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National forest timber bids and export price interlinkages in the USA: The bounds testing approach

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Abstract

We examine the interrelationships of national forest timber bid and log export prices for Douglas-fir (Region 6) in 2003–2021 and loblolly pine (Region 8) using time-series stationarity and bounds-testing approaches. The analysis shows the difference in time series properties across different geographies and time scales. Bid prices for these dominant species of timber in each of two Forest Service regions are found to be stationary, while log export prices for those same species appear to be non-stationary. Bounds testing conducted with autoregressive distributed lag modeling methods provides strong evidence for a cointegrating relationship between timber bid prices and log export prices in Forest Service Region 6. In Region 8, evidence for a cointegrating relationship was weak. The share of salvage wood in national forest timber sales is a statistically significant control variable in all models estimated.

Keywords: prices, cointegration, national timber, exports, salvage

Highlights:

- Federal timber bid prices are associated with log export prices
- Association varies geographically
- Increased federal timber harvests may translate into lower regional wood prices
- Short-term prices in Region 6 are driven by past salvage wood share
- Short-term prices in Region 8 are driven by past bid prices

1. Introduction

Forest sector market models are designed to account for the complex interdependencies between markets and forest ecosystems. In general, such models are employed to assess the potential forest sector outcomes of sociopolitical or environmental impacts of observed or hypothetical shifts in natural resource management decisions, policy changes, and economic or biophysical shocks. Such models include a set of assumptions based on theory or empirical evidence regarding supply and demand behavior and linkages across spatially distributed markets. With regard to the latter, accurate quantification of the degree to which shocks are transmitted among local markets, consistent with the Law of One Price (e.g., Richardson 1978, Goodwin et al. 1990), may be critical to providing policy analyses that are useful to decision makers. Among forest sector market models, global forest sector market models most commonly assume that the US and global markets are integrated and prices between regions differ by no more than the cost of transport plus other trade costs (see Latta et al. [2013]).

There is a substantial literature testing assumptions regarding market integration in forest products. Most such studies focus on the existence of cointegrating relations as evidence or measures of such connections, and supporting evidence has emerged from around the world over the last two decades, including from the United States (e.g. Parajuli et al. 2016, Ning and Sun 2014, Nagubadi and Zhang 2013, Zhou and Buongiorno 2006, Prestemon and Holmes 2000, Bingham et al. 2003), Canada (Nanang 2000), Sweden (Jaunky and Lundmark 2015), New Zealand (Niquidet and Manley 2008), regionally in the Baltics (Mutanen and Toppinen 2007), Nordics (Eriksson and Lundmark 2020), and in the European Union (Banaś et al. 2022) and their trading partners (e.g., Kuuluvainen et al. 2018). Studies into market integration of public timber are rare (e.g., Daniels 2011).

Forest sector market models often assume that timber producers respond identically to market shocks, regardless of ownership. Implicit here is that prices for timber observed on public lands covary with aggregate market prices. In other words, timber shocks experienced on public lands would transmit to private producers, and vice versa. As forest management decisions focused on climate change mitigation and adaptation strategies are increasingly adopted on public lands, potentially including actions affecting timber removals, accurate characterization of these price linkages is becoming increasingly relevant.

Publicly owned forests in the United States provide multiple ecosystem services, including economic, recreational, and cultural opportunities for forest-dependent communities across the United States. National forests and woodlands consist of both protected and managed areas located on federal public land across the United States. As of 2022, there are 154 national forests managed by the USDA Forest Service and distributed among nine administrative regions that are generally defined geographically (USDA 2022a). Additionally, several other federal departments manage forests, including the Department of the Interior (Bureau of Land Management, Fish and Wildlife Service, Bureau of Indian Affairs, Bureau of Reclamation), the Department of Energy,

and the Department of Defense. Federal forests include national forests and all the rest of the forests and woodlands that are managed by federal organizations. Under conditions of market integration, shocks to the public timber resource from any of these federal departments may be reflected in the broader market. Murray and Wear (1998) and Wear and Murray (2004) offered evidence that this is the case. However, those analyses focused on a large, permanent change in federal lands policy that limited public timber harvests; evidence on the strength of such relationships on the scale of transient or smaller scale shocks is still lacking (e.g., Zhou 2021).

Timberland comprises 67% of forestland in the United States, and the federal government owns 21% of all timberland, comprising 30% of the U.S. timber inventory (Oswalt et al. 2019). The structure and spatial arrangement of timber markets in the U.S. vary across the different geographies. About 86% of the forests in the U.S South are privately owned, of which 58% is owned by non-corporate private owners. In contrast, Pacific Northwest private ownership accounts for 39% of forests, of which 17% is owned by non-corporation forest owners; the federal government holds about 50% and state governments hold an additional 21% of the forest area in that region (Butler et al. 2020, 2022).

Tests into the strength and extent of spatial market linkages in the United States have been facilitated by evidence from large market supply shocks generated by natural disturbances. Henderson et al. (2022) simulated alternative scenarios for market impacts of hurricane damages on forest growing stock. They demonstrated that large scale tree-planting after hurricanes mitigates future price increases, particularly in pulp wood markets in the long-term, and alleviate the storm-related losses in forest carbon. Prestemon and Holmes (2000, 2010) conducted research on the spatial transmission of price shocks and found that the shocks had a limited geographical reach, likely due to transport costs. This is similar to the findings of Holmes (1991) in a study of a large outbreak of southern pine beetles in Louisiana and Texas in 1984-1986. The researchers showed that much of the short-run timber price dynamics observed after Hurricane Hugo, which had a significant impact on South Carolina in 1989, was due to salvage operations. These operations produce abundant quantity of lower-quality wood, which temporarily substitutes for green timber. Prestemon and Holmes (2000) found that prices in the affected region remained high for several years after the event, suggesting a contraction in forest inventory. However, they also noted that the spatial impact on prices was limited.

Even while large disturbances have provided an opportunity to statistically evaluate issues of spatial market integration, the findings from the cited studies provide guidance on testing to evaluate linkages of federal timber to the broader market. It is presumable that the quantity of salvage wood in federal timber sales offered can affect the accepted bid price, with such an impact linked not only to changes in timber quality but also to concomitant shifts in the amount of green timber offered. Green timber refers to timber that has been cut as part of a normal harvesting operation, typically from live, undamaged trees. In periods with a high proportion of salvage sales, it is possible that both supply and demand of green timber decrease simultaneously. In other words, when federal forests prepare more salvage sales, they may reduce the number of

normal (green) sales (e.g., Prestemon et al. 2006); when timber consumers have the opportunity to purchase salvage timber at lower prices, demand for green timber decreases due to substitution by salvage. The price impact on green timber then depends on the relative size of supply and demand shifts. A high share of salvage wood in the total sales quantity could result in a lower bid price and quantity for sales of green timber (q1, p1) compared to the counterfactual (q0, p0), as demonstrated in Figure 1. The case in which salvage consumption displaces demand for green timber (i.e., salvage is a poor substitute for green timber) could result in (q2, p2), making the price impact assumptions of higher share of salvage theoretically ambiguous, but nonetheless impactful.

- Insert figure 1 here

U.S. federal timber markets, competition and prices

A review of how timber sales are prepared and sold is important to understanding why federal timber prices could be linked to the broader timber product market. Timber offerings from federal lands are advertised based on Transaction Evidence Appraisal (TEA) for potential buyers with a minimum acceptable bid rate (total contract value) that aims to satisfy fair market value, accounting for costs incurred by the buyer in harvesting and transporting harvested wood to mills. The valuation of the advertised bid rate is based on a three-part appraisal process, described in Leefers and Potter-Witter (2006) as: estimating timber volume, assigning a minimum acceptable price per unit for appropriate products and species, and applying species–product unit prices to volumes to derive the minimum acceptable stumpage price. Many of the econometric studies rely on the assumption that, "…like any other commodity, timber price is determined by supply and demand in equilibrium" (Mei et al. 2010, p. 1507, see also e.g., Chudy and Hagler 2020), but in practice, and especially in the context of green and salvage timber from federal lands, the price determination is a more complex process, combining biological, market, and institutional factors. Previous research highlights several determinants that influence competition for and pricing of federal timber.

Location, season of sale, sale size, and species–product composition are among the determinants of federal timber valuation in the sale preparation process (Brown et al. 2012, Nautiyal et al. 1995, Carter and Newman 1998, Leefers and Potter-Witter 2006). Contractual provisions (e.g., contract length, seasonal harvesting restrictions, auction type) and institutional and administrative decisions (e.g., auction methods) influence which and how many firms bid for the timber (Davis et al. 2018, Brown et al. 2012, Leefers and Potter-Witter 2006, Johnson 1979, Mackay and Baughman 1996). Leefers and Potter-Witter (2006) compared four public agency pricing systems in the Lake States of the US (Michigan, Minnesota, Wisconsin), finding that federal timber sales there faced significantly less competition. Validating observations by Haile (2001), the authors found that a firm's willingness to bid on federal wood depended not only on the

value it would obtain from harvesting and processing the timber itself, but also on the opportunities to buy and sell in secondary markets. Because exports of roundwood harvested from federal lands is generally prohibited by statute[1], firms buying federal timber need to direct such harvests to domestic wood processors. It is conceivable that this export prohibition creates a structural barrier that limits market integration, particularly in the Pacific Northwest of the United States, where national forest softwood timber removals comprise about 7% of the region's roundwood market while private removals comprise 79% and other public removals the reminding 15% (Oswalt et al. 2019).

This study aims to narrow the research gap on how local markets are connected to regional and international markets, while accounting for the impact of salvage wood share. More specifically, we seek to understand, using the most up-to-date data, the short- and long-term interrelationships of national forest timber sale bid prices and log export prices for Douglas-fir (*Pseudotsuga menziesii*) in the West Coast (Forest Service Region 6) and loblolly pine (*Pinus taeda*), which is the most commonly harvested species among the six main commercial southern yellow pine species (also including *P. echinata, P. elliottii, P. palustris, P. rigida, P. virginiana*) in the US South (Forest Service Region 8). To do this, we carry out time-series bounds testing approaches using autoregressive distributed lag models. We address the following four research questions:

> *R1) Do log export market prices at the border covary with national forest timber sale bid prices in Forest service regions 6 and 8?*
> *R2) Do regional differences exist in the strength of these price relationships?*
> *R3) Does salvage affect these price relationships?*
> *R4) What are the implications of these results for federal land management policy and forest sector market models?*

In the next section, we describe the data and methods in more detail, which is followed by the results section. We then discuss the limitations of our approach and conclude with implications for federal harvesting decisions and global sector models.

2. Data and Methods

2.1. Description of data

[1] Four primary laws have been enacted prohibiting federal timber export and substitution: the Foreign Assistance Act of 1968 (Pub. L. No. 90-554, § 401, 82 Stat. 966 (1968)), the Interior and Related Agencies Appropriations Act of 1974 (Pub. L. No. 93-120, § 301, 87 Stat. 447 (1973)), the Forest Resources Conservation and Shortage Relief Act of 1990 (Pub. L. No. 101-382, Title IV, § 487, 104 Stat. 714 (1990)), and the Forest Resources Conservation and Shortage Relief Act of 1997 (Pub. L. No. 105-83, Title VI, § 602(a), 111 Stat. 1618 (1997)). (United States Government Accountability Office 2018, p. 7-11).

The national timber bid price series data for sawtimber were retrieved from the Timber Information Management database in September 2021 (USDA Forest Service 2021). The dataset contains data including all the national timber sales from the forests managed by the Forest Service for the years 2001–2021.

The studied species and products were selected using two criteria: i) the significance for the region's forest sector, and ii) the availability of data. Douglas-fir was chosen as an indicator species for Forest Service Region 6 (national forests in Washington and Oregon) and loblolly pine for the Forest Service Region 8 (national forests in all 13 southern states[2]). The states bounded by regions 6 and 8 represent the two parts of the United States with the most public and private timber harvest volume nationally. Timber sale information for national forests of regions 6 and 8 is also the most complete, permitting the construction of uninterrupted quarterly time series of prices for Douglas-fir and loblolly pine. Given the highly developed markets in regions 6 and 8, we assumed that the regions are the most likely to relate to international trade flows (i.e., through an indirect roundwood arbitrage related to substitution of private timber with federal timber) by market actors, justifying the focus only on these two regions.

Loblolly, shortleaf, longleaf, and slash pine trees, also referred to as "southern yellow pine," comprise most of the softwood timber inventory in the thirteen states of the U.S. South, accounting for 90% of the net volume of softwood growing stock on timberland (Oswalt et al. 2019). Yellow pine is used in the pulp and paper industries, as well as for dimension lumber and plywood. In the southeast (states of the Atlantic coastal South) and southcentral subregions, yellow pine constitutes 89% and 92% of the total growing stock, respectively. Loblolly pine and shortleaf pine alone accounted for 63% and 84%, respectively, of the total growing stock measured by net volume (Oswalt et al. 2019). Region 8 national forests typically produce only 1 to 2% of southern timber harvests, so it is likely that the timber sold (and hence their prices) would not be consistently related to the quantity of timber harvested from private lands over time.

Douglas-fir represents the majority of planted trees in Oregon and Washington state and comprises about 54% of the net volume of softwood growing stock on timberland in the Pacific Northwest (Oswalt et al. 2019). This softwood species is used for dimension lumber, plywood sheathing, as well as for marine structures (e.g., docks), railroad ties, fencing, pulp, and furniture. Douglas-fir in Region 6 national forests accounts for about 10% of the volume of the Pacific Northwest's total (public plus private) timber harvests. Consequently, we anticipate more consistent relationship with the prices and quantities harvested from private lands over time in the Region 6 compared to the Region 8 (Figure 2).

- Insert figure 2 here

[2] Alabama, Arkansas, Florida, Georgia, Louisiana, Kentucky, Mississippi, Oklahoma, North Carolina, South Carolina, Tennessee, Texas, Virginia.

After the data were filtered to contain only the studied species, the quarterly time-series were constructed based on the date the timber sale was awarded. We omitted all sales that contained salvage wood so that the modeled price was only for green timber. As the presence of salvage wood was likely to reduce market prices in a region (due to expected average lower quality of salvage compared to green timber as in Henderson et al. 2022, Prestemon and Holmes 2000, 2010), we constructed a quarterly time series of salvage wood percentage of the total sales quantity (in hundred cubic feet) to be used as an independent variable. Figure 3 portrays the federal green Douglas-fir sale quantity in Region 6 and green loblolly pine sale quantity in Region 8, and the physical share of salvage wood of total sales quantities in both regions.

- Insert figure 3 here

We constructed logarithmic quarterly median unit price and quarterly volume-weighted average time series for sawnwood for Forest Service regions 6 and 8 ($US/CCF) (Figure 4). The median and average price series were similar, but the median price series proved to contain less “noise,” and so we decided to proceed with modeling only median prices. The outliers were carefully detected based on descriptive statistics including percentiles and minimum and maximum values. Furthermore, boxplots were used to evaluate potential outliers visually. Individual values that appeared as extreme cases were removed. After removing the outliers, we observed that Region 6 and Region 8 had approximately 8% and 10% missing values, respectively. Since regional markets for homogenous wood products usually follow similar price patterns (Prestemon and Holmes 2000, Bingham et al. 2003), we used bid price information from adjacent regions to linearly interpolate the missing quarterly values. For example, we assumed that the missing values in Region 6 were a function of Region 5 values, and the missing values in Region 8 were a function of Region 9 values (estimates available from the authors).

To explore the impact of different techniques for handling missing data, we used a smoothing technique to create a new time series where each observation was a moving average of the five previous quarters. While this method reduced some variation and controlled for seasonality in the data, it also resulted in more unsystematic results. We also considered other popular techniques for replacing missing values, such as multiple imputation methods. However, we opted for linear interpolation due to the moderate number of missing observations. As our results were consistent, we believe this simple approach was preferable in our case to the potential risk of statistically inconsistent parameter estimates that could arise from multiple imputation methods (Jakobsen et al., 2017). Nevertheless, their potential is further elaborated in the discussion. We also controlled for seasonality impacts with quarterly dummies but found that none of the

dummies were statistically significant. Instead, we controlled for seasonal variation in the data using the share of salvage wood, which we discuss in more detail later in the study.

- Insert figure 4 here

Quarterly time series data on U.S. exports of "logs and timber, in the rough, not treated" Douglas-fir (HTS code 440320004) and southern yellow pine (HTS code 4403210020) were collected from the United States International Trade Commission's (USITC) dataweb portal during the last quarter of the year 2021 (USICT 2021), and unit values (logarithmic US/m^3) were assumed to be unbiased proxies for export prices of Douglas-fir logs and loblolly pine logs (Figure 5). The export price data for different Forest Service regions were constructed so as to match the data from different ocean ports to the respective Forest Service regions.

- Insert figure 5 here

Prices were deflated to 2012 dollars using the Gross Domestic Product (GDP) deflator (U.S. Bureau of Economic Analysis 2022) and logarithmically transformed. Data examination and analysis were conducted using R-studio software (RStudio Team 2020) and STATA side by side (Statacorp 2021).

The relationship between stumpage median bid prices and average export prices is assumed to operate through public-private roundwood arbitrage relationships, which would require that roundwood from public and private lands is substitutable. Therefore, we also make the assumption that the quality of material of the same species or species group is consistent so that comparison of federal timber and exported logs is valid.

2.2. Stationarity testing

After constructing and visualizing the quarterly price series for data from 2003–2021, we evaluated their price series properties and stationarity. We analyzed the order of integration with different standard stationarity tests, with and without integrating the information about the structural breaks determined by the statistical cumulative sum structural change test by Bai and Perron (1998). As the time series, especially for the national timber sale prices, were somewhat volatile, we applied a battery of stationarity tests to reduce ambiguity about their time series properties (e.g., Prestemon et al. 2004), including the Augmented Dickey-Fuller (ADF) (Dickey and Fuller 1979), Phillips and Perron (PP) (Phillips and Perron 1988), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) (Kwiatkowski et al. 1992) tests, each with varying null-hypotheses. The null of

the ADF test is that the data contain a unit root. The null of the PP test is that the time series is integrated in order 1. The null of the KPSS test is stationarity of a series around a deterministic trend. Furthermore, to ensure that the series are not integrated at I(>1), we also run ADF tests for the differenced values. Results of the selected lag lengths based on Akaike information criterion (AIC) are reported in Table 1 and Table 2 for the regions 6 and 8 respectively.

Table 1. Stationarity test results and lag order selection based on AIC, Region 6, 2003(q1) –2021(q2). Bid price 6 is the bid price for Douglas-fir in Region 6, Export 6 is the export unit price for Douglas-fir in Region 6, Salvage 6 is the percentage of salvage wood of total sales in Region 6. ADF is the Augmented Dickey Fuller test, PP is the Phillips and Perron test, KPSS is the Kwiatkowski-Phillips-Schmidt-Shin test.

	Lags (AIC)	ADF Test statistics	PP Test statistics	KPSS Test statistics	Conclusion[1]
Bid price 6	4	-6.95***	-2.75*	.17**	I(0)
Export price 6	1	-1.90	-2.70	.34***	I(1)
Salvage 6	4	-3.64***	-6.28***	.14*	I(0)

*** indicates significance at the 1%-level, ** 5%-level, *10%-level, [1]I(0) = stationary at level, I(1) = stationary at first difference

Table 2. Stationarity test results and lag order selection based on AIC for Region 8 2003(q1)–2021(q1). Bid price 8 is the bid price for loblolly pine in Region 8, Export 8 is the export unit price for southern yellow pine in Region 8, Salvage 8 is the percentage of salvage wood of total sales in Region 8. ADF is the Augmented Dickey Fuller test, PP is the Phillips and Perron test, KPSS is the Kwiatkowski-Phillips-Schmidt-Shin test.

	Lags (AIC)	ADF Test statistics	PP Test statistics	KPSS Test statistics	Conclusion[1]
Bid price 8	3	-2.77*	-6.47***	.14*	I(0)
Export price 8	3	-0.82	-1.23	.36***	I(1)
Salvage 8	4	-3.11**	-5.56***	0.06*	I(0)

*** indicates significance at the 1%-level, ** 5%-level, *10%-level, [1]I(0) = stationary at level, I(1) = stationary at first difference

The stationary testing indicates that the Bid prices (stumpage prices) are stationary, so that national forest timber sale prices do not permanently retain price shocks. Time series for export prices proved to be I(1), and salvage wood share of the total wood sales I(0).

The stationarity testing results of the time series incorporating information about the structural breaks yielded similar results as if structural breaks were not considered. The statistical significance of the structural breaks in the cointegration model is discussed in more detail in the following sections.

2.3. Bounds testing

An autoregressive distributed lag bounds testing method by Pesaran et al. (2001) may be used to overcome restrictions of conventional cointegration testing methods (Kuuluvainen et al. 2018, Zhang et al. 2015). The bounds testing method can capture a short-term and long-term causality relationship when the variables are integrated at the different level of order (Pesaran et al. 2001). As the asymptotic distribution of F-statistics of bounds testing is independent of whether the variables are I(0) or I(1), the test can assess whether there are level effects between national forest timber sale prices for logs, exported log price, and salvage wood. The ARDL Bounds test approach requires three steps. The first step is to determine the existence of a long run cointegrating relationship among the variables based on autoregressive distribution lag model (ARDL). The ARDL model used in this study can be expressed as follows (Eq. [1]).

Eq. (1),

$$\Delta bid\ price = a_0 + \sum_{i=1}^{p} a_{1i}\Delta bid\ price_{t-i} + \sum_{i=0}^{q1} a_{2i}\Delta export\ price_{t-i} + \sum_{i=0}^{q2} a_{3i}\Delta salvage_{t-i} + b_1 bid\ price_{t-1} + b_2 export\ price_{t-1} + b_3 salvage_{t-1} + \varepsilon_t$$

In the empirical specification, the prices are expressed in logarithmic terms and the coefficient can be interpreted as elasticities (Equation 1). Bid price is the mean bid price of federal timber in real (2012 US dollar) terms, export price is average export price in real terms; a_0 is the constant; a_1, a_2 and a_3 are short-term coefficients; b_1, b_2, and b_3 are long-term coefficients; *p, q_1, and q_2* are the optimal lag orders of bid prices, export prices, and salvage shares, respectively, based on the AIC, allowing for a diverse number of optimal lags for different variables; ε_t is the error correction term; and where $H_0 : b_1 = b_2 = b_3 = 0$, H_a: $b_1 \neq b_2 \neq b_3 \neq 0$.

The long-term level relationship among the variables is determined using the Wald-coefficient F-test, where the critical values for lower and higher bounds are adopted from Pesaran et al. (2001) with constant and no trend. The null hypothesis of no cointegration is tested by setting the coefficients of all the *t-1* lagged level variables equal to zero against the alternative hypothesis of non-zero coefficient values (Pesaran et al. 2001). The bounds test involves only critical values for the upper and lower bounds. The F-test statistic calculated for cointegration must be greater than the upper bound critical value. If the calculated F-test statistic is found between the lower and upper bound of the critical value, there is no definite result for the cointegration, and the decision is inconclusive regarding the null hypothesis of no cointegration. If the F-test statistic is below the lower bound, then there is no evidence of cointegration.

If the bounds testing concludes that there is a cointegrating relationship between the variables, then an unrestricted error correction model (UECM) can be estimated in the second stage of the analysis. The UECM is estimated by replacing the long-term component in the Eq. (1) with an error correction term (ECT_{t-1}) (Eq. [2]). ECT_{t-1} are the lagged residuals obtained from the estimated cointegration model in the step 1.

Eq. (2),

$$\Delta bid\ price_t = a_0 + \sum_{i=1}^{p} a_{1i} \Delta bid\ price_{t-i} + \sum_{i=0}^{q1} a_{2i} \Delta export\ price_{t-i} + \sum_{i=0}^{q2} a_{3i} \Delta salvage_{t-i} + \lambda ECT_{t-1} + \varepsilon_t$$

Where λ is the speed of adjustment parameter (with a negative and statistically significant sign) of the ECT_{t-1}. a_1, a_2, a_3 are the short-term dynamic coefficients of the model's adjustment towards a long-term equilibrium. The long-run elasticities are calculated from the estimated coefficients independent (and it's lags) variable divided by 1 minus the sum of the lagged bid price coefficients. The short-run elasticities are represented by the coefficients of the respective first difference variables.

If bounds testing concludes that no statistically significant co-integrating relationship exists at stronger than the 10%-level, only the short-term ARDL model may be specified in the third stage of the analysis (Eq. [3]). The short-term coefficients a_1 a_2 and a_3 can be interpreted as ceteris paribus effects where inference is based on the usual OLS standard errors and test statistics:

Eq. (3),

$$\Delta bid\ price_t = a_0 + \sum_{i=1}^{p} a_{1i} \Delta bid\ price_{t-i} + \sum_{i=0}^{q1} a_{2i} \Delta export\ price_{t-i} + \sum_{i=0}^{q2} a_{3i} \Delta salvage_{t-i} + \varepsilon_t$$

2.4. Structural breaks and model diagnostic testing

Even though coefficients of long-term equilibrium equations are relatively persistent, the presence of unmodeled structural breaks can mask cointegrating relationships and reduce the credibility of stationarity testing (Schweikert, 2022). As the long-term equilibrium in time series analysis may differ for subsamples, we test time-series

properties and cointegrating relationships with and without information about structural breaks. The effects of significant structural change periods are captured by dummy variables by assigning a value of 1 for the assessed time period and 0 otherwise. Pesaran et al. (2001) argue that the asymptotic theory developed in the ARDL bounds test approach is not affected by the inclusion of such "one-zero" dummy variables (e.g., Fuinhas and Marques 2012). The dummies identified no statistically significant impact, neither on the cointegration testing nor on the ARDL or ECM -modeling, but rather made models more unstable; therefore, they were left out of the analysis.

We aimed to select the most parsimonious model possible that passed the diagnostic tests: (i) a Breusch–Godfrey serial correlation LM test with a null hypothesis of no serial correlations, (ii) a White test for homoscedasticity, (iii) a Jarque–Bera test for Normality of estimated residuals, and (iv) a CUSUM stability tests, which in time series analysis uses the sequence of residuals to indicate whether an autoregressive model is mis-specified.

3. Results

The bounds test showed that there exists a cointegrating relationship at the 5% significance level, with an F-value of 18.27 (Table 3). For Region 8, the F-statistic was 4.47, an inconclusive result at the 5%-level but a significant result at the 10%-level. Therefore, we proceed with estimating both long-term ECM and short-term ARDL models for both regions.

Table 3. Test results from Bounds-testing, region 6 lag structure (1 0 1), Region 8 lag structure (3 0 0), 2003(q1)–2021(q2).

	F-statistics	Critical I(0) and I(1) values at 5%-level[1]	Conclusion
Region 6	18.27	[4.41, 5.52]	Cointegration relationship exists at the 5% (and 1 %) level
Region 8	4.47	[3.91, 5.00][2]	No cointegration relationship exists / Co-integration inconclusive at the 5% level

[1]Critical levels adopted from Pesaran/Shin/Smith (2001). [2]Due to lost degrees of freedom during the interpolation of the missing values, the critical values are higher than

reported here. We anticipate that in Region 8, a cointegrating relationship is unlikely to exist, despite the presented 5%-level test results indicating an inconclusive finding. Because the cointegrating relationship cannot be confirmed, only the short-term model is estimated for Region 8.

Table 4 presents results from the long-term UECM estimations for Region 6, with the optimal lag-structures based on the minimum of the AIC. The adjustment parameter (-0.90) is negative and statistically significant, reflecting a high speed of adjustment (a little bit over one quarter) towards the state of long-run equilibrium. The export price elasticity (0.95) is statistically significant at the 10%-level (p-value 0.08). Furthermore, the long-term elasticity for salvage wood percent (0.53) is statistically significant (p-value 0.01). The short-term elasticity for salvage wood percent is highly significant (p-value <0.01), indicating that a one percent increase in the salvage wood share is associated with 0.54 percent decline in the bid prices.

Table 4. Results from long-term UECM for the Region 6 2003(q1)–2021(q2). The dependent variable is the bid price.

	Region 6	
	Coef.	p-value
Adjustment parameter		
Lag 1	-0.90***	< 0.01
Long-term elasticities		
Export price	0.95*	0.08
Salvage %	0.53***	0.01
Short-term elasticities		
Lag 1 First-difference bid price	-	
Lag 2 First-difference bid price	-	
First-difference Salvage %	-0.54***	< 0.01
Constant	-0.30	0.78
Adjusted R^2	0.46	
N	73	
Model testing	Test-value	p-value
Breusch–Godfrey LM	0.60	0.44
White's test-value	4.80	0.99
Jarque-Bera normality	1.03	0.60

Region 6 lag structure (1 0 1), *** indicates significance at the 1%-level, ** at 5%, * at 10%.

The adjusted R^2 is 0.46 for Region 6, showing that almost half of the variation in the dependent variable can be explained by model independent variables in both regions

over the study period. The models pass the diagnostic tests, as no autocorrelation, heteroscedasticity, abnormal, or unstable residuals are detected.

In the short-term ARDL estimates, the lagged bid prices are not statistically significant in either of the regions, which is consistent with the long-term UECM results (Table 5). Only the third lag for Region 8 (0.23) is significant at the 5% level. The export price elasticity in Region 6 indicates that a one percent change in the export price is associated with a 0.86% increase in the bid price, which is significant at the 10%-level. The relationship between the export price and the bid price is not significant in Region 8. While salvage wood percent is not significant in either of the regions, the first lagged salvage wood percent was highly significant in Region 6, with an elasticity of 0.54 (p-value smaller than 0.01). Similar to the long-term estimation, the ARDL models pass all the diagnostic tests.

Table 5. Results for the short-term ARDL-model for Region 6 and for Region 8, 2003(q1)–2021(q1). The dependent variable is the bid price.

	Region 6		Region 8	
Variable	Coef.	p-value	Coef.	p-value
Lag 1 bid price	0.09	0.46	0.09	0.41
Lag 2 bid price	-		0.07	0.49
Lag 3 bid price	-		0.23**	0.05
Export price	0.86*	0.09	0.05	0.32
Salvage %	-0.06	0.76	0.01	0.91
Lag 1 salvage %.	0.54***	<0.01	-	
Constant	-0.29	0.77	0.93***	<0.01
Adjusted R^2	0.16		0.11	
N	73		74	
Model Testing	Test-value	p-value	Test-value	p-value
Breusch–Godfrey LM	0.6	0.43	2.56	-0.46
White's test-value	4.8	0.99	28.85*	-0.09
Jarque-Bera normality	1.03	0.60	1.07	-0.59

Region 6 lag structure (1 0 1), Region 8 lag structure (3 0 0): *** indicates significance at the 1%-level, ** at 5%, * at 10%.

4. Discussion and conclusions

The long-term association between federal timber, export prices and salvage wood are highly statistically significant in Region 6, the Pacific Northwest. In Region 8, the US South, the association cannot be confirmed. These results correspond to our first research question (R1) regarding whether log export markets are connected to federal timber prices. We find that a long-term relationship between export prices and bid prices is detected, but only with confidence in Region 6, where federal and state governments possess a large share of the forest land.

Our results outline two different cases that describe the association of federal timber prices and export log prices under varying rates of timber harvesting from federal forests (R2). First, where regional and export timber prices are associated with each other in Region 6 and the prices adjust toward a long-term equilibrium quickly, the price impact of changes in federal timber harvesting levels is conditional on global market demand in the long-term. Consistent with the Law of One Price and arbitrage theory, regional prices for Douglas-fir respond to global markets for Douglas-fir logs. If markets are integrated at regional and higher levels, global market model assumptions are met (c.f. Region 6).

These results indicate that changes in federal harvests are likely to lead to changes in market log prices, including at borders, but evidence is strongest in the Pacific Northwest. In the South, changes in loblolly pine timber harvests from federal lands are unlikely to lead to persisting impacts on southern pine market prices, including for the prices of logs at borders. The loblolly pine results also are perhaps unsurprising, to the extent that federal loblolly pine timber harvests in Region 8 are a small share of total regional output of that species.

Due to the existing research gap, there is no strong empirical or theoretical basis for predicting the direction of price changes for green timber due to substitution by salvage sales. As noted in the methods, we excluded salvage sales from the bid prices, so the salvage percent variable used in the analysis will catch this dynamic. The results regarding salvage wood price impacts are quantifiable in Region 6, which is a fire-prone region with the accentuated risk for high shares of salvage wood. Based on our results, a higher share of salvage wood share is associated with a lower price for green timber in the short-term. In the long-term, a high salvage wood share is associated with a higher price. These results contribute to the research question 3 (R3). Our results resonate with previous findings regarding the effect of salvage on southern pine timber prices (Holmes 1991, Prestemon and Holmes 2000) and align with the Fuchs et al. (2022) hypothesis and the Prestemon and Holmes' (2000) empirical findings on the "market effects" of forest disturbances, suggesting that post-disturbance prices drop in the short-term due to the increase in supply from salvage but rise in the long-term due to the reduced stock of green timber caused by the disturbance. Salvage wood share appeared as an efficient control for seasonality in the data as well. We can conclude that salvage wood share is an important variable for price predictions and harvesting models, especially in regions with considerable amounts of salvage wood. However, future research is needed to further elaborate on the substitution dynamics between green timber and salvage sales and their wider societal consequences under different economic and environmental conditions (Prestemon and Holmes 2004, Fuchs et al. 2022). The focus of our study was to evaluate the price inter-relationships between federal timber and export log prices; more detailed inferences regarding the salvage-green timber supply dynamic were beyond the scope of our analysis.

Our results also indicate that the speed of adjustment towards the state of long-run equilibrium is fast. In Region 6, the market shocks are absorbed by 90% in the first subsequent quarter. Regarding the impact of the optimal lag structure selection, our results suggest that the bid prices in Region 6 can be explained by the past salvage wood percent, while the bid prices in Region 8 are more completely explained by past bid prices. These results further explain the regional divergences regarding the price inter-relationships between federal timber and export prices (R2), indicating variation in the impacts of environmental and economic attributes on the price inter-dependencies.

As Fuchs et al. (2022) outline, the assessment of the market effects of prices and disturbances require advanced time series analysis to capture time lags in the market responses. Our analysis shows that the Bounds-testing approach (Pesaran et al. 2001) provides a viable approach for assessing the price inter-relationships between federal timber prices and log export prices by controlling for the effect of salvage wood share. The approach allows for evaluating cointegrating relationships when time series are integrated of a different order – either I(0) and I(1).

Our findings are relevant to evaluation of the effects of federal harvest changes being considered today. Recently, the USDA Forest Service launched the 10-year Wildfire Crisis Strategy, which calls for treating up to an additional 20 million acres on National Forest System lands and 30 million acres of other federal, tribal, state- and privately-owned lands (USDA 2022b). These treatments, typically designed to reduce stand densities, could lead to increased quantities of timber and other wood assortments sold in domestic U.S. markets. Our findings suggest that, at least for the Pacific Northwest, such treatments could depress national forest bid prices and log export prices for at least Douglas-fir. These results can also be extrapolated to analyze the relationship between federal timber prices and import border prices, since differences in import and export prices at the border are mainly due to tariffs. It's important to note, however, that Canada, which happens to be the largest lumber exporter, is unable to export softwood logs by law. Therefore, the import price impacts remain theoretical in this case. Consistent with the Law of One Price and the modeling assumptions and findings of Barbour et al. (2008) and Prestemon et al. (2008), treatment harvest price impacts would likely be transmitted spatially and across ownerships (Barbour et al. 2008), and they may potentially impact trade flows. However, the magnitude of such impacts will depend on the specific design features, geographic distribution, and the rate of these treatments as they are carried out on federal lands in the coming years.

The results from the econometric analysis have implications for the global market models, as outlined in the final research question four (R4). Global market models assume that the US and global markets are integrated. This study provides new evidence of market integration, when the federal and export timber markets are assessed in the context of two dominant U.S. softwood timber species most commonly available in the federal timber sales. We outlined earlier the two different cases that describe the association of federal timber prices and log export prices, with strong

evidence of integration in Region 6 and little evidence of integration in Region 8. Updating forest sector market models to account for these underlying region-specific findings could yield more accurate predictions of the impacts of policy and market shocks under varying forest ownership structures and timber market conditions.

Regional timber markets can be integrated, and price movements in one market may affect the neighboring markets as well, as found in the southern stumpage markets (Parajuli et al. 2016, Mei et al. 2010, Prestemon and Holmes 2000) and log markets (Bingham et al. 2003). Nonetheless, our econometric analysis leaves room for more disaggregated and geographically dispersed analysis in the future. It's also worth highlighting that this analysis did not attempt to test causality in the bid price – log export price relationship. The common trends in these prices that were identified in this study therefore are associative until more definitive causal relationships are assessed. The percentage of missing variables in time series data holds varying degrees of significance, depending on the specific context and the intended purpose of the analysis. In our case, we encountered a moderate number of missing values, which we addressed by using linear interpolation based on the price information of a homogenous product in the adjacent region. This method produced consistent results and was deemed sufficient for our analysis. However, we recognize that evaluation of more advanced techniques, such as multiple imputation with the ARDL method in the federal wood price inference and price transmission studies, could provide more comprehensive insights into constructing the most representative price data series for federal timber sales. We recognize that application of imputation methods could generate more nuanced findings and better inform our understanding of the impact of missing variables on time series data, and so we would suggest exploration of those methods in future studies.

This study was the first attempt to quantitatively assess the time series behavior of local federal timber bid prices that were aggregated at the regional level. To assess the compatibility of the appraisal system with the local markets, it would be useful to understand the interplay between local private timber prices and federal timber prices in more detail. While the timber sales data are not easy to obtain, it could be beneficial to construct a database built from stumpage sale prices information to monitor the impacts of regional and global market fluctuations on the federal timber sales over time. The price information may be beneficial not only for internal stakeholders who are pricing the timber for sale, but also for external stakeholders, who are keen on engaging in the bidding process.

We acknowledge that behaviors of commodity prices depend on the time span under consideration, leaving our results with uncertain usefulness for forward-looking market assessments (e.g., Pindyck et al. 1998). Lastly, timber prices can be best observed from periodic (not necessarily regular but more frequent than monthly or quarterly) timber sales within a region. Monthly or quarterly timber prices may indeed denote an average of these more frequent prices. Therefore, information may be lost in the

aggregation process, which can result in imprecise parameter estimates (Haight and Holmes 1991). Additional data and methodological innovation are therefore needed to more confidently assess market integration and the potential effects of market shocks and policies affecting national forests.

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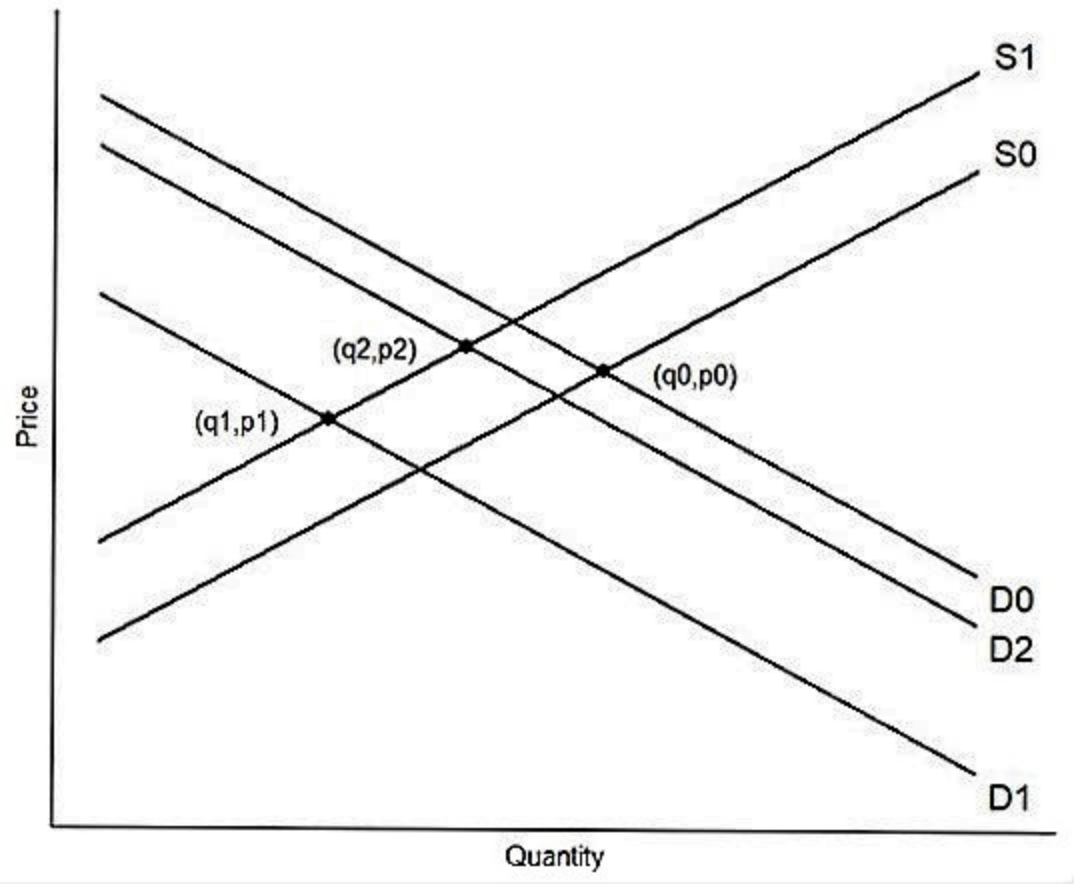
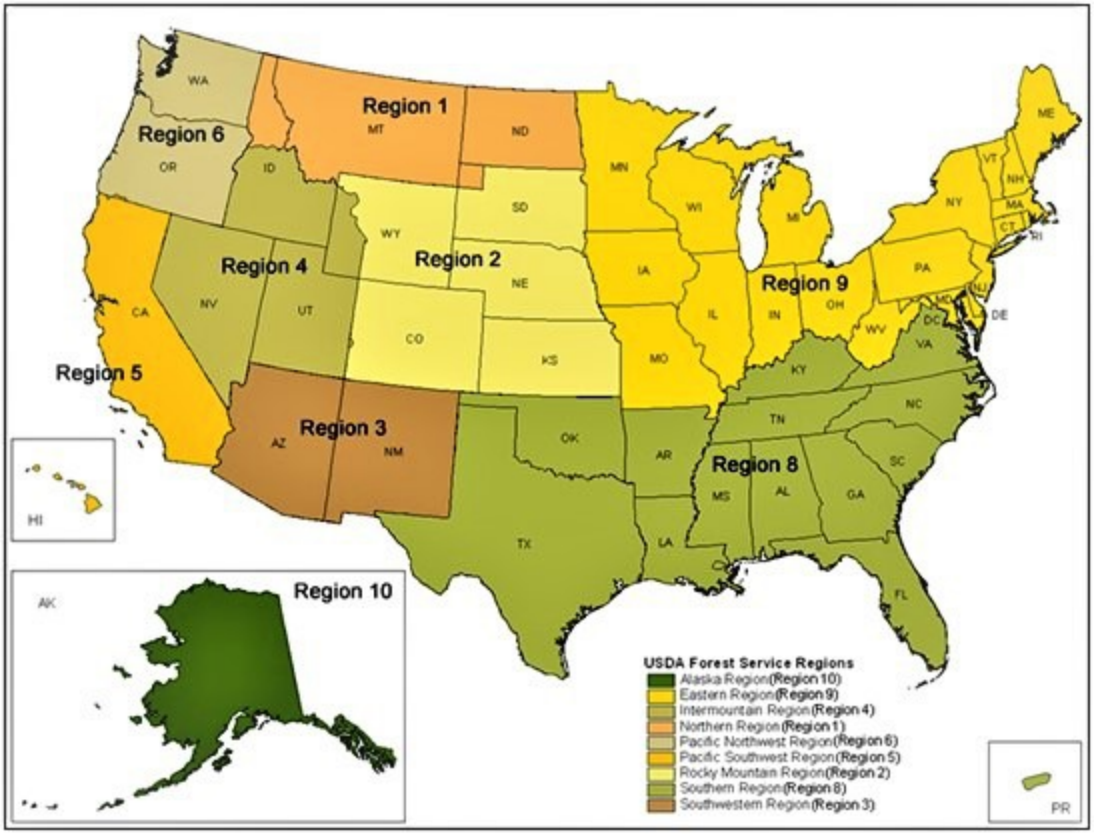

S1
S0
(q2,p2)
(q0,p0)
(q1,p1)
D0
D2
D1
Price
Quantity


Region 1
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Region 10
WA
OR
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ID
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CO
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GA
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SC
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VA
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NY
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DC
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RI
MA
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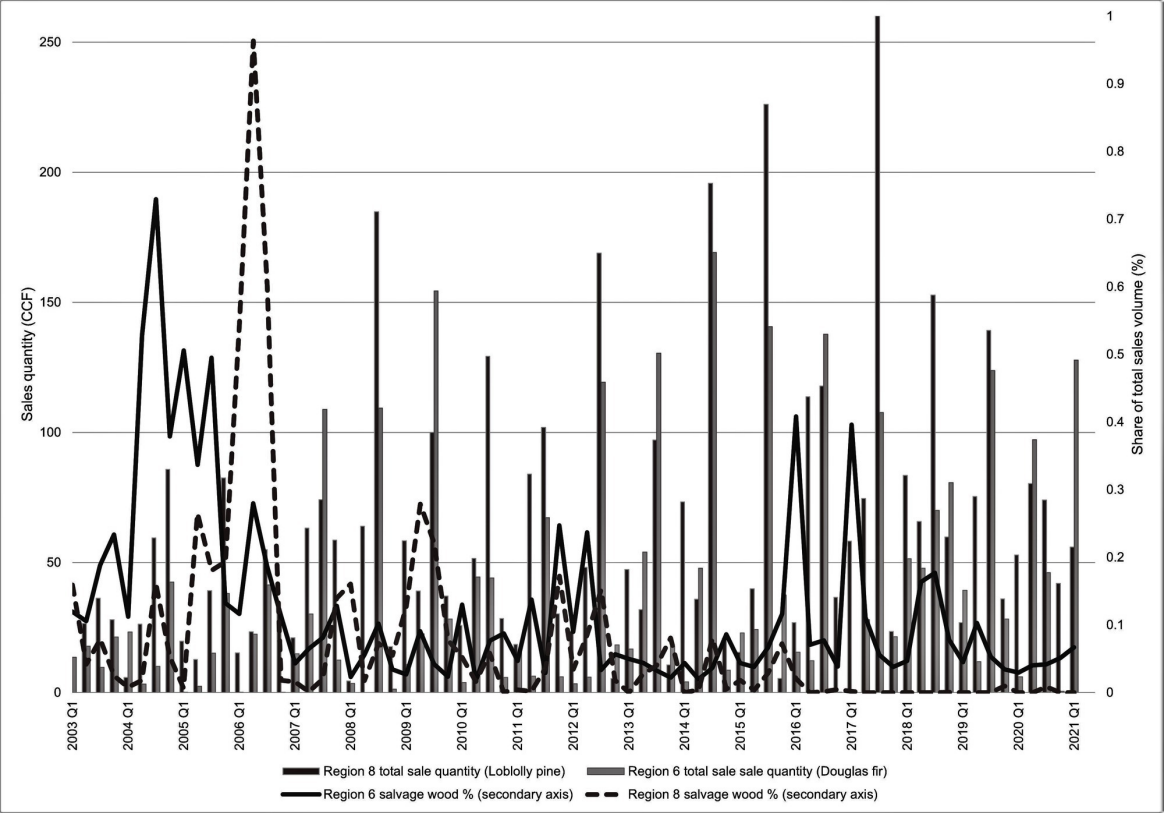
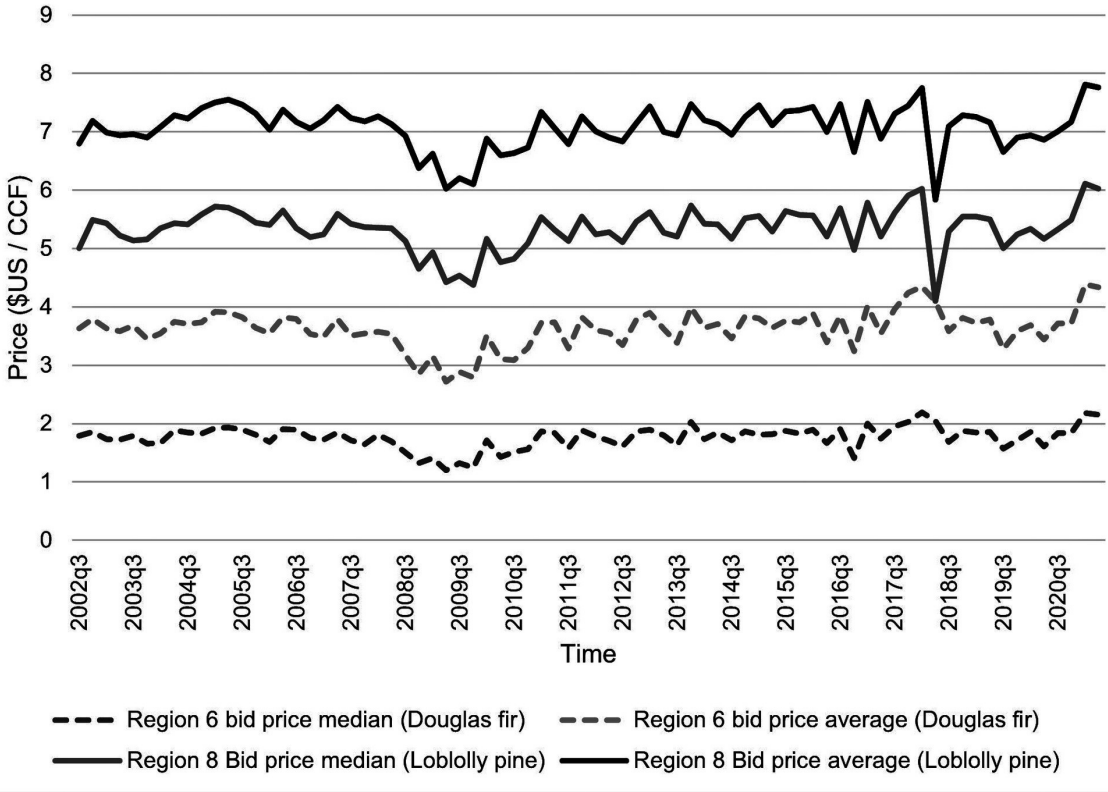
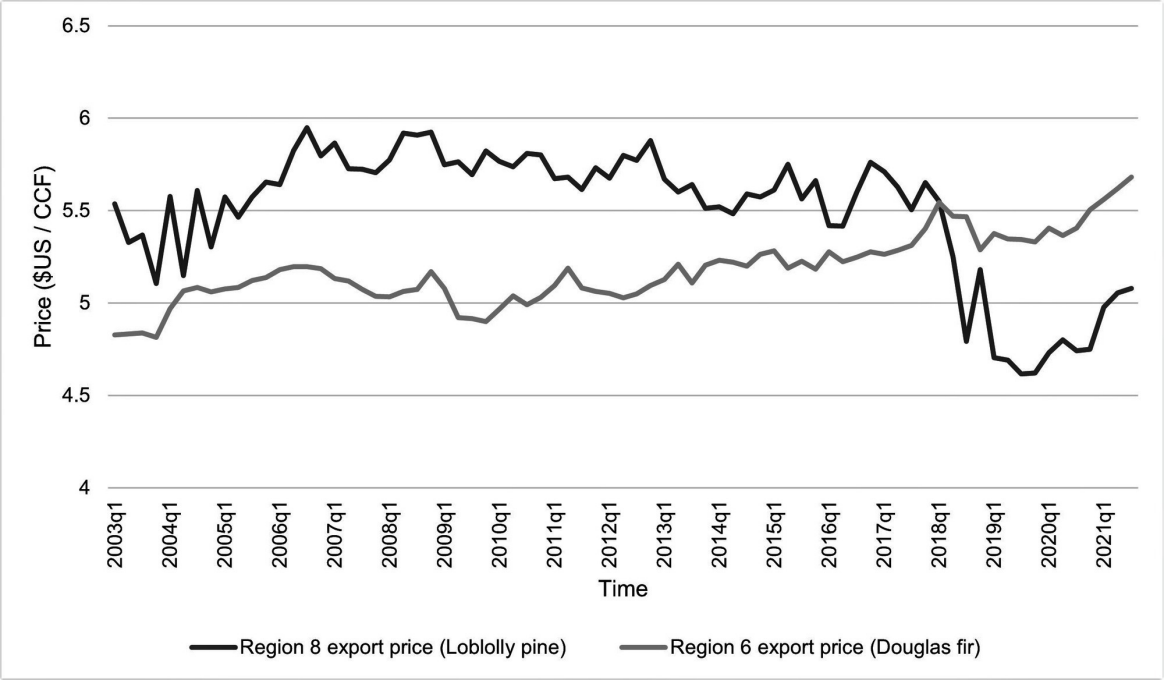
NH
ME
HI
AK
PR
USDA Forest Service Regions
Alaska Region (Region 10)
Eastern Region (Region 9)
Intermountain Region (Region 4)
Northern Region (Region 1)
Pacific Northwest Region (Region 6)
Pacific Southwest Region (Region 5)
Rocky Mountain Region (Region 2)
Southern Region (Region 8)
Southwestern Region (Region 3)


Sales quantity (CCF)
Share of total sales volume (%)
250
200
150
100
50
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2003 Q1
2004 Q1
2005 Q1
2006 Q1
2007 Q1
2008 Q1
2009 Q1
2010 Q1
2011 Q1
2012 Q1
2013 Q1
2014 Q1
2015 Q1
2016 Q1
2017 Q1
2018 Q1
2019 Q1
2020 Q1
2021 Q1
Region 8 total sale quantity (Loblolly pine)
Region 6 total sale sale quantity (Douglas fir)
Region 6 salvage wood % (secondary axis)
Region 8 salvage wood % (secondary axis)


9
8
7
6
5
4
3
2
1
0
Price ($US / CCF)
2002q3
2003q3
2004q3
2005q3
2006q3
2007q3
2008q3
2009q3
2010q3
2011q3
2012q3
2013q3
2014q3
2015q3
2016q3
2017q3
2018q3
2019q3
2020q3
Time
Region 6 bid price median (Douglas fir)
Region 6 bid price average (Douglas fir)
Region 8 Bid price median (Loblolly pine)
Region 8 Bid price average (Loblolly pine)


6.5
6
5.5
5
4.5
4
Price ($US / CCF)
2003q1
2004q1
2005q1
2006q1
2007q1
2008q1
2009q1
2010q1
2011q1
2012q1
2013q1
2014q1
2015q1
2016q1
2017q1
2018q1
2019q1
2020q1
2021q1
Time
Region 8 export price (Loblolly pine)
Region 6 export price (Douglas fir)