limitations and Opportunities for Improvement

Stump-to-truck processing and haul costs represented the largest portion of TEA sale cost center estimates for both regions. Harvest productivity and operational costs are critical in determining the financial viability of thinning treatments (Louis et al. 2022), with key factors including volume per acre, skidding distance, tree size, site characteristics, and machine system configuration all influencing total costs. The selected combination of harvesting machines used for felling, skidding, and processing stump-to-truck operational costs are referred to as a system (Chang et al. 2023). In a given treatment, the skid-yard costs related to estimating operational productivity are heavily influenced by system balance (Rummer 2008; Vitorelo et al. 2011). The current TEA method for calculating timber sale skid-yard costs is not designed to incorporate fluctuations in productivity or system balance into operational cost estimates, potentially hindering efforts to estimate the true cost of planned treatments.

Although skid distance is an important site-specific factor that can create system imbalances and increase production costs (Rummer 2008), it is not incorporated into the Region 2 logging cost adjustment (LCA). Increases in average skid distance directly raise estimated skid-yard costs (Soman et al. 2019) and have been identified as the most expensive component in whole-tree (WT) or tree-length (TL) harvesting systems (Han et al. 2004; Adebayo et al. 2007). Along with TL operations, WT harvesting methods are commonly used in the western US for fuel reduction treatments (Han and Han 2020). Higher average skidding distances reduce harvesting production rates, so careful consideration of road, landing, and skid trail placement is essential during the operational planning and sale design phase (Pan et al. 2008). The omission of skid distance from Region 2's LCA equation, and the notable impact it has on stump-to-truck harvesting cost, may therefore result in inaccurate or inconsistent skid-yard cost estimates and advertised rates across regions.

Increasing logging operations on steep slopes may help expand treatment acreage in the western US, but it can present logistical challenges and significantly impact machine productivity and overall cost (Woolsey et al. 2024; Louis et al. 2022; Chang et al. 2023). Ground slope (as a percentage) is not currently incorporated into TEA skid-yard cost calculations but including it could provide a more accurate estimate of stump-to-truck harvest costs as such operations become more common.

To improve the consistency and accuracy of the TEA skid-yard cost calculation, regional operational cost variables could be unified into a single updated equation that incorporates key factors, such as ground slope, fuel costs, and skid distance. Alternatively, an external stump-to-truck cost estimation tool could draw on available prescription or cruise report data to incorporate a broader range of operational and site-specific variables into TEA skid-yard cost estimates. The ThinCost_1.0 model (Chang et al. 2023) offers such an approach, combining field-derived productivity equations and user inputs—machine cost rates, stand variables (e.g., ground slope and species composition), prescription data (tree volumes and average DBH), and operational variables (skid distance)—to estimate stump-to-truck costs. While further validation with Forest Science TEA timber sale data is needed, ThinCost_1.0 represents a promising framework for standardizing and improving skid-yard cost consistency across regions.

Transportation Costs and Forest Products

In the analysis of TEA data from Regions 2 and 3, haul estimates for transporting sawlogs and other timber products accounted for the second largest portion of total stump-to-truck harvesting and delivery costs, at 28.9% in Region 2 and 38.0% in Region 3 (Fig. 2). Transportation costs alone can account for up to one-third of the entire stump-to-mill treatment costs (Han et al. 2004), particularly when material is transported over long distances on temporary or unpaved roads (Pan et al. 2008). Understanding how sale design, distance to processing facilities, and market conditions influence transportation costs is essential for developing and incorporating strategies to reduce them and improve the economic feasibility of treatments.

As shown in Table 3, average haul costs for sawtimber products on the Coconino NF ($88.56/CCF), Kaibab NF ($87.13/CCF), and Gila NF ($84.62/CCF) in Region 3 illustrate that limited market availability for forest products resulting from mechanical thinning operations contributes to significantly higher estimated transportation costs. By comparison, the three NFs in Region 2 with the highest haul costs (Pike-San Isabel, San Juan-Rio Grande, and White River) averaged $63.35/CCF. As small-diameter timber is removed from various different projects in the Southwest for restoration and wildfire fuel reduction purposes, the lack of markets and infrastructure for processing and manufacturing this timber often leads to increased hauling costs, hindering efforts to scale up treatments across the landscape (Woolsey et al. 2024; Townsend et al. 2019; Hjerpe et al. 2009). Based on data from Region 3, the average DBH for sawtimber (product 01) was 15.9 inches, while non-sawtimber (product 08) averaged 11.0 inches, underscoring the prevalence of small-diameter timber, which is less marketable, in recent sales across Arizona and New Mexico. A similar trend is observed in Region 2, where the average DBH for sawtimber from 63 sales was 11.7 inches. For instance, the San Juan-Rio Grande NF ($65.17/CCF) in Southwestern CO and Pike-San Isabel NF ($63.05/CCF), southwest of Denver, CO, exhibited the highest haul costs, total miles, and round-trip minute estimates for transporting sawtimber sale products to nearby processing facilities.

Reduced capacity and sawmill closures across the western US have limited the availability of nearby timber sale appraisal points, thus increasing haul cost estimates (Spelter 2002). In Region 3, for instance, sawtimber from the Coconino and Kaibab NFs is often appraised at facilities in the White Mountain region of eastern Arizona, typically over 100 miles from sale locations. Similarly, several Region 2 sales on the San Juan-Rio Grande NF have been appraised to Montrose, CO, also at a distance exceeding 100 miles. These patterns again highlight how limited processing infrastructure amplifies haul costs and reduces market competitiveness for timber sales.

To address this, conducting a regular census of regional wood processing facilities, including their production capacity and product outputs (e.g., firewood, pallets, poles), could help ensure that appraisal locations remain up-to-date as timber markets evolve and mills close or adjust production. Integrating this data with optimized haul routes (e.g., through ArcGIS Pro Network Analyst tools) may further improve consistency in future TEA haul cost estimates. Additionally, coordinating the timing and location of timber sale offerings with mill capacity and demand could support contractors' financial planning, encourage bids, and enhance overall market efficiency. While such measures may not resolve the broader issue of limited processing facilities, they could help ensure that TEA haul cost estimates remain accurate and regionally relevant.

Factors Influencing Purchasers' Bids

Examining regional trends in TEA bids can help identify sale characteristics most likely to influence bid rates and attract competition. For each potential offering, factors such as physical site conditions, treatment objectives, sale characteristics, contractor efficiency, and harvesting method will influence the amount a bidder is willing to pay for stumpage (Kilgore and Blinn 2005). While limited to timber sale characteristics data recorded and tracked by the Forest Service TEA method, the analysis of bids was constrained by the exclusion of factors explored in similar studies, such as the seasonality of offerings and harvest restrictions (Dahal and Mehmood 2005; Brown et al. 2012), as well as a lack of available data on contractor productivity and costs.

In both regions, the amount of sawtimber volume (in CCF) available in a given sale was a significant factor influencing high bid amounts, reinforcing findings from similar studies that total appraised volume is a key determinant of bid behavior and an important element of sale design (Kilgore and Blinn 2005; Brown et al. 2012; Dahal and Mehmood 2005). In Region 3, sawtimber volume had a stronger positive effect, with each additional hundred cubic feet increasing the bid price per 100 CCF by 1.9% more than in Region 2 (Table 6). Stand density and total sawtimber volume impact productivity and cost. Lower sale volumes increase contractor costs due to greater machine travel distances between trees, reducing efficiency (Parajuli et al. 2020). Designing TEA sales with greater volume per acre (Brown et al. 2012) may therefore lower operational costs, increase high bid amounts, and potentially attract more competition, helping to ensure that timber sales are successful. Although harvesting larger trees generally enhances productivity and lowers costs (Louis et al. 2022), responsible restoration objectives can still be met with increased volumes by applying diameter caps that limit maximum tree size on Southwest sales (Hjerpe et al. 2009).

In Region 2, longer haul distances are often associated with lower advertised rates under the TEA method, which may reduce perceived financial risk for bidders. Additionally, limited processing infrastructure in areas such as the San Juan-Rio Grande NF makes longer haul distances a common and expected aspect of operating in the region. Familiarity with these market conditions may help explain why purchasers still bid competitively to secure volume and meet mill quotas despite extended hauls.

Operational sale characteristics that could impact stump-to-truck harvest productivity and cost were a relevant factor in bid behavior only in Region 3, where increases in skid distance estimates were associated with a decrease in high bid amounts by approximately 19.1%. In Region 2, however, skid distance did not significantly influence high bid prices (p-value = 0.789) (Table 6). Timber sale guidelines that estimate skid distances or the location of landings may be difficult to ground-truth prior to bid preparation for an upcoming sale. Although lower extraction distances have been shown to increase skidder productivity (Chang et al. 2023), contractors may not place significant emphasis on TEA skid distance estimates prior to purchasing a sale. It may be more feasible to create a logging plan layout with skid trail and landing locations strategically designed to maximize productivity and reduce costs once a sale has been purchased and ground-truthed.

In a survey of timber sale bidders in Minnesota, Kilgore and Blinn (2005) found that guidelines specifying merchantable residual trees required to be left on-site had a greater influence on bid behavior than guidelines concerning skid trail and landing placement or slash disposal. Additionally, few timber harvesters took the opportunity to physically visit a potential sale site before preparing their bids (Kilgore and Blinn 2005). Finally, a contractor survey in the Southwest could help identify sale variables associated with increased interest and bid preparation for future TEA sales.

Market Competition and Number of Bids

Competition for Forest Service TEA timber sales can be assessed regionally by evaluating the number of bids received for the stumpage offered for each individual sale (Leefers and Potter-Witter 2006). The number of bids received per sale in Region 2 was significantly lower than Region 3, where approximately 65% of the timber sales analyzed received only one bid (Fig. 3). With a lower number of total sale offerings during the analysis period, Region 3 experienced higher levels of competition, as indicated by overall bid totals per sale. Similar to previous studies showing that an increased number of bids raised stumpage prices, signifying heightened competition (Brown et al. 2012; Dahal and Mehmood 2005; Leefers and Potter-Witter 2006), the number of bids received for a sale had a significant positive influence on high bid amounts in Region 3. Sales that receive no bids may occur, while practices such as intentional underpricing and preclusive bidding may also exist and can be difficult to detect. However, increasing the number of bidders and competition for sales could lead to higher bid amounts. This, in turn, may help establish consistent TEA base period prices that better reflect market values.

Providing detailed and accurate sale characteristics, including species composition, timber volume and quality, and harvesting guidelines or restrictions (Kilgore and Blinn 2005), or offering sales with increased volume per acre (Brown et al. 2012), can effectively increase high bid amounts, help bidders accurately predict operational costs, and potentially draw more competition.

Regional Differences and Study Limitations

The TEA dataset provided a well-balanced distribution of sales sizes across both regions. In Region 2, 44% were small (< 5,000 CCF) and 56% large (> 5,000 CCF), while in Region 3, 54% were small and 46% large, with mean volumes of 6,515 CCF and 9,197 CCF, respectively. While still subject to the TEA process, stewardship and service sales were excluded from analysis because they do not contribute to BPP calculations and often resulted in incomplete or inconsistent data. Their exclusion reduces potential bias when analyzing competitive market trends and bids based on TEA-derived BPPs. When appropriate, adjusting TEA cost center calculations to ensure consistency across Forest Service regions is beneficial when timber species, site conditions, and lumber industry infrastructure exhibit sufficient similarities. Sale feature differences (e.g., salvage sales in Region 2) can still be addressed in the TEA method through quality adjustments, while incorporating skid distance into skid-yard cost calculations might enhance consistency across regions. Haynes et al. (2016) proposed reorganizing TEA regional appraisal zones to better align with local lumber markets. Similarities in markets delineated by haul miles and RTM between NFs in SW Colorado (R2) and Arizona (R3) present an opportunity to create new zones that address discrepancies in haul cost estimates, ensuring more consistent expected advertised rates for bidders across both regions. Updated appraisal zones could also potentially address regional variations in contractor availability, mill capacity, and total number of sale offerings.

Conclusion

To meet the WCS goal of increasing the pace and scale of fuels and forest health treatments in the coming years, it is essential to understand the nuances and barriers to implementing mechanical thinning restoration treatments in priority landscapes. Evaluating the economic feasibility of these treatments, particularly harvest productivity costs and transportation expenses, is key to scaling up efforts to expedite treatment acreage across western landscapes. Accurately assessing these operational aspects is crucial for balancing treatment objectives with the need to ensure financial returns, thereby maintaining the economic viability of the process for all parties involved.

The Forest Service TEA method is designed to provide a consistent and accurate determination of fair market value for stumpage by assessing operational costs, regional competition, and market adjustment factors. Recent TEA sales in Regions 2 and 3 have allocated a significant portion of sale cost adjustments to stump-to-truck processing and hauling estimates. While further research is needed, integrating emerging harvest productivity cost modeling tools that encompass additional sale characteristics could provide more accurate and consistent skid-yard cost estimates across both regions.

Despite challenges like limited market availability and high transportation costs in the southwest US, updated data on processing facilities and production capacity could help refine haul cost estimates and alleviate some of the economic pressures logging contractors face. Increasing sawtimber volumes to incentivize future sales, and strategically timing offerings based on location and market demand, may also boost competition by attracting more bidders.

These strategies could help balance economic feasibility with restoration objectives by supporting contractor viability, ensuring the Forest Service receives fair market value for timber, and maintaining focus on treatment efficiency. A detailed understanding of the current TEA method, coupled with potential improvements and bidding behavior considerations, assures accurate economic analysis of fuel restoration treatments in the western US. To achieve broader landscape-scale objectives in addressing the wildfire crisis, aligning operational cost estimation methods, market incentives, and restoration goals could enhance implementation of treatments to restore and maintain healthy, productive forest ecosystems.

Data Availability Data will be made available on request.

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