A Nonlinear Asymmetric Model of Lumber Price Transmission

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Suggested citation format:
Davis, J. and M. K. Adjemian. 2023. "A Nonlinear Asymmetric Model of Lumber Price Transmission." Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. [http://www.farmdoc.illinois.edu/nccc134].

“A Nonlinear Asymmetric Model of Lumber Price Transmission”

James Davis[*], Michael K. Adjemian[†]

June 16, 2023

Abstract

The housing supply chain requires a constant supply of lumber products. Yet, even as housing and lumber prices have grown throughout the past decade, the underlying value of timberland remains low. We use monthly and quarterly price and inventory data to estimate a nonlinear autoregressive distributed lag model of the complete timber-lumber-housing supply chain. Our methodology builds on previous lumber price studies by developing a less rigid framework for identifying nonlinear asymmetric relationships between end-use, product, and factor prices, when controlling for inventories. Our results show that in the long-run a 1% increase is housing prices corresponds to a 0.28% (95%–C.I.: 0.03%;0.53%) increase in lumber prices. Negative shocks to housing have no significant effect on lumber prices. Furthermore, we find that lumber and stumpage are only marginally cointegrated with positive and negative shocks to lumber having no significant effect on stumpage prices.

Keywords: Vertical Price Transmission, Nonlinear Autoregressive Distributed Lag Model, Forest Policy

Econ Lit Codes: Q18, Q23, & L73

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1 Introduction

Vertical price transmission analysis is a useful tool in examining how changes to governmental policies affect each stage of the supply chain. For instance, since the 1950s, U.S. forest policy pursued region specific strategies with regard to timber production, e.g. restricting harvests in the West and promoting a more efficient plantation model in the South. These policies fundamentally transformed how and where Americans get their wood products, and equally important, how the owners of timberland and the manufacturers of wood products benefit from exogenous shocks to consumer demand from their end-uses (e.g. housing, industrial pallets, etc.). We assess the contention that the ample wood basket of the South, spurred into existence by federal policy and market conditions, insulate the owner of timberland from price shocks to housing and finished lumber markets. We focus on housing as our primary wood product market, since it represents the greatest proportion of total consumption. We add to the price transmission literature by considering the entire supply chain of softwood lumber from standing trees to finished framing lumber, which is used in new home construction. Using monthly price and inventory data from January 1992 to August 2021, we use a nonlinear asymmetric framework that decomposes positive and negative price shocks between markets, from which we estimate the long-term elasticities between housing and finished lumber. Using quarterly data from first quarter of 1992-Q1 to second quarter 2021-Q2, we also estimate long-term elasticities between lumber and harvestable timber (i.e. stumpage).

We adapt the nonlinear autoregressive distributed lag model (NARDL) developed by Greenwood-Nimmo and Shin (2013) to estimate price transmission from the housing market to lumber, and then from lumber to stumpage. A NARDL modeling approach confers several econometric advantages over traditional threshold vector correction models. We estimate the housing-lumber model with monthly data and the lumber-stumpage model with quarterly data. Our estimated results show that positive housing price shocks significantly affect wholesale lumber markets, while negative price shocks do not. Further, we find that when we control for lumber inventories positive and negative shocks to the softwood lumber price do not pass through to stumpage owners. Our results also support previous findings by Haynes (1977) and Merrifeld and Haynes (1984). These studies found that stumpage demand is more inelastic than lumber demand, so that lumber prices respond more readily to price changes than stumpage prices along the supply chain. Our findings suggest that timberland owners should diversify how they market their timberland so as to maximize its value in the face of price transmission asymmetry.

2 Historical Background

The spatial composition of the softwood lumber industry changed dramatically in response to substantive reforms in U.S. forest policy. Until the 1990s, the Western United States was the largest lumber producing region. For example, from 1960s till the late 1970s, 55% of all lumber produced in the United States came from the West. Old-growth timber accounted for much of this production, sourced from federally owned lands in the Pacific Coast region (i.e. Washington, Oregon, and California). In the 1980s, the proportion of lumber coming from the West decreased to just under half of total production, because of declining levels of timber from public lands and increasing levels of production in the South. In the early 1990s, the federal government removed large areas of public timberlands from harvest further decreasing western production. In 1990, the South became the nation's wood basket, accounting for 35% of all softwood lumber and 80% of all hardwoods (Howard, 2007). Subsequently, softwood lumber production in the South continued to increase reaching a peak in 2005. After 2005, with the advent of the Great Recession, lumber production declined across all regions as housing demand fell. Since 2011, production rebounded across all regions, with the South still dominating production (Howard and Liang, 2019). Figure 1 depicts these trends.

Lumber consumption in the United States in 2020 for all uses totaled more than 54.7 billion board feet (BBF) (see figure 1), an increase of 17.0 BBF since 2009 at the low point of the great recession. Lumber consumption since 2009 increased in each of the last 12 years.

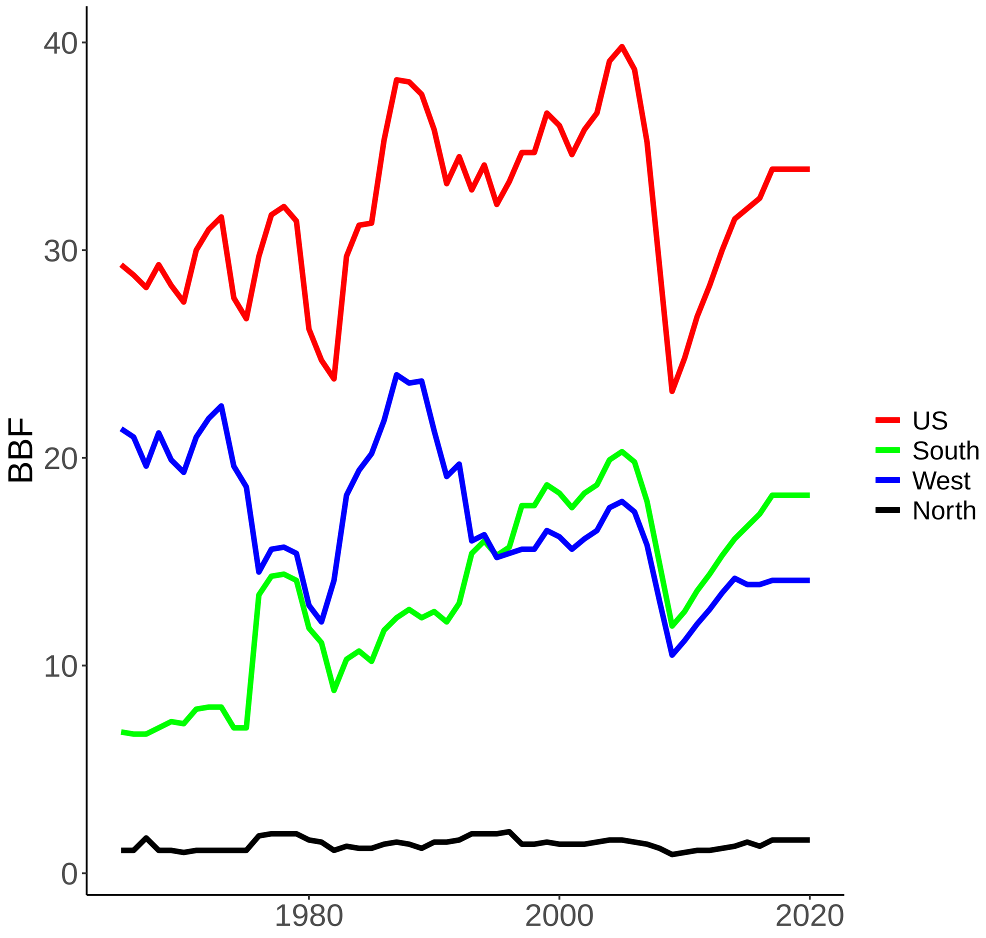

Figure 1: U.S. Total Softwood Lumber Production by Region 1965-2019
Source: Howard and Liang, 2019

Lumber consumption peaked at 74.5 BBF in 2005, a record high that even exceeded 1900 levels, when lumber was the most important raw material used in the United States for construction, manufactured products, and shipping (Howard and Liang, 2019).

The primary driver behind this year after year consumption growth is home construction, renovation, and maintenance. In fact, about 69% of the softwood lumber consumed in 2017 was used for housing, with 30% for the construction of new units and 39% of consumption for the upkeep and improvement of existing units. The Western Wood Products Association (WWPA) estimates that new nonresidential construction accounted for about 11.1% of consumption. Lumber consumption used for shipping (pallets, containers, etc.) accounted for 13.8%. The remaining 6.1% was for all other uses (WWPA, 2018; Howard and Liang, 2019). In 2017, softwood species made up approximately 98% of the domestic lumber production used in new housing. A decline in hardwood flooring and rapid increase in house size lead to the increase in the percentage of softwood lumber consumed by housing. Even with the heterogeneity in the different end use markets, softwood lumber consumption as a percentage of total lumber consumption has remained around 86% since the 1960s (Howard and Liang, 2019).

Given the established link between softwood lumber and housing market trends, it is unsurprising that the upward trajectory observed in lumber production and consumption directly coincides with an expanding housing market. For instance, since the Great Recession, single-family housing starts almost doubled, increasing by 97%. Furthermore, multifamily housing starts also increased by 99% since 2011. Another important industry measure of home builder expectations is new approved housing units. In December 2021, new approved housing units peaked at more than 1.8 million units, a 29% increase from December 2019 (FRED, 2022). Timely completion of new home construction requires a consistent supply of lumber. In fact, strong housing demand pushed framing lumber prices up, driving mills (primarily in the South) to expand production creating more inventory. The National Association of Home Builders estimates that for 2021 the average price of a new single-family home increased by more than $18,600 due to framing lumber costs (Emrath, 2022). As a result, the national average price to build a home increased significantly (Kilroy, 2021). Figure 2 shows the monthly median price of approved housing units and total merchantable wholesale lumber inventory from 1992 to 2021. The correlation between new approved housing unit prices and lumber inventory is stark. Between 2005 and 2009, housing prices and lumber inventories ballooned before a significant decline in the aftermath of the Great Recession. Since 2011, prices and inventories followed a positive linear trend, with a brief interruption due to the COVID-19 pandemic. Subsequently, housing and lumber inventories resumed an exponential growth trend.

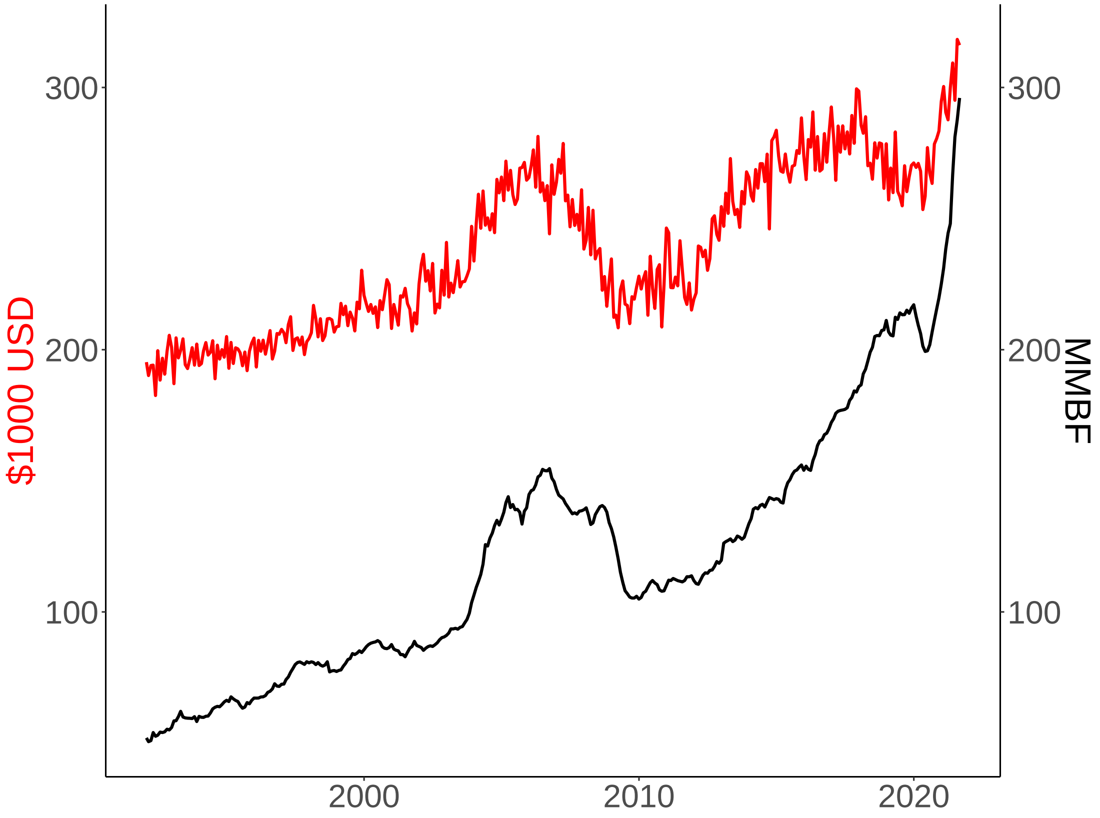

Figure 2: Monthly Wholesale Lumber Inventories (black) & Median New Housing Prices (red) 1992-2021

Source: Bloomberg (2021) & Census Bureau (2022)

Note: Median New Housing Prices are deflated using the FRED CPI series for City-Housing Residential at base month-year, January 2012.

The cost-sharing initiatives implemented through the Conservation Reserve Programs

(CRP) increased the number of trees planted after 1988. Given the life-cycle of softwood species, the trees planted in the late 1980s only began to produce sawtimber (i.e. timber of desirable dimensions for lumber productions) during the Great Recession. Hence, many landowners delayed the harvest of their timber because of low housing prices following the housing market collapse (Maggard and Zhang, 2021). The combination of these factors resulted in a serious oversupply of standing timber across the South. The oversupply of timber is the primary cited reason for the decline in stumpage prices observed in figure 1, according to data from Timber-Mart South (TMS). In contrast, given the significant changes in the housing market, lumber prices were considerably more volatile during this period, according to Federal Reserve Economic Database (FRED). However, in May 2021, lumber prices peaked at over \$1000 per thousand board feet (MBF), an almost 250% increase from the year prior, while stumpage prices remained unchanged over that same time frame (Trading Economics, 2023). Figure 1 displays these trends using the Softwood Lumber Price Index from the Federal Reserve Economic Database (FRED).

Figure 3: Quarterly Stumpage Prices & Lumber Price Index
Source: TMS (2022) & FRED (2022)
Note: Stumpage prices are deflated using the Logging PPI series from FRED at base year-quarter, 2012-Q1. Similarly, Softwood Lumber Price Index is re-based from 1986-Q1 to 2012-Q1.

The disconnect between stumpage (input factor) and lumber (product) markets is traditionally understood in the context of derived demand theory (Tomek and Robinson, 1990). Stumpage is the primary factor of production and lumber is the most consumed value-added product. Therefore, if the demand for the product increases, ceteris paribus, the factor price increases as does the quantity produced. The resulting adjustment process culminates, when factor and product markets stabilize (i.e. reach new factor and product equilibriums). Under this framework, the price of the factor is positively affected by the price of product. Moreover, an asymmetric effect is possible, given the abundant supply of standing timber, low product market concentration, and the volatility in housing demand over time.

2.1 Federal Restrictions in the West

The South supplanted the West as the nation's wood basket, owing partially to the environmental restrictions implemented there by the federal government. The most significant, which we highlight here, was the federal action to preserve critical animal species. The specific prescriptions adopted included efforts to protect the habitat of the Northern Spotted Owl on federal lands as mandated by the Endangered Species Act of 1973 (ESA). To preserve the owl's habitat, the federal government proposed changes in forest management in 1986, but these changes were litigated in federal court (Wear, 1998; Wear and Murray, 2004; Riddle, 2022). As a result, the court placed a moratorium on a significant portion of the national forest timber sale program in the West in 1989. Legal issues continued until the 1993 "Forest Summit," lead by President Clinton and a subsequent federal forest plan. These forest plans adopted complex Planning Rules for management of federal forest lands. The Planning Rules are based on the economic principle of maximum sustainable yield and mandate consideration of non-timber multiple-use products sourced from forest lands (e.g. amenity value, carbon sink, and environmental protection). These rules resulted in an immediate impact on the amount of timber harvested from these lands. For example, prior to this policy change, annual harvests had risen from the 1950s through the 1980s, sometimes exceeding 10 BBF. However, following 1989, timber production from federal lands decreased year after year. Specifically, timber sales volumes from western federal forests in 1989 amounted to only 70 percent of sales in 1988. By 1995, timber sales volume dropped to 15 percent of the 1986 peak production levels. Annual harvested volumes continued to decrease in the early 1990s and remained between 1.8 and 2.8 BBF since 2003. In 2018, harvests from federal land was 2,8 BBF. In the aggregate, 15% of total U.S. timber production was harvested from federal lands in 1991. Since 2011, the share of timber harvested from federal lands is less than 2% (Riddle, 2022).

Of the 765 million acres of timberland, in the U.S. the Forest Service manages 96.1

million acres and the Bureau of Land Management (BLM) manages 6.1 million acres. Most of this productive timberland ($\approx 75\%$) is concentrated in the 15 Western states (Vincent et al., 2019; Riddle, 2022). Conversely, the South's timber landscape is dominated by private owners (90%). Roughly 20% is held by corporations that own wood-processing facilities, but the large majority is held by nonindustrial entities. This category includes Timber Real Estate Investment Trusts (or REITS), which offers investors access to a relatively stable asset class with higher avreage returns and less correlated with other investments than the wider stock market (Charles Schwab, 2023). Besides the difference in the composition of timberland ownership, in the South, harvests are more predominantly derived from agricultural forestry, with forests growing on shorter (20- to 30-year) rotations. The Forest Service Southern Region and land grant university research spurred the advancement of applied agroforestry in the South. We detail the institutional support and market incentives that enables the south to overtake the West in the next section.

2.2 Federal Support and Market Incentives in the South

A confluence of factors contributed to the expanded softwood production of the South. Pine species predominate due to their short rotation periods and suitability in the Southern climate and soils. In addition, the productivity gains from Southern land grant university research trials contributed significantly to increasing pine wood production. Before the 1970s, for instance, the South had only 1.8 million acres of pine plantations. And, in 2000, the South had over 32 million acres. Moreover, by one measure of yield, the mean annual increment[1] (MAI), pine plantations in the South more than doubled the MAI in the region.

From the end of the Civil War through World War II, large amounts of agricultural land was abandoned throughout the South due to declining soil fertility, low prices for the major cash crops, and pest infestations (e.g. the boll weevil plague for cotton production). As a result, the South has a significant proportion of cleared land ripe for reforestation. Concurrently, the Southern pulp and paper industry was revitalized, providing a consistent market for softwood timber (Reed, 1995; Fox et al., 2004). This reforestation required an abundant supply of quality seedlings. The Forest Service lead a concerted research effort, producing a series of informative monographs, detailing practical techniques on the planting and establishing of pine stands (Fox et al., 2004). The monographs provided foresters comprehensive information on seed collection and processing, seedling production, and planting requirements as well as a widely used grading system for determining the quality of seedlings. Subsequently, the survival rates of seedlings increased on plantations across the South. Selective breeding programs also improved the genetics in new seedlings. Breeding programs focused on improving volume growth (i.e. timber yield), tree form (e.g. desirable straight trees with few limbs), disease resistance, and wood quality (Zobel and Talbert, 1984).

In conjunction with improved seed genetics and establishment practices, Southern foresters developed site preparation strategies for pine. Removal of residual residues, followed by

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[1] The average growth per year a stand of trees has exhibited up to a specified age.

tillage for soil preparation, became the standard practice to limit competition from hardwood species (Fox et al., 2004). However, productivity of successive rotations can decline under intense site preparation post-harvest. Then, the challenge becomes determining the amount of soil tillage required to achieve optimal seedling establishment by not removing most of the organic matter from the soil (Dyck and Cole, 1994).

Concurrent with the push for the adoption of intense site preparation, research institutions also advocated fertilization with diagnostic testing to ensure effectiveness. In the late 1960s, the Cooperative Research in Forest Fertilization (CRIFF) Program at the University of Florida and North Carolina State Forest Fertilization Cooperative was established. CRIFF developed a rigorous soil classification system to determine the likelihood of obtaining an economic growth response from fertilization, which was widely adopted throughout the South (Fisher and Garbett, 1980). This new method of forestry increased productivity from site-specific applications of modern silviculture techniques. The effect was immediate. For example, the rate of nitrogen and phosphorus application increased from 15,000 acres annually in 1988 to 975,000 acres in 2000 (Fox et al., 2004). The economic impact of fertilization were significant. Fox et al. (2007) found that mid rotation fertilization yields an internal rate of return (IRR) of 16%, assuming an average growth response from fertilization and fertilizer costs of $90 per acre.

Competition from hardwood species is the most detrimental factor in pine plantation establishment. Nevertheless, chemical site preparation declined throughout the 1970s and 1980s because of government limitations on herbicide use and difficulty accessing sites for chemical application (Fox et al., 2007). Yet, even as pesticide use declined, advances in plant breeding filled the gap. For example, McKeand et al. (1997), Jansson and Li (2004), and Bettinger et al. (2009) show that the use of clonal plant breeding from high-producing genotypes developed within a certain ecosystem improves the economics of pine plantations and increases their overall resiliency to pests and climate.

Government programs have also kept pace with technological advancements in pine production. In 2010, the National Resource Conservation Council (NRCS) piloted a program to incentivize the production of Longleaf Pine across the Southeastern United States. Under the Longleaf Pine Initiative (LLPI), NRCS works with timberland owners to establish Longleaf Pine plantations by subsidizing a significant portion of establishment costs and providing technical assistance to foresters. As a result, by 2021, NRCS has contracted over 870,000 acres under LLPI in almost 10,000 producer contracts (NRCS, 2021).

2.3 Lumber Market Concentration

The capacity of the top 10 U.S. softwood lumber producers is 22.8 BBF. They represent over half (52%) of the total softwood lumber production capacity in the U.S. (see figure 3). Capacity of the top 10 firms increased by 3.9 BBF since 2017 and by 0.5 BBF since 2019 alone. Nevertheless, the actual total production of the top 10 producers is only about 50% of the U.S. total (figure 1). In fact, each of the top 10 producers had at least 1 BBF in productive capacity in 2021.

Business activity in the U.S. softwood lumber industry is characterized by volatility due to the low level of firm concentration and a high dependence on sales from the domestic construction industry (United States International Trade Commission, 1999; Mehrotra et al., 2014; Howard and Liang, 2019). The softwood lumber industry is the largest U.S. forest sector industry by timber volumes processed and employment generated (Howard, 2007; Howard and Liang, 2019; Forisk, 2021). In 2007, there were approximately 1,700 softwood sawmill establishments in the United States, employing about 50,000 employees. Following the downturn in housing demand and the oversupply lumber inventories, the number of softwood mills declined to less than 990. In addition, employment numbers fell as firms scaled back production and adopted more efficient technology (Howard and Liang, 2019). Hence, the sector is now characterized by a proliferation of small-scale operations, with approximately 55 per-

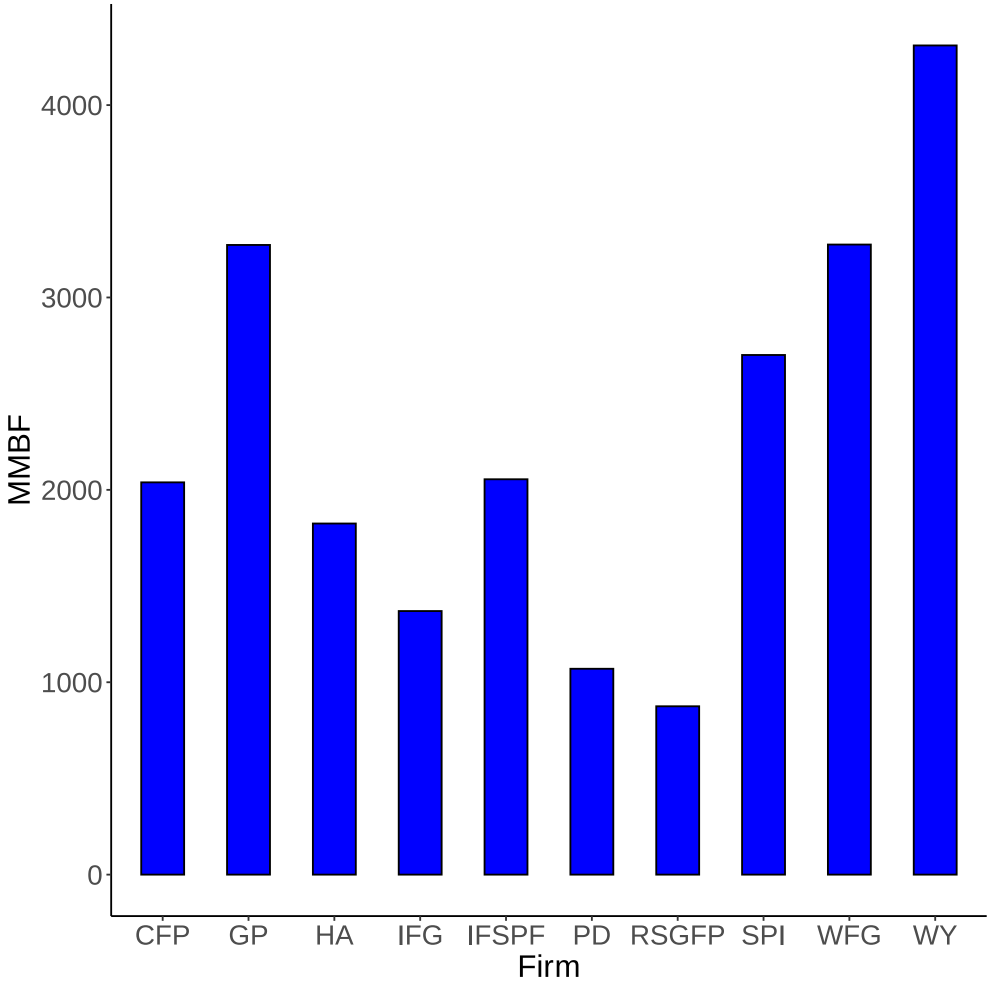

Figure 4: Top 10 Lumber Producers by Productive Capacity 2021
Source: Forisk 2021

cent establishments employing fewer than 20 employees (Spelter et al., 2009; Mehrotra et al., 2014; Riddle, 2022). It is also characterized by a significant concentration of demand for its output, with residential construction (including repair and remodeling) accounting for about 60% of domestic consumption and an additional 10% (approximately) used for nonresidential construction (Howard and McKeever, 2011; Howard and Liang, 2019). Thus, the value-added lumber market is highly competitive, where many firms compete away any arbitrage opportunities that arise. Therefore, sudden changes in consumer lumber consumption are more directly felt by lumber producers compared to timberland owners (Mehrotra et al., 2014). Empricially, Haynes (1977), Zhou and Buongiorno (2005), and Sun (2011) support this finding, using traditional vertical price transmission models. These studies find consistently that the derived demand for stumpage is less elastic than the lumber demand.

Concentration in the U.S. stumpage market is, on the other hand, region specific. In 2019, Forest2Market completed a comprehensive analysis of the spatial characteristics of U.S. timberland. In particular, they found that 74% of all timberland is privately-owned while only 26% is publicly-owned. Figure 5 breaks down the share of public and private timberland by region. In contrast, a majority of timberland in the Northwest is publicly owned. Private ownership dominates the Northeast and Appalachia, with almost parity in the Midwest. This feature of timberland ownership in the South confers a comparative advantage with regard to property rights. For example, private timberland owners are not held to the Planning Rules under the various federal forest plans.

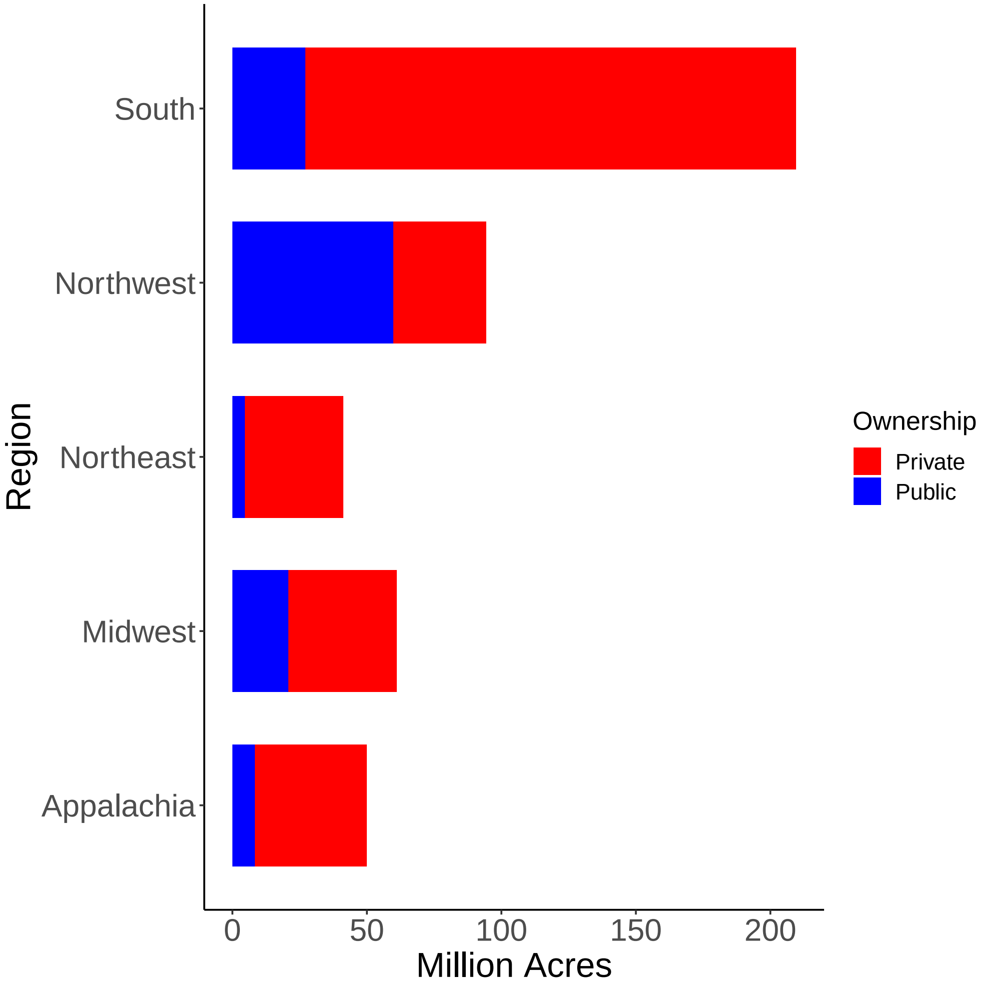

Figure 5: Public & Private Timberland Ownership by Region
Source: Forest2Market (2019)

Timberland owners who wish to establish a softwood pine plantation can pursue production plans that employ yield maximizing techniques such as fertilization, intense site preparation, increased planting densities and periodic chemical pesticide treatments. The application of these techniques increased the output of sawtimber from private timberland in the South relative to publicly owned timberland in the West. In response, lumber producers shifted investment in new sawmills from the West to the South. In 2020, according to the Forestry Inventory Analysis (FIA) Database, of 1560 total producing mills in the South, 240 were primarily devoted to milling softwood sawtimber. In contrast, there were only 51 mills in the Northwest milling softwood sawtimber (FIA, 2020).

3 Relevant Literature

Numerous studies evaluate price transmission in lumber markets. A review of this literature reveals two key factors. One factor is that the standard econometric models used are relatively inefficient, compared to recently proposed nonlinear asymmetric models. Second, linearity is assumed for price shocks between contintegrated price series, a rather strong assumption. Linear models of price transmission in the literature include Zhou and Buongiorno (2005) and Luppold et al. (2014). Ning and Sun (2014) use an Engle and Granger two-step vector error correction model (VECM) to estimate the asymmetric cointegration relationship between stumpage and lumber prices. Their results show that in terms of spatial price transmission the South shows slightly stronger market cointegration than the West. In addition, they find significant asymmetric price transmission between stumpage and delivered timber prices as well as between delivered/lumber prices. Parajuli and Chang (2015) employ a multivariate time-series approach to estimate an unrestricted Johansen VECM of price transmission between finished lumber and stumpage. Using Louisiana sawtimber data, they find that softwood inventory has near unit elasticity compared to the own stumpage price elasticity, which was highly inelastic. Therefore, inventories responded in greater magnitude to lumber price changes than downstream prices and at a greater speed. Other notable studies of lumber price transmission that use less efficient models (such as Threshold VECM) but relax the linearity assumption include (Sun , 2011; Sun and Ning, 2014; Yang et al., 2020; and Wang et al., 2021).

A major criticism of the Engle and Granger and Johansen approaches is that the NARDL approach is more advantageous, econometrically (Greenwood-Nimmo and Shin, 2013; Shin et al., 2014). First, it performs better with small samples compared to alternatives. Second, it is more efficient. Third, it does not require the restrictive assumption that all series are integrated of the same order allowing for the inclusion of both I(0) and I(1) series in a long-run relationship. Finally, it relaxes the assumption implied by linearity that adjustments be symmetric in the long and short run.

There are several empirical studies that employ the NARDL model in agricultural commodity price analysis. Fousekis et al. (2016) analyzes price asymmetry along the beef supply chain. They find significant asymmetry between farm, wholesale, and retail price levels. Chowdhury et al. (2021) estimates a NARDL model for energy and food commodities. Their results show that energy prices have an asymmetric effect on food prices. In particular, a positive shock in energy prices has a more pronounced effect on agriculture commodity prices than a negative shock. Ali et al. (2022) estimates the short- and long-run elasticites between renewable energy prices and environmental quality in South Africa. They find that renewable energy prices have a positive short- and long-run effect on environmental quality.

4 Data

For our analysis, we use monthly U.S. price and inventory data for new housing units and softwood lumber from FRED, Census Bureau, and Bloomberg. Median new housing unit prices are deflated by the FRED consumer price index (CPI) for city-housing residential. All prices are further expressed in January, 2012 dollars. We also collect average 30-year fixed rate mortgage data from FRED to account for the cost of home purchase borrowing. Table 1 presents the summary statistics for each of our monthly series.

Table 1: Monthly U.S. Lumber-Housing Data from Jan-1992 to August-2021

Statistic	Name	Mean	St. Dev.
Approved Housing Units (1,000 units)	*new_builds*	1,350	412
Nominal Median New Home Price ($)	*hous_price*	222,347	70,122
Real Median New Home Price ($)	*hous_price*2012	238,172	30,798
30-Year Fixed Rate Mortgage Avg. (%)	*mort_rates*	5.76	1.70
Wholesale Lumber Inventories (MMBF)	*inven*	12,158	4,918
Softwood Lumber Price Index	*SPLI*_2012	123.46	31.82

Source: FRED (2022), Census Bureau (2022), & Bloomberg (2021)
Note: All real prices are expressed in Jan-2012 dollar terms. Home Prices are deflated using the FRED CPI series for City-Housing Residential. $N = 356$ observations.

Table 2 presents the summary statistics for our quarterly lumber and stumpage market data, including the south-wide average softwood stumpage price. To create quarterly series for the U.S. lumber price index and inventories, we average over the months corresponding to each quarter. For example, the first quarter lumber price index in 1992 is the average of the monthly values from January to March. Quarterly stumpage prices are sourced from Timber-Mart South. We deflated this series using the producer price index (PPI) for logging equipment from FRED. All prices for the quarterly data reflect 2012-Q1 dollars.

Table 2: Quarterly Stumpage-Lumber Data from 1992-Q1 to 2021-Q2

Statistic	Name	Mean	St. Dev.
Nominal South-Wide Average Softwood Stumpage Price ($/ton)	*stump*	30.70	6.58
Real South-Wide Average Softwood Stumpage Price ($/MBF)	*stump*_2012*MBF*	26.61	6.49
Softwood Lumber Price Index	*LPI*	122.98	30.83

Source: FRED (2022) & TMS (2022)
Note: All prices are expressed in 2012-Q1 terms. Stumpage prices are deflated using the FRED Logging PPI series. $N = 118$ observations.

Next, we determine whether or not our price series contain a unit root. First, we take the first difference of our logged price series. Then, we perform Augmented-Dicky Fuller (ADF) tests along with Phillips-Perron (PP) tests. Our test results are shown in table

3. We reject the null hypothesis of the presence of a unit root in each of the three price series for both the ADF and PP test statistics. The results suggest that prices along the stumpage-lumber-housing supply chain are I(1).

Table 3: Unit Root Tests on Stumpage-Lumber-Housing Price Data (1992-2021)

Series	ADF Test Statistic	Phillips-Perron Test Statistic
$SPLI\_2012$	-3.22	-3.34
$hous\_price2012$	-6.18^{***}	-7.46^{***}
$stump$	-3.25	-3.27
$\Delta\ln(SPLI\_2012)$	-12.03^{***}	-10.63^{***}
$\Delta\ln(hous\_price2012)$	-33.57^{***}	-42.43^{***}
$\Delta\ln(stump)$	-9.18^{***}	-9.09^{***}

Note: *** signifies p-values less than 0.01 α-level. ** signifies p-values less than 0.05 α-level.

5 Theoretical Model

Gardner (1975) showed under what assumptions a marketing margins approach of price relationships for factor and product prices is appropriate. In general, under zero elasticity of substitution between factors the approach is valid. That is, factors are transformed into product at fixed rates. Haynes (1977) argues this is not an unreasonable assumption given the rather inflexible nature of forestry technology and timber harvesting. As a result, marketing margins between stumpage and lumber are typically modeled using one of three assumptions: (1) constant percentage markup, (2) linear in product prices, (3) a fixed coefficient regression model. Merrifield and Haynes (1984) estimate supply, demand, and price transmission elasticities for Pacific Northwest lumber and stumpage. They find that stumpage demand is more inelastic than lumber demand and find evidence to suggest that there is substitution between labor and capital at the factor market level[2]. One extension

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[2] Lewandrowski et al. (1994) develops a structural model of lumber markets that accounts for inventories. They estimate their model using simultaneous equation methods and find that short-run vs. long-run inventory parameters have significant opposite effects on lumber supply and price expectations

to this modeling framework is to account for the influence of inventories.

Equation (1) adapts the regression model for lumber-stumpage marketing margins to include inventories. We denote m as the marketing margin; p^x represents the product price; and p^a represents the factor price. β describes the linear relationship between product and factor prices. γ denotes the linear relationship between inventories and price markups. ϕ represents nonlinearities between prices and inventories. We let $\gamma > 0$ and $0 < \phi < 1$.

$$\begin{aligned} p^x &= p^a + m \\ m &= \beta p^x + \gamma I^{\phi}. \end{aligned} \tag{1}$$

Comparative statics for product and factor prices quickly show that:

$$\begin{aligned} \frac{\partial p^x}{\partial I} = \gamma\phi I^{\phi-1} > 0 \quad \text{and} \quad \frac{\partial^2 p^x}{\partial I^2} = \gamma\phi(\phi-1)I^{\phi-2} < 0\,, \\ \frac{\partial p^a}{\partial I} = \gamma\phi I^{\phi-1} < 0 \quad \text{and} \quad \frac{\partial^2 p^a}{\partial I^2} = \gamma\phi(\phi-1)I^{\phi-2} > 0. \end{aligned} \tag{2}$$

Hence, product prices grow with inventories at a decreasing rate, while factor prices decrease as inventories grow at an increasing rate. We can now examine the elasticity of price transmission by rearranging (1) and examining how it changes from one time period (i) to the next:

$$\begin{aligned} p^a &= \beta p^x - \gamma I^{\phi}\,, \\ p^a_i &= p^a_{i-1} + \beta(p^x_i - p^x_{i-1}). \end{aligned} \tag{3}$$

If we normalize the product price to 1 and solve for the price ratio, we have an expression for the elasticity of price transmission (η):

$$\eta = \left(\frac{1 - p^a_i}{\gamma}\right)^{\frac{1}{\theta}}. \tag{4}$$

Therefore, by assuming prices are a nonlinear function of inventories, the resulting price transmission elasticity is primarily a function of inventory response parameters and the stumpage price.

6 Empirical Framework

The NARDL(p, q) is obtained for two time series $\{y_t, x_t\}$, where y_t is downstream prices and x_t is the upstream price, by partitioning x_t into positive and negative partial sums and combining the resulting long-run equilibrium relationship with the standard linear ARDL(p, q):

$$\begin{aligned} \Delta y_t = a_0 + \rho y_{t-1} + \theta^+ x^+_{t-1} + \theta^- x^-_{t-1} + \gamma z_{t-1} + \sum_{j=1}^{p-1} a_j \Delta y_{t-j} + \sum_{j=0}^{q-1} (\pi^+_j \Delta x^+_{t-j} + \\ \pi^-_j \Delta x^-_{t-j}) + \epsilon_t \,, \\ \text{s.t.} \qquad x^+_t = \sum_{j=1}^{t} \Delta x^+_j = \sum_{j=1}^{t} \max(\Delta x_j, 0) \,, \\ x^-_t = \sum_{j=1}^{t} \Delta x^-_j = \sum_{j=1}^{t} \min(\Delta x_j, 0). \end{aligned} \tag{5}$$

We estimate two equations of the above form: (1) wholesale lumber → stumpage; and (2) new housing prices → wholesale lumber. In equation (5), the nonlinear long-run asymmetric relationship is given by $\theta^+ x^+_{t-1} + \theta^- x^-_{t-1}$, where x^-_t an x^+_t are the negative and positive partitions of the partial sums. z_{t-1} is a vector of controls including the average 30-year fixed rate mortgage and lumber inventories, and lagged differences for y_t are included to account for seasonals and trends. π^+_j, π^-_j are the asymmetric distributed-lag parameters, and ϵ_t is an i.i.d. process with zero mean and constant variance, σ_ϵ. Our estimated models are then:

$$\begin{aligned}\Delta SPLI\_2012 = a_0 + \rho SPLI\_2012_{t-1} + \theta^+ hous\_price^+_{t-1} + \theta^- hous\_price^-_{t-1} + \\ \sum_{l=0}^{L}(\gamma_{1,l} mort\_rate_{t-l} + \gamma_{2,l} new\_builds_{t-l}) + \sum_{j=1}^{p-1} a_j \Delta SPLI\_2012_{t-j} + \\ \sum_{j=0}^{q-1}(\pi_j^+ \Delta hous\_price^+_{t-j} + \pi_j^- \Delta hous\_price^-_{t-j}) + u_{1t}.\end{aligned} \tag{6}$$

And,

$$\begin{aligned}\Delta stump = a_0 + \rho stump_{t-1} + \theta^+ LPI^+_{t-1} + \theta^- LPI^-_{t-1} + \\ \sum_{l=0}^{L}\gamma_{1,l} inven_{t-l} + \sum_{j=1}^{p-1} a_j \Delta stump_{t-j} + \\ \sum_{j=0}^{q-1}(\pi_j^+ \Delta LPI^+_{t-j} + \pi_j^- \Delta LPI^-_{t-j}) + u_{2t}.\end{aligned} \tag{7}$$

The long-run relationships for positive and negative shocks are defined by:

$$\begin{aligned}\beta^+ = -\frac{\theta^+}{\rho}, \\ \beta^- = -\frac{\theta^-}{\rho}.\end{aligned} \tag{8}$$

7 Results & Discussion

We estimate the housing→lumber model in (6) by least squares. The results are shown in table 4. The calculated t-stat for $\hat{\rho}$ is significant at 0.01 α-level, indicating we can reject the null hypothesis of no cointegration. In addition, the diagnostic F-test developed by Pesaran et al. (2001) is significant at 0.01 α-level, so we can reject the null hypothesis of no cointegration ($\rho = \theta^+ = \theta^- = 0$). In fact, we find a significant cointegration relationship with respect to positive shocks to home prices, according to the significant t-statistic for θ^+. We also conduct a standard Wald test for short- and for long-run asymmetry. The test for long-run asymmetry assumes a null of symmetry in the long-run price transmission elasticities ($\beta^+ = \beta^-$). In the short-run version, the null assumes $\pi_j^+ = \pi_j^- \forall j = 1, \cdots, q-1$. For the estimated model, we fail to reject the null of symmetry in the short-run, but reject the null for the long-run version. Finally, we find amongst our controls only new housing units has a significant positive short-run effect on lumber prices.

Table 4: Estimated NARDL Results: Housing → Lumber (Monthly, 1992-2021)

Coefficient	Estimate	S.E.	t-stat	p-value
Intercept	0.08	0.08	0.94	0.94
$\hat{\rho}$	0.39	0.05	7.40	$<0.01^{***}$
$\hat{a}_1$	-0.68	0.09	-7.67	$<0.01^{***}$
$\hat{a}_2$	0.22	0.06	3.50	$<0.01^{***}$
$\hat{\theta}^+$	-0.11	0.05	-2.28	0.02^{**}
$\hat{\theta}^-$	0.002	0.10	0.02	0.98
$\hat{\gamma}_{1,0}$	-0.006	0.004	-1.5	0.13
$\hat{\gamma}_{2,0}$	0.042	0.01	3.6	$<0.01^{***}$

Note: *p<0.1; **p<0.05; ***p<0.01

$N = 356$ observations.

Residual standard error 0.043 on 344 DF; Adjusted-R^2 0.24

Pesaran et al. (2001) cointegration test F-statistic I(1): 13.53^{***} on 8 and 344 DF

Wald test for short-run asymmetry test statistic: 1.24

Wald test for long-run asymmetry test statistic: 8.15^{**}

From (8), we now calculate the long-run price transmission elasticities for housing prices and new housing units. Point estimates, standard errors, and asymptotic Wald 95% confidence intervals are shown in table 5. We find that a 1% increase in median new housing prices corresponds to a 0.28% (95%–C.I.: 0.03%;0.53%) increase in lumber prices. This results supports the correlation in housing prices and lumber inventories we observed in figure 2. That is lumber manufacturers take advantage of large inventories to capture long-run positive trends in housing prices and insulate themselves from negative housing price shocks -0.004% (95%–C.I.: -0.49%;0.49%). New housing inventories have a significant negative effect on lumber prices. We interpret this result to reflect the fact that more new housing units increases the supply of housing so that demand for new homes is decreasing along with the demand for the products needed to build them.

Table 5: Housing → Lumber Asymmetric Long-Run Elasticities

	Estimate	S.E.	95% Wald CI
$\beta^{+}_{hous\_price}$	0.28	0.13	(0.03; 0.53)
$\beta^{-}_{hous\_price}$	-0.004	0.25	(-0.49; 0.49)
β_{new_builds}	-0.11	0.036	(-0.18; -0.04)

Next, we estimate the lumber→stumpage model in (7) using the same procedure. The results are shown in table 6. The calculated t-stat for $\hat{\rho}$ is only marginally significant at 0.1 α-level, indicating that lumber and stumpage prices may not be cointegrated. Furthermore, the diagnostic F-test is significant only at 0.10 α-level, so we fail to reject the null hypothesis claim these two series exhibit no cointegration. Again, we detect, using a Wald test, no asymmetry in the short-run and the presence of asymmetry in the long-run. However, θ^{+} is not significant, while θ^{-} is only in the short-run. Moreover, in terms of general model performance, the adjusted-R^2 for this regression, which controls for lumber inventories, is less than 0.10.

Table 6: Estimated NARDL Results: Lumber → Stumpage (Quarterly, 1992-2021)

Coefficient	Estimate	S.E.	t-stat	p-value
Intercept	-0.072	0.30	-0.24	0.81
$\hat{\rho}$	-0.053	0.028	-1.92	0.058^{*}
$\hat{\theta}^{+}$	0.027	0.035	0.79	0.43
$\hat{\theta}^{-}$	0.066	0.025	2.62	0.01^{**}
$\hat{\gamma}_{1,0}$	0.03	0.041	0.75	0.46

Note: *p<0.1; **p<0.05; ***p<0.01

$N = 118$ observations.

Residual standard error 0.044 on 112 DF; Adjusted-R^2 0.085

Pesaran et al. (2001) cointegration test F-statistic I(0): 3.71^{*} on 4 and 112 DF

Wald test for short-run asymmetry test statistic: 3.02

Wald test for long-run asymmetry test statistic: 1072.73^{***}

Using the estimated cointegration coefficient and asymmetry parameters, we calculate the long-run elasticities. Table 7 includes the point estimates, standard errors and asymptotic Wald 95% confidence intervals. Each confidence interval includes zero, and so positive nor negative lumber shocks have a significant effect on stumpage prices. The same is true for the effect of lumber inventories. We interpret these results to imply that lumber and stumpage prices are conditionally independent, when controlling for lumber inventories. As a result, the value of stumpage in the long-run is distinct from lumber prices.

Table 7: Lumber → Stumpage Asymmetric Long-Run Elasticities

	Estimate	S.E.	95% Wald CI
β^{+}_{LPI}	0.51	0.84	(-1.14; 2.16)
β^{-}_{LPI}	1.26	0.88	(-0.46; 2.98)
β_{inven}	0.58	0.63	(-0.65; 1.81)

8 Policy Implications and Further Research

Using monthly housing and lumber market data, we estimate a NARDL model of housing supply chain price transmission. We find a significant positive asymmetric relationship between housing and lumber prices. We also find that as the inventory of new housing units increases there is a significant negative effect on lumber prices. And, negative shocks to housing prices has no significant impact on lumber prices.

We apply the same procedure to quarterly stumpage and lumber market data. We find little evidence of a cointegrating relationship between stumpage and lumber prices, when controlling for inventories. The implication is that the cost of holding inventories for lumber manufacturers is such that they can strategically plan inventories to asymmetrically capture positive housing price shocks, preventing pass-through to stumpage markets.

Possible extensions of this work include estimating the asymmetric relationships under alternative approaches. Specifically, a NARDL implicitly assumes rather strict assumptions with regard to the set threshold in the estimated VECM. Therefore, estimating the model under different threshold regimes is a logical next step for this work.

Our results show that stumpage lumber prices are conditionally independent, when controlling for lumber inventories. The result is that the owners of softwood timberland cannot rely on lumber products alone to maximize the value of their timber products. Alternative timber use products such as payment for ecosystem services provide viable diversification strategy for timberland owners.

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