THREE ECONOMETRIC ANALYSES OF SOUTHERN TIMBER MARKETS

by

MATTHEW VICTOR ARMSTRONG

(Under the Direction of Jacek P. Siry)

ABSTRACT

Timberland attracts capital as an investment. Timberland is an asset class that institutional investors are pursuing for inclusion in mixed portfolios. The reason that investors are including timberlands into mixed portfolios is because the timberland asset class provides significant diversifying benefits to institutional investors. The attractiveness of timberland as an investment starts with the underlying investment return drivers. The returns for timberland assets are driven from the appreciation of the underlying land and the income from selling timber products. This dissertation focuses on investigating timber product prices and specifically econometrically analyzing timber prices.

The first essay uses a mixed effects model to explain the effects of precipitation and temperature on softwood timber prices in the US South. The results of the model indicate that softwood timber prices are inversely related to changes in temperature and positively related to changes in precipitation. This result explains part of the softwood timber price variability attributable to weather in the US South.

The second essay uses a mixed effects hedonic model to examine the effect of timber sale characteristics on timber prices in the US South. The results of the model provide coefficient estimates for timber sale type, number of bidders, harvest type, and area harvested. This result explains part of the timber price variability attributable to the timber sale type, number of bidders, harvest type, and area harvested in the US South.

The third essay tests for cointegration between the softwood sawtimber prices in a region in Georgia and a region in Oregon using the Engle and Granger test. The results of the test suggest that the softwood sawtimber prices in a region of Georgia and a region of Oregon are cointegrated. The consequence of this result is that one would expect the long-run price change between the respective regions in Georgia and Oregon to be similar.

INDEX WORDS: Mixed effects model, random effects model, cointegration, timber prices, weather, precipitation, hedonic

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DEDICATION

I am dedicating this dissertation to my wife, children, parents, and grandfather. Meg, thank you for your patience and support while I finished this up. Eloise and Amelia, thank you for being patient while dad missed out on family time while he worked on his “school work/phd”. Mom and Dad, thank you providing me the support, encouragement, and environment so I could pursue my academic endeavors. Papa, thank you for instilling in me the importance of education.

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CHAPTER 1

INTRODUCTION

Timberland attracts capital as an investment. Timberland is an asset class that institutional investors are pursuing for inclusion in mixed portfolios. The reason that investors are including timberlands into mixed portfolios is because the timberland asset class provides significant diversifying benefits to institutional investors (Newell and Eves 2009). Additionally, several previously vertically integrated forest product companies, including Weyerhaueser, Potlach, and Rayonier, have reinvented themselves as timberland REITs to focus their business on timberland, as opposed to manufacturing. The attractiveness of timberland as an investment starts with the underlying investment return drivers. The returns for timberland assets are driven from the appreciation of the underlying land and the income from selling timber products (Aronow et al. 2004). This dissertation focuses on investigating timber product prices and specifically econometrically analyzing timber prices.

These investigations of timber prices concentrate on timber markets in the US South. The region is the focus of these investigations for two reasons. First, it is the largest timber market in the United States (Oswalt 2012) and the world. The US South possesses the largest inventory of trees in the United States and that inventory represents about one third of the standing timber in the United States. Second, the US South has a timber price reporting service, Timber Mart-South (Norris 2014), that makes available robust data sets for econometric analyses. Timber Mart-South began reporting timber prices in 1976. Combining the length, geographic span, and the amount of underlying price data of the Timber Mart-South price series allows for meaningful econometric investigations.

Timber prices are one of the main investment return drivers for a timberland investment. Timber prices' behavior has received significant research attention, both private and academic. Much of the research effort has gone towards providing explanations of the variance of timber prices. This dissertation builds on these previous investigations of timber markets in the following chapters. The three topics of the chapters are weather's effect on timber prices, timber sale characteristics' effect on timber prices, and long-run price relationships between softwood sawtimber prices in Georgia and Oregon.

For the first topic, weather's effect on timber prices is investigated. Many foresters have anecdotal accounts that timber prices increase during periods of wet weather. Additionally, many published articles concluded that seasonality is a significant explanatory variable in determining timber prices (Bare and Smith 1999; Dahal and Mehmood 2005; Kolis et al. 2014). Although many authors included seasonality as a dummy variable in pricing models, no published articles were found that investigated the underlying variables, such as temperature and precipitation, explanatory effects on timber prices. The microeconomic justification for there being an effect of weather on timber prices rests on constriction of supply. In microeconomic theory, if a demand curve is negatively sloped, then if supply becomes scarcer, price increases. Weather effects supply by disrupting the logging operations and consequently the timber supply chain (Greene et al. 2004). As loggers' productivity declines as a result of weather, the amount of timber that is available to be delivered to a processing facility declines (Todd and Rice 2005). Wet weather primarily reduces the short-run supply of timber by impacting loggers' productivity and limiting the acreage of timberland available for harvesting operations. As short-run timber supply shrinks, one would expect that short-run prices to increase. The chapter investigates the effect of precipitation and temperature on timber prices. The results could be useful to entities buying and selling timber, budgeting revenues from timber sales, and utilizing short-run timber price forecasting models.

For the second topic, timber sale characteristics effect on timber prices are investigated. Similar to the first topic, many published articles exist that explore the effects of timber sale characteristics on timber prices (Bare and Smith 1999; Dahal and Mehmood 2005; Dunn 2000; Huebschmann et al. 2004; Sydor and Mendell 2008). The unique aspect of the second topic is the robustness of the underlying data, including geographic scope. No published articles were encountered that studied timber sale characteristics' effect on timber prices for the entire US South. The topic is important partly because it provides explanations of timber price variability. The economic topics represented by the modeled timber sale characteristics include competition, economy of scale, and profit maximization. The effects of competition are examined by including the method of sale and number of bidders as explanatory variables. The effects of economy of scale are examined by including the area of timber sales as explanatory variables. Finally, the effects of cost reduction via operational efficiency are examined by including the type of timber harvest. Estimating the impact of timber sale characteristics on timber prices and providing values to timber sale characteristics and lowering the amount of unexplained variability in timber sales should be valuable to entities that transact timber. Similar to the first topic, the results could be useful to entities buying and selling timber, budgeting revenues from timber sales, and utilizing short-run timber price forecasting models.

For the third topic, softwood sawtimber prices from the Timber Mart-South Georgia Region 2 and the Oregon Department of Forestry Region 1 are examined for long-run price relationships. The question is explored because published evidence suggests that softwood lumber prices are cointegrated with delivered softwood timber prices in both the US Pacific Northwest and US South, and softwood lumber prices are cointegrated across the United States (Ning and Sun 2014; Yin and Baek 2005). Extrapolating these results one could conclude that the delivered softwood sawtimber prices in the US Pacific Northwest and US South are also cointegrated. However, differences in geography, climate, species composition, and silviculture between the US Pacific Northwest and US South would seem to preclude the delivered softwood sawtimber prices from the US Pacific Northwest and US South being cointegrated. One of the important results of price series cointegration is the long-run price relationship and the impact on long-run returns. Cointegration is a property of time series where a combination of two non-stationary time series produces a stationary result. Alternatively stated, the two time series are moving similarly. So if softwood sawtimber prices are cointegrated between the US Pacific Northwest and US South, then the long-run returns attributable to long-run softwood sawtimber prices will be similar. As TIMOs, REITs, and forest product companies manage timberlands as investments across timber markets, the price relationships and expected long-run returns for those investments across the country are of interest. The expected long-run regional investment returns are important for many uses, including setting return expectations, portfolio engineering, and marketing.

In summary, this dissertation focuses on three econometric timber price investigations. Weather effects on timber prices, timber sale characteristics effects on timber prices, and long-run price relationships between the US Pacific Northwest and US South provide results beyond previously published findings. In addition to not only providing new information, the results in this dissertation are of value to timberland industry.

LITERATURE REVIEW

The literature review for the first chapter is a review of research regarding timber sale characteristics effect on price and timber price relationships.

Regarding the timber sale characteristics and the effect on timber prices, several studies examine attributes of timber sales to explain timber prices. These studies examine a variety of variables, including the sale's timber species composition, distance to processing mill, tract attributes, best management practices, harvesting guidelines, season, month.

Sydor and Mendell (2008) examined how sale specific attributes affect stumpage prices. The authors use a hedonic model to account for and explain price variability due to timber sale attributes. The data came from Forest2Market price service and spanned the January 2004 to August 2005 period in the central Georgia timber market. The timber sale information included state and county, seller and buyer type, timber type, harvest type, qualitative loggability variable, tract size, and others. The sale information included total bid price, allocated product unit prices, mean tract DBH, and volumes. The final model included pine sawtimber price, quality of timber, timber type, pine pulpwood ratios, inventory type, loggability, tract size, seller type, and average sawtimber DBH. Using the hedonic model, total price risk, represented by standard deviation, was reduced from \$7.89 to \$3.08, suggesting that knowing and accounting for observable factors may reduce stumpage price risk.

Bare and Smith (1999) also used a hedonic model to investigate stumpage prices from lump sum timber sales. The data comes from lump sum sales from state lands in Washington in 1996. The model incorporates log quality, volume, stand characteristics, seasonality, and region. Regarding seasonality, the 2nd and 3rd quarter variables, \$74 and \$48 respectively, were both significant explanatory variables at the 95% confidence level, while the 4th quarter variable, a minus \$6, was not significant at the 95% confidence level.

Burak (1996) used ordinary least squares to model timber prices from stand characteristics and market conditions in Northeast Florida. Some of the variables used are tree type and size, stand composition, logging conditions and month of year. Two variables, loggability and topography, that relate to wetness of a site were statistically significant. Also, the month of the year variable was statistically significant in that generally prices were higher in winter and spring months than the summer and fall months, with all other variables held constant.

Dahal and Mehmood (2005) used ordinary least squares to explain bid prices from determinant variables. The data used came from two national forests, the Arkansas Forestry Commission, and private forestry consultants from spring 2002 to fall

2003. The model regressed bid price per acre on number of bidders, site characteristics, contract arrangements, seasonality, regional differences, and ownership type. In all, 15 variables were significant, including dummy variables for seasonality. Variables winter, spring, and summer all had negative coefficients. Also, a variable for wet weather logging permission produced a positive coefficient.

Huebshmann et al. (2004) used linear regression to relate US Forest Service timber bids to tract characteristics. The data consists of 150 timber sales from 1992 to 1998 on National Forests in Arkansas and Oklahoma. The final model used a log transformation of bid price on total pine sawtimber, total pine pulpwood, average sawtimber volume per acre, average sawtimber volume per tree, and a ratio of Producer Price Index (PPI) southern yellow pine (SYP) #2 dimension lumber to PPI sawlog. The authors found this price transmission to be represented as a .85 correlation between PPI SYP #2 and PPI sawlog. Also, a 1% increase in the above ratio resulted in a .52% increase in the bid price.

Kilgore and Blinn (2005) used a survey to learn how loggers develop bids on timber tracts. The survey explored the tract-specific factors (tract size, sale volume, site characteristics, appraised value, species composition), sale-specific factors (knowledge of timber appraiser, proximity to other sales, need for tracts), and guidelines (harvesting within inclusion, leave trees, road/skid trail placement, landing placement, logging slash, retain snags.) The survey was sent to 36 logging business owners located in Minnesota. Volume was the highest rated factor in developing a bid, closely followed by composition and site characteristics.

Snyder et al. (2007) examined forestland prices on 387 unimproved forest tracts in St. Louis County, Minnesota. The authors used a hedonic model to value a tract's characteristic. Interestingly, timber volume was not a significant factor in determining forestland price at a 10% significance level. Proximity to population centers, proximity to water (i.e. lakes or river), and method of sale emerged as the important drivers of forestland price.

Deckard (2000) reviewed Louisiana's quarterly sawtimber prices from 1956 to 1998 as a time series. Deckard found four distinct time periods of price increase or decrease. He also found from 1986 to 1998, there was a statistically significant variable for seasonality. With winter as the baseline, summer and fall were ~$26/mbf lower at a 95% confidence level, while spring was ~$15/mbf lower at an 80% confidence level.

Moss (1997) examined eight potential determinants for southern pine sawtimber stumpage in Georgia. The eight determinants are nationwide new housing starts, southwide new housing starts, real residential remodeling and repair expenditure, timber harvest volumes from National Forests, net softwood lumber imports, US-Canadian currency exchange rates, trade weighted US dollar index, and average rainfall in Georgia. Three significant determinants, nationwide housing starts, harvest volumes from National Forests, and trade weighted US dollar index, were found and included in the final model. Additionally, from 1986-1995 using only annual rainfall produced a significant correlation with current stumpage prices.

For Alabama, Dunn (2000) inspected high bid and timber sale contractual characteristics. Similar to other research, timber volume is the biggest influence on bid price, but similar to Dahal and Mehmood (2005) the number of bidders variable was positive and significant at $33/acre.

Munn and Palmquist (1997) studied timber sale prices and timber sale characteristics in North Carolina. The variables used include timber volumes, accessibility, harvest type, contract length, and geographic dummy variables. In addition to testing the significance of timber sale characteristics on price, the authors also compared results from ordinary least squares to stochastic frontier analysis.

In Ontario, Puttock et al. (1990) used a hedonic model to estimate timber prices from lump sum sales. The variables included total volume, species proportions, individual tree volume, timber quality, haul distance, and an industry price series. Further, Prescott and Puttock (1990) examined stumpage prices in Southern Ontario. In this instance, the authors use a hedonic model where the dependent variable is total stumpage sale price and the independent variables are species composition, product composition, time, total volume and volume per tree.

Kolis et al. (2014) examined stumpage sale characteristics impact on bid prices in Finland. The authors included region, haul distance, volume, species composition, harvest type, time and seasonality in an ordinary least squares model. This study only used sales where unit prices were available.

Brown et al. (2012) investigated the impact of timber sale characteristics on lump sum timber sales in Minnesota. The researchers used lump sum sales and the appraised inventory to calculate a price/cord value. The authors included volume, time, density, location, operability, and species composition in the model.

Niquidet and van Kooten (2006) explored timber sale characteristics on competition and bid prices in British Columbia. To help alleviate the softwood lumber dispute between Canada and the United States, British Columbia began selling more timber sales at auction to substantiate that British Columbia's government administered sales were transacting at competitive prices. The authors included volume, location, species mix, slope, harvest method, and lumber price as variables in the models.

Jackson and McQuillan (1979) produce a hedonic model that regressed timber sale characteristics on stumpage price in the Lolo National Forest in Montana. The variables included average tree diameter, lumber price, logging method, volume per acre, regeneration method, and haul distance. The authors calculated the dependent variable, per unit stumpage values, by dividing total sale price by total sale volume. The results showed that all the independent variables to be significant at 95% confidence level except haul distance.

Nautiyal (1982) employed a nonlinear hedonic model to derive the stumpage values by diameter class for stumpage sales in Ontario. The conclusion from the article is that stumpage prices by diameter class for timber sold in Ontario are best modeled as discontinuous and step like.

In addition to the explanatory capacity of timber sale characteristics on timber prices, this dissertation explores the long-run relationship of timber prices. Previously, several articles addressed the long-run price relationship of timber prices and lumber prices. There are many published articles dedicated to testing market integration in timber or timber product markets. The tests for market cointegration span regional level of timber markets and national level for lumber markets, but the literature review did not reveal any article testing for market integration between timber markets between the two largest wood producing regions in the United States.

Yin et al. (2002) used co-integration techniques to explore at the southern softwood timber markets. The authors use Timber Mart-South data while employing the Dickey-Fuller test and Johansen Test. They found that the 13 softwood sawtimber and 11 softwood pulpwood regions were not fully co-integrated, but the pulpwood market was more integrated. They concluded the 13 softwood sawtimber regions are at least 3 different markets, not a single market. Similarly, the 11 pulpwood markets are at least 3 different markets. Nearly all-neighboring pairs of regions are co-integrated, suggesting a gradual transition across markets in the US South. The authors' opinion was that the southern timber markets were not cointegrated because of the bulky nature of the commodity.

Prestemon and Holmes (2000) used cointegration and time series to examine short and long term effects on timber prices from changes in supply, in this case from Hurricane Hugo. They used Timber Mart-South prices in South Carolina Regions 1 and 2. Their first conclusion was that southern pine stumpage markets are informationally efficient. Their second conclusion was the existence of intertemporal arbitrage, but little if any interspatial arbitrage. The final conclusion is after a catastrophe, there is a shortrun negative price spike due to a pulse in supply followed by a longrun price enhancement to residual supply.

Prestemon (2003) employed Timber Mart-South data to examine market informational efficiency. The author used an augmented Dickey-Fuller test and Fama-French regressions to test if the time series are stationary. He found most real Timber

Mart-South prices are nonstationary. The results contradict Yin and Newman (1996) and Hultkrantz (1993), partly because the authors limited the lag length in the Dickey-Fuller test. The author concluded that southern stumpage prices are likely a mixed ARIMA process.

McGough et al. (2004) created a theoretical model where timber prices are an AR1 process. The authors then simulate prices based on the model. The authors addressed the idea that harvesting rules only work if the market is inefficient. The key theoretical result is stationary serially correlated prices can arise in an informationally efficient market when shocks are identically distributed and independent.

Nagubadi (2001) investigated the hardwood stumpage markets in the six states in the US South. First, the author investigated long-run price relationships by testing the cointegration of Timber Mart-South prices for hardwood pulpwood, mixed hardwood sawtimber, and oak sawtimber by utilizing both the Johansen test and the Engle and Granger test. After using both test, he concluded that the six states are not fully cointegrated for any of the three timber products. However, he concluded that hardwood sawtimber is closer to being cointegrated than hardwood pulpwood because the pair-wise Engle and Granger tests showed that mixed hardwood sawtimber price was cointegrated in five of the six states. Second, he utilized an error correction model to examine short-run price relationships between the states to determine short-run price relationships.

Ning and Sun (2014) examined the vertical price integration between stumpage, delivered, and end product prices in the US Pacific Northwest and US South. The authors found that the stumpage and delivered prices were more integrated than delivered prices and lumber prices. Additionally, the US South had a stronger degree of vertical cointegration than the US West. They used Oregon Department of Forestry, Timber Mart-South, and Random Lengths for prices and determined cointegration by using the Johansen test and Engle and Granger test.

Yin and Caulfield (2002) used a Brownian motion model to investigate Timber Mart-South prices. This paper discusses the existence of two distinct time periods for the Timber Mart-South price series, with the demarcation roughly the late 1980's. The authors investigated real and nominal price growth rates and volatility for selected Timber Mart-South regions and products. The authors also compared prices between the US Pacific Northwest and US South, showing that sawtimber prices follow lumber prices due to the inputs high portion of final cost, and the lack of relationship between pulp and paper prices and pulpwood stumpage conversely due to pulpwood input being a small cost of the final product.

Several articles address the Law of One Price in the softwood lumber markets. Uri and Boyd (1990) , Jung and Doroodian (1994), and Yin and Baek (2005) all concluded that the US lumber market is cointegrated and so the Law of One Price holds. The authors came to the same conclusions after refining the methodology of the previous article. Uri and Boyd tested for market cointegration with Granger causality tests. Jung and Doroodian employed the Johansen test to confirm Uri and Boyd's conclusion. Yin and Baek raised issues with the Jung and Doroodian's interpretation of the Johansen procedure results. Consequently, Yin and Baek used more robust model structures in their tests along with using a more granular data set than the one used by

Uri and Boyd, and Jung and Doroodian. Yin and Baek confirmed the conclusions of the previously published work regarding Law of One Price for the US lumber market.

Baek (2006) expanded the scope of his work with Yin to test the market cointegration of the North American lumber market. Baek concluded that the North American softwood lumber market is cointegrated. Additionally, he concluded that the North American softwood lumber market structurally shifted after US federal restrictions on timber harvesting in the US Pacific Northwest. Baek used Perron's method to test for the structural shift.

Nanang (2000) tested for Canadian softwood lumber market cointegration. Nanang tested five geographic regions and concluded that all of the regional lumber markets had unit roots, but that the markets were not cointegrated when the Johansen test was applied.

Alavalapati et al. (1997) investigated the long and short run price relationships in the Canadian wood pulp market. One of the main findings of the article is that the US and Canadian wood pulp markets are cointegrated so the Law of One price holds.

Bingham et al. (2003) explored market cointegration for pulpwood and sawtimber in the US South. The authors utilize the Engle and Granger method to test for pair-wise cointegration for roundwood prices in Timber Mart-South regions. The tests results rejected the Law of One price for the US South roundwood markets being cointegrated. The results from the Engle and Granger tests were combined with distance, volume, and mill variables to produce a meta-regressions analysis. From these meta-regression results, the authors present visually contrived markets for sawtimber and pulpwood.

In summary, many articles exist explaining the price effects of timber sale characterisitics and the national or international cointegration of wood products or regional cointegration of timber markets. The essays in this dissertation provide evidence explaining timber sale price variability and show a cointegrated relationship between timber prices in the US Pacific Northwest and US South. These results are new findings regarding timber markets.

CHAPTER 2

THE EFFECT OF WEATHER ON TIMBER PRICES[1]

[1] Armstrong, M. and J. Siry. To be submitted to *Forest Science*

ABSTRACT

This chapter uses a random effect model to explain the effects of precipitation and temperature on softwood timber prices in the US South. The results of the model indicate that softwood timber prices are inversely related to changes in temperature and positively related to changes in precipitation. This result explains part of the softwood timber price variability attributable to weather in the US South.

INTRODUCTION

Timberland receives significant interest as an investment. Two of the main return drivers for timberland as an investment are income from selling timber products, such as timber, and appreciation in the value of land (Aronow et al. 2004). One of the functions in both of these return drivers is timber price. The revenue from forest operations is a function of the volume of wood harvested and price paid per unit of wood. The land value appreciation of a forest investment results from increases in bare land values that are generally calculated by discounting future income from forest operations or alternative higher and better land uses. The price paid per unit of wood changes depending on a tree's size. Generally in the US South, the smallest size of merchantable trees, known as pulpwood, makes pulp and paper, then the next size class of trees, known as chip-and-saw, makes boards and chips, and the next larger size class of trees, known as sawtimber, makes lumber. As a tree grows through these three product classes, generally it's per unit price increases.

Timber prices are functions of quantity supplied and demanded. In the US South, timber prices segregate into regional markets (Yin et al. 2002). In 2009, there were 83 pulpmills and 1,216 sawmills in the US South. There are many more sawmills than pulpmills, but roughly 81% of sawtimber consumption is concentrated in a group of 253 of the larger sawmills (Johnson 2011). Within timber markets, oligopsonies exist due to a few large mills demanding timber as a raw material from many sellers (Murray 1995). The short-run demand for pulpwood within these oligopsony markets is relatively fixed, due to the large capital investment and expensive processes in pulp and paper mills (Todd and Rice 2005). Several studies found timber demand to be inelastic. Newman(1987) reported demand elasticities for pulpwood and sawtimber of -.43 and -.57, respectively. Carter (1992) reported a pulpwood demand elasticity of -.41. Likewise in the short-run, the timber supply is fairly fixed as it is composed of the existing timber inventory (Carter 1992). Newman (1987) reported pulpwood and sawtimber supply elasticities of .23 and .55, respectively. Wear and Newman (1991) found short-run pulpwood supply inelastic with a value of .48. One can increase the short-run supply by importing trees from other regions, but transportation costs present a significant barrier. Short-run supply and demand for pulpwood is inelastic, so a price change's effect on quantity supplied and consumed is low.

In spite of the relatively fixed nature of the short-run supply and demand for pulpwood, the prices in these regional markets fluctuate. The relationship between input factor and final good prices in the factor demand function would point to price transmission between input factors and output prices (Wetzstein 2005). Zhou and Buongiorno (2005) found a price transmission from lumber to sawtimber, but no evidence of a price transmission between pulp and paper to pulpwood. The lack of price transmission between pulpwood and outputs is likely due to the high capital investment in pulp and paper mills compared to the relatively low cost of pulpwood as a raw material (Yin and Caulfield 2002). The pulpwood output product price for 4th quarter 2014, represented by the FOEX Northern Bleached Softwood Kraft index (FOEX 2014), of \$932/ton compared to the 4th quarter 2014 pine pulpwood price of \$10.52/ton illustrates the high cost of production. It takes roughly 4 tons of pulpwood to produce 1 ton of finished product (Haygreen 1996), so pine pulpwood stumpage roughly comprises less 5% of the cost of a ton of kraft paper. Pulp and paper prices are relatively volatile, while pulpwood prices are much less volatile.

Weather's effect on short-run supply potentially explains part of the movement in pine stumpage and delivered prices. Weather can affect the wood supply and price. Preston and Holmes (2000) showed an extreme weather event, a hurricane, affects timber prices. Greene et al. (2004) implied that non-extreme weather affects supply and price by disrupting the supply chain. Loggers are integral in supplying wood to processing facilities. Loggers harvest trees from timberland and transport it to processing facilities. Weather can affect a logger's productivity, which in turn impacts the short-run supply of wood (Todd and Rice 2005). Wet weather primarily reduces the supply of timber in two ways. As precipitation increases, loggers' productivity declines and the acreage of timberland available for harvesting operations also declines. Weather based changes in productivity and supply of operable timberland acreage should result in price movements.

Winter, spring, summer, and fall, comprise the US South's four seasons. Generally, winter and spring will have higher precipitation and soil moisture levels than summer and fall. Within a regional pulpwood market, a mill may anticipate how a season will affect the short-run timber supply and increase its mill inventory. Todd and

Rice (2005) showed mill inventory levels respond to anticipated seasonal weather. However, weather is variable and an uncharacteristically wet or dry season may change the short-run supply along with the timber price despite a mill's tactical inventory plans.

This chapter will examine the relationship between weather and timber prices. It is well known among foresters transacting timber that the weather can be a powerful engine to move timber prices, but little has been published on the timber price and weather relationship. The results of the research could be useful to many users, ranging from Timberland Investment Management Organization (TIMO) portfolio managers and Real Estate Investment Trusts to local wood buyers.

LITERATURE REVIEW

As mentioned above, there has been little published research involving timber prices and weather. This review focuses on literature relevant to timber prices.

Todd and Rice (2005) investigated pulpwood inventories in the US Northeast. The authors surveyed 15 mills in four states. The research identified four inventory patterns, all of which are responses to weather. The authors concluded that weather affects logger's productivity, which then affects timber availability and price. Survey respondents reported low timber availability resulted in increased timber price.

Greene et al. (2004) investigated the causes and costs of logging production capacity. The authors surveyed loggers in Maine and the US South. Loggers operated at approximately 80% capacity, as measured by loads per week. Weather accounted for approximately 24% of the lost capacity. Market conditions accounted for the largest contribution of unused capacity at approximately 31%. The authors discussed the causes of unused capacity and that the majority of them, except weather, are controlled by either the buyer or seller.

Several studies evaluated attributes of timber sales to explain stumpage price variability on the supply side. These studies evaluated a variety of variables that range from the timber sale's species composition, distance to processing mill, tract attributes, best management practices, harvesting guidelines, season, month, among others. Sydor and Mendell (2008) examined how sale specific attributes affect stumpage prices. The authors use a hedonic model to account for and explain price variability due to timber sale attributes. The data came from Forest2Market price service and spanned the January 2004 to August 2005 period in the central Georgia market. The property information included state and county, seller and buyer type, timber type, harvest type, qualitative loggability variable, tract size, and others. The sale information included total bid price, allocated product unit prices, mean tract DBH, and volumes. Final model included pine sawtimber price, quality of timber, timber type, pine pulpwood ratios, inventory type, loggability, tract size, seller type, and average sawtimber DBH. Using a hedonic model, total price risk, represented by standard deviation, was reduced from $7.89 to $3.08, suggesting that knowing and accounting for observable factors may reduce stumpage price risk.

Bare and Smith (1999) also used a hedonic model to examine stumpage prices from lump sum timber sales. The data comes from lump sum sales from state lands in Washington in 1996. The model incorporates log quality, volume, stand characteristics, seasonality, and region. Regarding seasonality, the 2nd and 3rd quarter variables, $74 and $48 respectively, were both significant explanatory variables at the 95% confidence level, while the 4th quarter variable, a minus $6, was not significant at the 95% confidence level.

Burak (1996) used ordinary least squares to model timber prices from stand characteristics and market conditions in Northeast Florida. Some of the variables used are tree type and size, stand composition, logging conditions and month of year. Two variables, loggability and topography, that relate to wetness of a site were statistically significant. Also, the month of the year variable was statistically significant in that generally prices were higher in winter and spring months than the summer and fall months, when all other variables were held constant.

Dahal and Mehmood (2005) used ordinary least squares to explain bid prices from determinant variables. The data used came from two national forests, the Arkansas Forestry Commission, and private forestry consultants from spring 2002 to fall 2003. The model regressed bid price per acre on number of bidders, site characteristics, contract arrangements, seasonality, regional differences, and ownership type. In all, 15 variables were significant, including dummy variables for seasonality. Variables winter, spring, and summer all had negative coefficients. Also, a variable for wet weather logging permission produced a positive coefficient.

Huebshmann et al. (2004) used linear regression to relate US Forest Service timber bids to tract characteristics. The data consisted of 150 timber sales from 1992 to 1998 on National Forests in Arkansas and Oklahoma. The final model used a log transformation of bid price on total pine sawtimber, total pine pulpwood, average sawtimber volume per acre, average sawtimber volume per tree, and a ratio of Producer Price Index (PPI) southern yellow pine (SYP) #2 dimension lumber to PPI sawlog. The authors found this price transmission to be represented as a .85 correlation between PPI SYP #2 and PPI sawlog. Also, a 1% increase in the above ratio resulted in a .52% increase in the bid price.

Kilgore and Blinn (2005) used a survey to learn how loggers develop bids on timber tracts. The survey explored the tract-specific factors (tract size, sale volume, site characteristics, appraised value, species composition), sale-specific factors (knowledge of timber appraiser, proximity to other sales, need for tracts), and guidelines (harvesting within inclusion, leave trees, road/skid trail placement, landing placement, logging slash, retain snags.) The survey was sent to 36 logging business owners located in Minnesota. Volume was the highest rated factor in developing a bid, closely followed by composition and site characteristics.

Snyder et al. (2007) examined forestland prices on 387 unimproved forest tracts in St. Louis County, Minnesota. The authors used a hedonic model to value a tract's characteristic. Interestingly, timber was not a significant factor in determining forestland prices at a 10% significance level. Proximity to population centers, proximity to water (i.e. lakes or river), and method of sale emerged as the important drivers of forestland prices.

In addition to timber sale characteristics, changes in demand contribute to timber price changes. Zhou and Buongiorno (2005) examined how final product prices affect stumpage prices. The authors used time series methods to examine the relationship of product price, lumber and paper, on factor price, sawtimber and pulpwood stumpage. The authors used Timber Mart-South for factor prices and Producer Price Indices from US Bureau of Labor Statistics for the product prices (softwood lumber, paper, and wood pulp). All the prices examined were nonstationary and not cointegrated. A positive one-to-one causality was found between the national lumber price and sawtimber stumpage prices in the US South. Interestingly however, there was not a reciprocal effect of an increase in sawtimber stumpage prices leading to an increase in lumber prices. For the national pulp price, there was a positive one-third price response in national pulp price, although there was no response between national paper and pulp prices and regional pulpwood prices.

Malaty et al. (2007) used Harvey's structural time series model (STSM) and the Kalman filter approach to model sawlog prices in Finland from January 1995 to April 2006 and compare those results to autoregressive moving average (ARIMA) and vector autoregressive (VAR) models. The STSM decomposes time series into unobserved parts like level, trend, seasonality, and cyclical behavior. Three of four regions displayed zero seasonal effect and the fourth regions coefficient was irregular. Additionally, the authors found that the four Finnish markets did not follow pure random walk series and none of the models were able to predict a market upturn in 2006.

Deckard (2000) reviewed Louisiana's quarterly sawtimber prices from 1956 to 1998 as a time series. Deckard found four distinct time periods of price increase or decrease. He also found from 1986 to 1998, there was a statistically significant variable for seasonality. With winter as the baseline, summer and fall were ~$26/mbf lower at a 95% confidence level, while spring was ~$15/mbf lower at an 80% confidence level.

Moss (1997) examined eight potential determinants for southern pine sawtimber stumpage in Georgia. The eight determinants are nationwide new housing starts, US South new housing starts, real residential remodeling and repair expenditure, timber harvest volumes from National Forests, net softwood lumber imports, US-Canadian currency exchange rates, trade weighted US dollar index, and average rainfall in Georgia. Three significant determinants, nationwide housing starts, harvest volumes from National Forests, and trade weighted US dollar index, were found and included in the final model. Additionally, from 1986-1995 including only annual rainfall produced a significant correlation with current stumpage prices.

Newman (1987) modeled the southern regional timber market using three stage least squares for simultaneous parameter estimation in the above markets. For pulpwood supply, he found own price elasticity very inelastic (.23), while cross price elasticity is positive and smaller (.08). For pulpwood demand, he found own price was inelastic (-.43) and final good price was positive, but not significant. The results imply pulpwood is a net substitute for solidwood stumpage. Solidwood coefficients are inelastic, but larger in magnitude than pulpwood, meaning solidwood producers respond to changing market conditions more so than pulpwood producers.

Yin et al. (2002) used co-integration techniques to examine the southern softwood timber markets. The authors used Timber Mart-South data while employing the Dickey-Fuller test and Johansen Test. They found that the 13 sawtimber regiongs and 11 pulpwood regions were not fully cointegrated, but the pulpwood was more integrated. They concluded the 13 sawtimber regions are at least 3 different markets, not a single market. Similarly, the 11 pulpwood markets are at least 3 different markets. Nearly all-neighboring pairs of regions are cointegrated, suggesting a gradual transition across markets in the US South.

Carter (1998) used flexible least squares (FLS) to test for structural stability in the US South timber market. The FLS produces a series of varying elasticity models. The results rejected structural stability on supply side and failed to reject structural stability on the demand side. Also, he concluded that supply elasticities have been rising, possibly indicating lower inventories and lower prices in the short and medium term.

Carter (1992) developed a short-run pine pulpwood market model for Texas using both three stage least squares and three stage least squares ridge regression. Supply is developed using utility maximization and demand is developed using profit maximization. Supply and demand were found to be inelastic with respect to changes in pulpwood price (.28 and -.41, respectively). Inventory, mill capacity, fiber input ratio, and income were the most important variables regarding pulpwood quantity and price.

Polyakov et al. (2005) used two stage least squares (2SLS) and 4 simultaneous linear equations to represent supply and demand. The models used Timber Mart-South prices and pulpwood capacity from the USDA Forest Service. Price elasticity for pine pulpwood and hardwood pulpwood were low. For hardwood sawtimber, they found it could be considered a substitute in production for hardwood pulpwood. Also, they found a substitution effect between Alabama and Mississippi, suggesting a tight linkage between the neighboring states.

Bingham et al. (2003) concluded that Law of One Price (LOP) fails across the South’s softwood timber market. They identified five distinct sawtimber markets and three distinct pulpwood markets. The meta-analysis revealed that distance is a factor in the integration of sawtimber markets, but not for pulpwood markets. They used the two-step estimator Engle and Granger test and meta-regressions to test for cointegration.

A variety of topics regarding timber markets in the US South garnered research interest. One popular topic revolves around the informational efficiency of stumpage markets. An efficient price is one where the price fully reflects all available information (Fama 1970).

Brazee and Mendelsohn (1988) compared a Faustmann rotation to a harvesting model with a reservation price. The authors concluded a reservation price decision model would increase revenue by taking advantage of the price variability of wood. The authors solved the problem and provided numerous examples. This reservation price model basically attempts to time the sales of timber for when timber prices are high. For this price reservation model to work, it requires knowledge about the future timber price behavior, which precludes an efficient timber market.

Brazee and Bulte (2000) created a model that allows for flexibility in thinning and harvest timing, along with reservation prices. The model assumptions were based on data from the Netherlands. The flexible model increased returns over Faustmann models 14% to 36%, and a further 7% with thinning. The management implications of the flexible model include earlier thinnings and later harvests. When utilizing reserve prices, the different price variances lead to different values and harvesting times.

Washburn and Binkley (1990) tested the efficiency of sawtimber markets. They examined whether current prices utilize all information from past price changes. This is a weak form test of market efficiency described by Fama (1970). With monthly price data, there is a negative correlation between months, but quarterly and yearly prices were found to be weak form efficient in that they were serially uncorrelated. They concluded that evaluating past prices will not present a profit making opportunity from timing harvests.

Prestemon and Holmes (2000) used cointegration and time series to determine short and long term effects on timber prices from changes in supply, in this case from Hurricane Hugo. They used Timber Mart-South prices from South Carolina Regions 1 and 2. Their first conclusion is that US South pine stumpage markets are informationally efficient. Their second conclusion is the existence of intertemporal arbitrage, but little if any interspatial arbitrage. The final conclusion is after a catastrophe, there is a short-run negative price spike due to a pulse in supply followed by a long-run price enhancement to residual supply.

Prestemon (2003) employed Timber Mart-South data to examine market informational efficiency. The author uses an augmented Dickey-Fuller test and Fama-French regressions to test if the time series were stationary. He found most real Timber Mart-South prices are nonstationary. The results contradict Yin and Newman (1996) and Hultkrantz (1993), partly because the authors limited the lag length in the Dickey-Fuller test. The author concluded that southern stumpage prices are likely a mixed ARIMA process.

McGough et al. (2004) created a theoretical model where timber prices are an AR1 process. The authors then simulated prices based on the model. They addressed the idea that harvesting rules only work if the market is inefficient. The key theoretical result is stationary serially correlated prices can arise in an informationally efficient market when shocks are identically distributed and independent.

Published literature concentrating on timber prices is expansive, but little has been published that examines the effect of weather on timber prices.

METHODS

Historical timber prices and weather data are available to test the hypothesis that weather affects timber prices. Many variables affect changes in timber prices and trying to capture all relevant variables proves difficult. Failing to include relevant variables can compromise coefficient estimates and hypothesis tests. Fortunately, the available data lends itself to panel data models that offer methods to address problems associated with omitted variables. Simply using ordinary least squares (OLS) to model weather and timber prices, could lead to inconsistent estimators. As an alternative, following notation in Wooldridge (2002), a random effects panel data model can be expressed as,

$y_{it} = \mathrm{x}_{it}\beta + c_i + u_{it}$, t=1,2,…,T Equation 2.1

and,

$\mathrm{E}(u_{it} \mid \mathrm{x}_i, c_i) = 0$, t=1,2,…,T Equation 2.2

where *i* represents a group

c represents a time constant

unobserved variable

and *u* represents the error.

In addition to zero conditional mean for *u*, the model assumes that *x* and *c* are uncorrelated, expressed as,

$\mathrm{E}(c_i \mid \mathrm{x}_\mathrm{i}) = \mathrm{E}(c_i) = 0$ Equation 2.3

The assumption that precipitation is not correlated with the unobserved variables, allows for the u_{it} to be included in the error term. The strict exogeniety and orthogonality assumptions above allow the panel data model to be written as,

$$y_{it} = \mathrm{x}_{\mathrm{it}}\beta + \upsilon_{it} \qquad \text{Equation 2.4}$$

$$\mathrm{E}(\upsilon_{it} \mid \mathrm{x}_{it}) = 0, \qquad t=1,2,\ldots,\mathrm{T} \qquad \text{Equation 2.5}$$

where

$$\upsilon_{it} = c_i + u_{it} \qquad \text{Equation 2.6}$$

In this form, Generalized Least Squares (GLS) can be used when a model's error component takes this form. With GLS, the model error component for each time period can be represented as

$$\mathrm{v}_i = c_i \mathrm{j}_T + \mathrm{u}_i \qquad \text{Equation 2.7}$$

where j_T is a T x 1 vector of ones. The variance matrix takes the form,

$$\Omega = \sigma_u^2 \mathrm{I}_T + \sigma_c^2 \mathrm{j}_T \mathrm{j}_T' \qquad \text{Equation 2.8}$$

Using the panel data random effects model outlined above, one will generate consistent coefficient estimates and valid variances for hypothesis testing.

The effect of weather on timber prices was modeled with a random effects panel data model using data from Timber Mart-South (Norris 2014) and National Oceanographic and Atmospheric Administration (NOAA 2014). The hypothesis is whether changes in precipitation and temperature affect the price of timber.

Timber Mart-South pine pulpwood and pine sawtimber stumpage prices are used as the pricing variables in the model. Following previous research, the change in price is calculated using first difference of natural log price (Washburn and Binkley 1990).

First difference natural log price is an approximation of percent price change, but it is nearly identical at small percentage changes.

The NOAA data provides several indices to capture past precipitation's effect on the current drought condition. Instead of using these calculated values to capture previous precipitation, past precipitation is input into the model as lags. The independent variables, quarterly precipitation, precipitation squared and temperature, are differenced, $X_{it} – X_{it-1,}$ so a change in explanatory variables over time corresponds to changes in the stumpage prices. Precipitation squared is included to show whether changes in precipitation cause changes in price at increasing or decreasing rates. Differences in precipitation and precipitation squared are lagged 4 quarters because current conditions are effected by previous quarters precipitation. The model is shown in equation 2.9.

$$\begin{aligned}\ln(\text{price}_{\text{it}}) - \ln(\text{price}_{\text{it}-1}) = \beta_0 + \beta_1(\text{temp}_{\text{it}} - \text{temp}_{\text{it}-1}) + \quad & \beta_2(\text{precip}_{\text{it}} - \text{precip}_{\text{it}-1}) + \\ \beta_3(\text{precip}_{\text{it-1}} - \text{precip}_{\text{it}-2}) + \quad & \beta_4(\text{precip}_{\text{it-2}} - \text{precip}_{\text{it}-3}) + \\ \beta_5(\text{precip}_{\text{it-3}} - \text{precip}_{\text{it}-4}) + \quad & \beta_6(\text{precip}_{\text{it-4}} - \text{precip}_{\text{it}-5}) + \\ \beta_7(\text{precip}^2_{\text{it}} - \text{precip}^2_{\text{it}-1}) + \quad & \beta_8(\text{precip}^2_{\text{it-1}} - \text{precip}^2_{\text{it}-2}) + \\ \beta_9(\text{precip}^2_{\text{it-2}} - \text{precip}^2_{\text{it}-3}) + \quad & \beta_{10}(\text{precip}^2_{\text{it-3}} - \text{precip}^2_{\text{it}-4}) + \\ \beta_{11}(\text{precip}^2_{\text{it-4}} - \text{precip}^2_{\text{it}-5}) \quad & \end{aligned} \qquad \text{Equation 2.9}$$

DATA

This research uses timber prices and weather data. The timber price data is from Timber Mart-South (Norris 2014) and the weather data is from the National Oceanic and Atmospheric Administration (NOAA 2014).

Timber Mart-South is a quarterly price series of multiple types of timber for 22 regions covering 11 states in the US South. The price series spans from the fourth quarter 1976 to current. Prices are gathered quarterly through use of a standardized survey to reporters. Reporters are individuals and companies who are engaged in frequent timber sales transactions. Prices are reported as average, Hi, and Lo. Hi and Lo are the 75th and 25th quartile respectively.

Timber Mart-South provides stumpage and delivered prices for multiple products. The stumpage price is the price for a ton of wood in a standing tree. The delivered price is the price for a ton of wood delivered to the gate of a processing facility. The delivered price includes the cost of harvesting and transporting the wood to a mill facility. Timber Mart-South provides these prices for pine pulpwood, pine chip-and-saw, pine sawtimber, pine poles, pine ply logs, mixed hardwood pulpwood, mixed hardwood sawtimber, oak sawtimber. The Timber Mart-South product specifications for pulpwood is 6 inch and higher diameter at 4.5 feet to a 3-4 inch top, chip-and-saw is 10 to 12 inch diameter at 4.5 feet to a 5 inch top, and sawtimber is 14 inch and higher diameter at 4.5 feet to a 4 inch top. These product measurements are a general guide due to different requirements by respective markets. Generally, the larger a tree's diameter is the higher the price. This is because larger trees take longer to grow and are able to produce higher value end products.

Timber Mart-South provides quarterly prices for 22 regions in 11 states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia) in the US South (Figure 2.1). Also, from 1980 through 1994, Timber Mart-South reported prices in Kentucky and Oklahoma. Currently, each state is divided into two regions. Prior to 1992, prices were reported for three regions per state, except Texas, which had two regions. Generally, the three regions were coastal plain, piedmont, and mountains. In 1992, Timber Mart-South began reporting two regions per state. The region transformation generally consisted of combining regions one and two respectively, into a new region one and reassigning region 3 to region 2. A table explaining the transformation from three to two regions is attached as Appendix A.

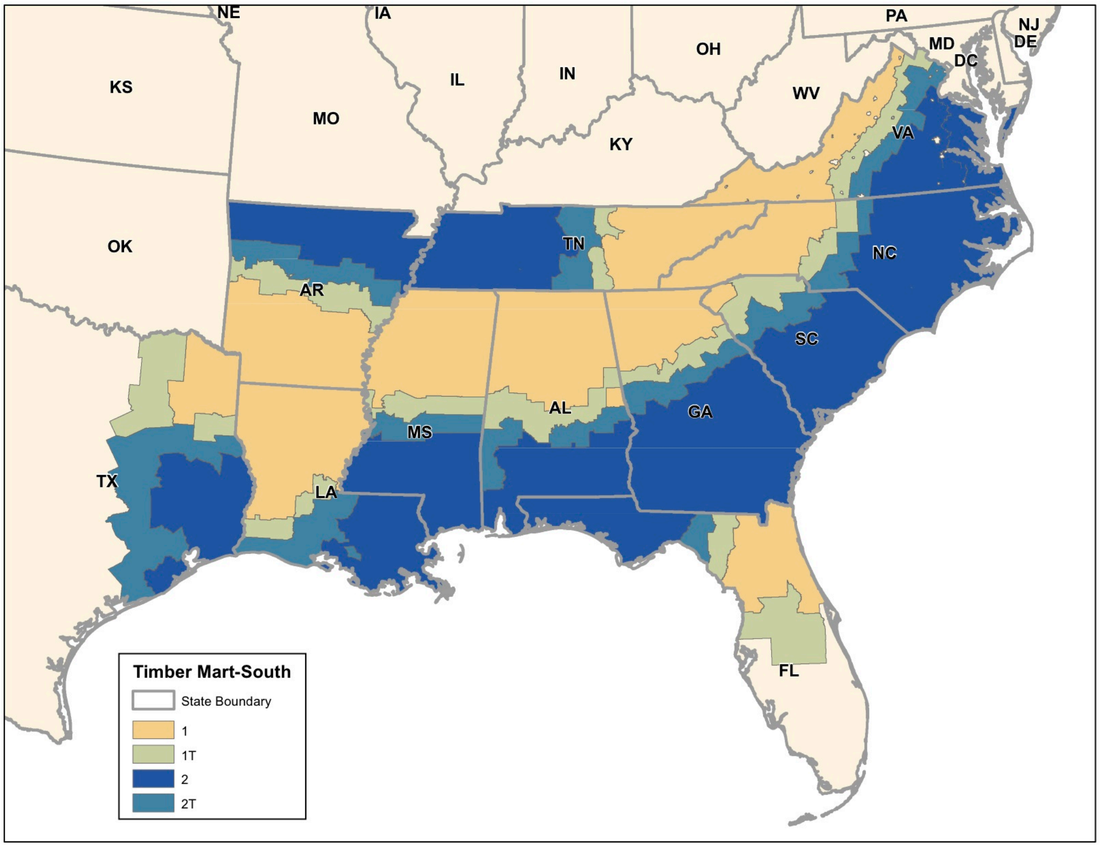
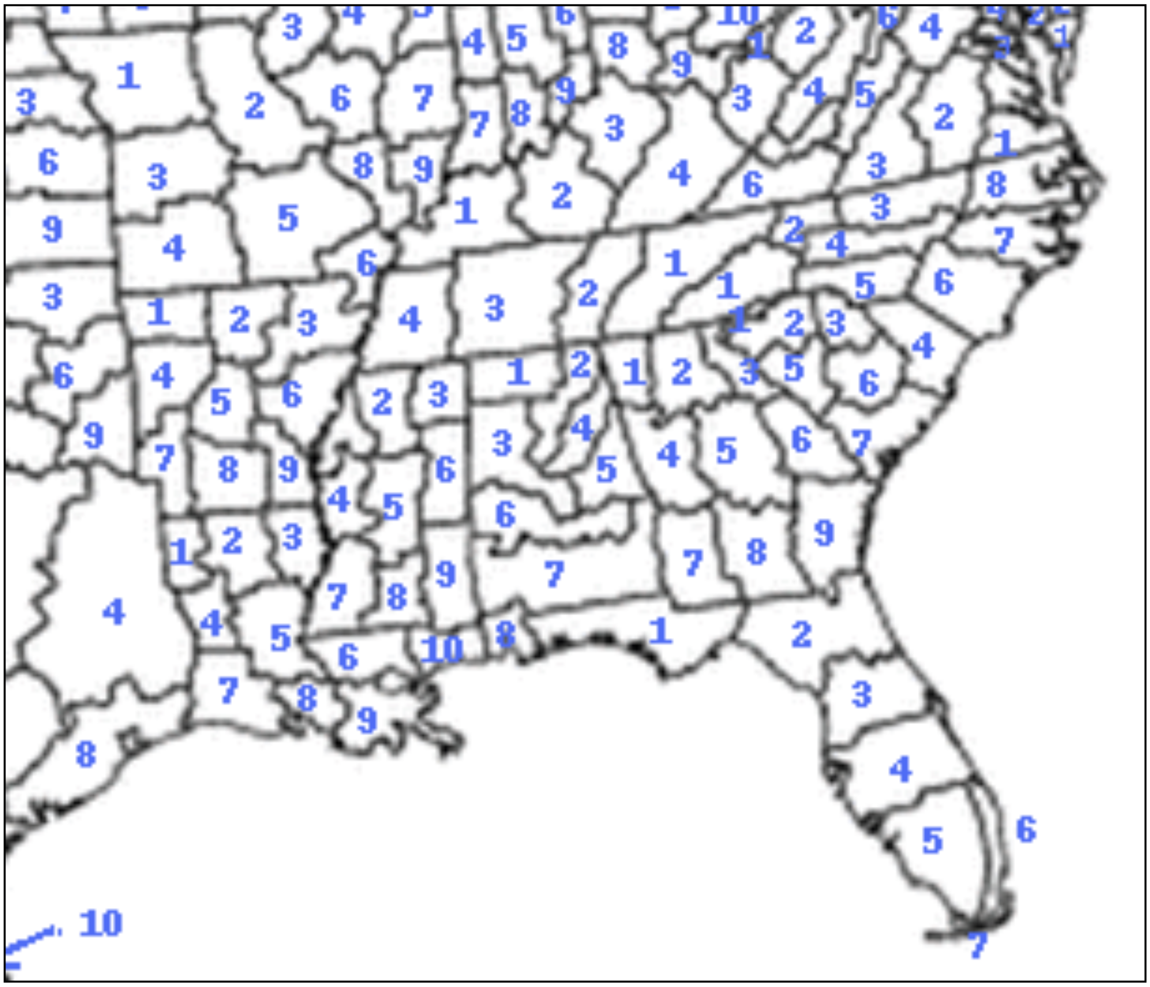


Figure 2.1. Timber Mart-South Timber Price Reporting Regions

Prior to 1988, Timber Mart-South reported prices monthly. After 1988, Timber Mart-South reported prices quarterly. The monthly prices from 1977 through 1987 were averaged to generate quarterly prices.

The National Oceanic and Atmospheric Administration's provides historical weather data through the National Climatic Data Center (NCDC) website (www.ncdc.noaa.gov). The 11 states in the Timber Mart-South price series spans

NOAA's Southern Regional Climate Center and Southeastern Regional Climate Center. NOAA breaks each individual state into climate divisions (Figure 2.2). Each division is composed of individual weather stations. Within a division, each weather station is weighted equal and averaged to produce divisional precipitation and temperature.



Source: http://www.esrl.noaa.gov/psd/data/usclimdivs/data/map.html 2015

Figure 2.2. National Oceanic and atmospheric Administration's Climate Division

For each division, NOAA provides monthly temperature (tenths of degree Fahrenheit), precipitation (hundredths of an inches), heating degree days, cooling degree days, Palmer Drought Severity Index (PDSI), Palmer Hydrological Drought Index (PHDI), Palmer "Z" Index (ZNDX), Modified Palmer Drought Severity Index

(PMDI), and the Standardized Precipitation Index (SPxx). Heating and cooling degree days is another way to show how hot or cold a day has been. To calculate a degree day, one averages the high and low temperatures for the day then compare it to 65° F. If the day's average is above 65°, then the difference is a cooling day value (requiring a building to cool itself). If the day's average is less than 65°, then the difference is a heating day value (requiring a building to heat itself). PDSI measures the severity of a wet or dry period meteorologically. PDHI measures the severity of a wet or dry period hydrologically. ZNDX measures the moisture variance from normal for a month. PMDI is a modification of the PDHI where NOAA selects a value from three generated values. If an area is in a dry or wet period, PDMI and PDHI will be the same, but when an area is between wet and dry the values may be different. SPxx represents the probability of an area receiving a given amount of precipitation compared to an area's average precipitation in a 1, 2, 3, 6, 9, 12, or 24 month period. NOAA's full definitions of the above indices and expected ranges for PHDI and ZNDX are in Appendix B.

The data regions for Timber Mart-South are larger than the divisions from the NCDC. NCDC divisions were grouped to coincide with Timber Mart-South regions. By comparing figure 2.1 and figure 2.2, NCDC divisions were aggregated and averaged so that the NCDC data would best overlap the Timber Mart-South data spatially. The aggregation of NCDC divisions to corresponding Timber Mart-South regions is in Appendix C.

RESULTS

For the pine pulpwood and pine sawtimber models, tests were conducted to insure the random effects panel model was the appropriate model to use. First, the

Bruesch-Pagan Lagrange Multiplier Test (Breusch 1980) rejected the hypothesis that the Timber Mart-South pricing regions had no individual effect on the model. Second, Wooldridge test (2002) failed to reject the hypothesis that there were no unobserved effects. Third, the Hausman Test (Hausman 1978) failed to reject the hypothesis that unobserved constants and the variables in the model were uncorrelated, so the following assumption,

$$\mathrm{E}(c_i \mid \mathrm{x_i}) = \mathrm{E}(c_i) = 0 \qquad \text{Equation 2.10}$$

is not rejected and the random effects panel model is appropriate for use. After running the model, a Bruesh-Godfrey (Bruesh 1978) test for serial correlation in errors rejected the hypothesis of no serial correlation. Serial correlation would compromise the variance estimates and the associated hypothesis tests, so a robust variance matrix was estimated as described in Wooldridge (2002). This robust variance matrix also addresses any potential heteroskedasticity.

For sawtimber stumpage, the coefficient estimates for precipitation difference and the one-quarter lag precipitation difference are significant in the model (Table 2.1).

Table 2.1. Weather and Pine Sawtimber Price Model Results

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.86	0.24	3.50	0.000
∆Temperature	-0.09	0.02	-6.26	0.000
∆ Precipitation	1.29	0.65	1.98	0.048
∆ $Precipitation_{-1}$	1.89	0.76	2.48	0.013
∆ $Precipitation_{-2}$	1.12	0.80	1.40	0.162
∆ $Precipitation_{-3}$	0.73	0.76	0.95	0.342
∆ $Precipitation_{-4}$	0.78	0.60	1.31	0.190
∆ Precipitation squared	-0.12	0.06	-1.90	0.057
∆ Precipitation $squared_{-1}$	-0.15	0.07	-2.02	0.044
∆ Precipitation $squared_{-2}$	-0.08	0.08	-1.00	0.315
∆ Precipitation $squared_{-3}$	-0.07	0.08	-0.86	0.389
∆ Precipitation $squared_{-4}$	-0.06	0.06	-1.05	0.295

For pine pulpwood stumpage, the coefficient estimates for the lagged differences for four periods for both precipitation and precipitation squared are significant (Table 2.2).

Table 2.2. Weather and Pine Pulpwood Price Model Results

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.75	0.29	2.63	0.009
ΔTemperature	-0.14	0.02	-8.21	0.000
Δ Precipitation	-0.06	0.68	-0.08	0.933
Δ Precipitation$_{-1}$	3.12	0.91	3.44	0.001
Δ Precipitation$_{-2}$	3.29	0.98	3.38	0.001
Δ Precipitation$_{-3}$	2.46	0.93	2.65	0.008
Δ Precipitation$_{-4}$	1.33	0.74	1.79	0.073
Δ Precipitation squared	0.02	0.07	0.31	0.754
Δ Precipitation squared$_{-1}$	-0.22	0.09	-2.49	0.013
Δ Precipitation squared$_{-2}$	-0.21	0.09	-2.18	0.029
Δ Precipitation squared$_{-3}$	-0.16	0.09	-1.77	0.077
Δ Precipitation squared$_{-4}$	-0.03	0.07	-0.40	0.689

DISCUSSION AND CONCLUSIONS

As expected, the relationship between changes in stumpage price and precipitation is positive and declining with time. Between the sawtimber and pulpwood models, the sawtimber model shows precipitation has a smaller effect on sawtimber prices and the lagged effect is not as persistent. Also, the precipitation squared difference estimators show that the price changes positively at a decreasing rate.

The difference between the coefficients and number of lags is likely due to the respective demand elasticites for pulpwood and sawtimber. Newman (1987) found pine pulpwood demand more inelastic, -.43, than pine sawtimber, -.57. Meaning that pine pulpwood quantity demanded is less responsive to changes in price than sawtimber quantity demanded. Precipitation can limit harvest operations and/or transportation (Todd and Rice 2005), which effectively reduces the short-run supply of wood. In the models above, a change in precipitation represents an increase or decrease in the timber available to furnish a mill. With pulpwood being more inelastic than sawtimber, it follows supply and demand theory that the price change would be greater for pulpwood. The greater number of lags could also be attributed to the more inelastic demand for pulpwood. The difference in temperature relates to moisture and the hydrologic cycle. As temperatures increase, the rates of evaporation and plant transpiration both increase, which lowers soil moisture. As soil moisture drops, the areas available for harvest operations increase, effectively increasing the supply of timber.

The effect of precipitation and temperature on pine stumpage prices is useful for buyers and sellers of timber. As discussed in previous literature, stumpage prices are a function of many variables. By themselves, the explanatory power of precipitation and temperature on pine pulpwood and sawtimber prices is very low, but changes in precipitation and temperature are significant variables in the stumpage price function and should be considered by buyers and sellers. A seller could utilize past and expected temperature and precipitation changes to time a sale to capture a high weather price effect. Brazee and Mendelsohn (1988) showed timing timber sales with reservation pricing could significantly increase returns on a timber investment and the results in this chapter provide useable results to help in formulating a reserve pricing strategy.

CHAPTER 3

TIMBER SALE CHARACTERISTICS' EFFECT ON SOUTHERN TIMBER PRICES[2]

[2] Armstrong, M. and J. Siry. To be submitted to *Forest Science*

ABSTRACT

This essay uses a mixed effects hedonic model to examine the effect of timber sale characteristics on timber prices in the US South. The results of the model provide coefficient estimates for timber sale type, number of bidders, harvest type, and area harvested. This result explains part of the timber price variability attributable to the timber sale type, number of bidders, harvest type, and area harvested in the US South.

INTRODUCTION

Timber sales are part of the foundation of timberland investments. Many Timberland Investment Management Organizations (TIMOs) use close-ended investments that range from 8 to 15 years in duration. The returns that TIMOs realize on timberland investments are based on the acquisition and disposition of the asset combined with the intermediate cash flows from timber sales and operations. For a closed end timber fund investment, the timber sales contribute returns to an investment similar to a bond coupon. It is similar to a coupon in that timber sales provide intermediate cash flows between the larger transactions of purchasing and selling the asset. When evaluating a potential timberland acquisition, an investor is exposed to a multitude of risks associated with the anticipated timber sale revenue, including inventory, projected growth rates, markets, and projected timber prices. Timber prices present a sizable risk to a timberland investment through price volatility from both macroeconomic and microeconomic factors.

The United States recession from 2007 through 2009 heavily impacted the forest products industry (Keegan et al. 2011). Reviewing Timber Mart-South (Norris 2014) timber prices, one can see southern softwood sawtimber and chip-and-saw timber prices drop that coincided with the US recession in 2007 and have been slow to recover through 2015. TIMOs inform part of the offer prices on timberland assets based on projected future timber prices. This drop in prices effect is twofold. First, the intermediate cash flows are less than anticipated, so value attributable to intermediate cash flows is smaller. This reduction in cash flows increases in importance if an asset is leveraged and debt payments are required. If debt interest payment is required, an investor must harvest more wood at a lower price to meet a given interest payment. Second, as a time period with poor timber prices lengthens, buyers of timberland may begin using lower assumed future timber prices to inform bids for timberland assets resulting in lower anticipated timberland sale price. Macroeconomic factors contribute a significant risk to timberland investment inputs, including timber pricing.

In addition to macroeconomic factors that drive timber prices, microeconomic factors also affect timber prices. This chapter evaluates how economies of scale, oligoposony, and marketing effect timber prices. The model used in this chapter employs a large reportered timber price data set from Timber Mart-South that allows one to assign values to timber sale characteristics. Many published journal articles explored the effects of microeconomic factors on timber prices, but the data set used in this chapter spans a much larger area than any of the previous work (Bare and Smith 1999; Dahal and Mehmood 2005; Dunn 2000; Huebschmann et al. 2004; Sydor and Mendell 2008). Additionally, the data set includes areas that have not yet had results published regarding timber sale characteristics effect on timber prices.

LITERATURE REVIEW

The list of articles regarding timber prices is long and distinguished. This literature review largely concentrates on hedonic models that include timber sale characteristics as independent variables. This chapter builds on the existing literature by expanding the geographic scope as the previous research was confined to a state or small region. The data from previous research is more varied and often more detailed than the Timber Mart-South data, but the Timber Mart-South data provides a larger data set representing a larger area than examined in previously published research.

Bare and Smith (1999) used total, or lump sum, sale price in a hedonic model to estimate stumpage prices for Washington state timber sales in 1998. The authors included species product volume, seasonality, and geographic variables in the model.

Dahal and Mehmood (2005) investigated determinants of sale prices in Arkansas. They used a hedonic model with per acre price as the dependant variable and multiple sales characteristics as independent variables, including seasonal variables, ownership, region, number of bidders, pine sawtimber volume per acre, pine pulpwood volume per acre, other pulpwood volume, loggability, and harvest type. Coefficients of interest include number of bidders at $43/acre and selection harvests at –$741/acre.

For Alabama, Dunn (2000) inspected high bid and timber sale contractual characteristics. Similar to other research, timber volume is the biggest influence on bid price. Additionally, the number of bidders variable was positive and significant at $33/acre, similar to Dahal and Mehmood (2005).

Another article examined bid price determinants in Arkansas and Oklahoma on the Ouachita and Ozark National Forests. Huebschmann's (2004) data included number of bidders and acreage of timber sales, but his final model results only included variables for a sawtimber inflation ratio, pine sawtimber per acre and total volume, and pine pulpwood per acre and total volume.

Munn and Palmquist (1997) studied timber sale prices and timber sale characteristics in North Carolina. The variables used included timber volumes, accessibility, harvest type, contract length, and geographic dummy variables. In addition to testing the significance of timber sale characteristics on price, the authors also compared results from ordinary least squares to stochastic frontier analysis.

In Central Georgia, Sydor and Mendell (2008) used a hedonic model where pay as cut pine sawtimber was the dependent variable and with continuous independent variables of pine pulpwood ratio to total pine volume and average pine sawtimber dbh and discrete variables for timber quality, age class, inventory, and loggability. The data set was reduced to 59 observations of pay-as-cut sales because the authors chose to discard stumpage sale observations due to concerns regarding the reported stumpage transaction values.

Burak (1996) employed a hedonic model exploring pine sawtimber price as a function of sales characteristics in northern Florida. The model included continuous variables for pine sawtimber volume, pine pulpwood volume, hardwood sawtimber volume, along with dummy variables for operability, topography, internal accessibility, external accessibility, harvest type, time, and month. With regards to the dummy variables, topography, operability, time, and some seasonality variables resulted as being statistically significant.

In Ontario, Puttock et al. (1990) used a hedonic model to estimate timber prices. The variables included total volume, species proportions, individual tree volume, timber quality, haul distance, and an industry price series. Further, Prescott and Puttock (1990) examine stumpage prices in Southern Ontario. In this instance, the authors used a hedonic model where the dependent variable is total stumpage sale price and the independent variables are species composition, product composition, time, total volume and volume per tree.

Kolis et al. (2014) examined stumpage sale characteristics impact on bid prices in Finland. The authors included region, haul distance, volume, species composition, harvest type, time and seasonality in an ordinary least squares model. This study only used sales where unit prices were available.

Brown et al. (2012) investigated the impact of timber sale characteristics on lump sum timber sales in Minnesota. The researchers used lump sum sales and the appraised inventory to calculate a price/cord value. The authors included volume, time, density, location, operability, and species composition.

Niquidet and van Kooten (2006) explored timber sale characteristics on competition and bid prices in British Columbia. To help alleviate the softwood lumber dispute between Canada and the United States, British Columbia began selling more timber sales at auction to substantiate that British Columbia’s government administered sales were transacting at competitive prices. The authors included volume, location, species mix, slope, harvest method, and lumber price as variables in the models.

Jackson and McQuillan (1979) produced a hedonic model that regressed timber sale characteristics on stumpage price in the Lolo National Forest in Montana. The variables include average tree diameter, lumber price, logging method, volume per acre, regeneration method, and haul distance. The authors calculated the dependent variable, per unit stumpage values, by dividing total sale price by total sale volume. The results showed that all the independent variables to be significant at 95% confidence level except haul distance.

Nautiyal (1982) employed a nonlinear hedonic model to derive the stumpage values by diameter class for stumpage sales in Ontario. The conclusion from the article is that stumpage prices by diameter class for timber sold in Ontario are best modeled in a discontinuous and step like manner.

In summary, many articles investigated the price effects of timber sale characteristics in varied geographic regions. However the geographic scope of the studies were limited to part of a state or, at most, a state. Considering the results of the previous research are geographically limited, this chapter investigates the price effects of timber sale characteristics over a broader geographical area. Additionally, the results of this chapter will be applicable to some areas that are currently without published timber sale characteristics price effects.

METHODS

The data underlying the modeling in this chapter is an unbalanced panel. This longitudinal data set allows one to investigate the effects of timber sales characteristics measured repeatedly across years and geographic regions. The model is set up as a hedonic model where the dependent variable is stumpage price and the independent variables are timber sale characteristics.

A hedonic model is able to determine values of characteristics that do not have an explicit market value. As a result of this, hedonic models are often used in valuing nonmarket goods, such as some forms of recreation or types of pollution. In this chapter, a hedonic model is utilized to determine the implicit values of timber sale characteristics. The general formulation for a hedonic model is,

$$y_i = \beta_0 + \beta_p x_i + \varepsilon_i \qquad \text{Equation 3.1}$$

Where *y* is the price,

x's are sale characteristics

i is the timber sale.

In the Timber Mart-South data set, time and location of the data points provide variability to the model, but are not variables of interest for the question of the effect of timber sale characteristics on timber prices. To address the serial relationships present in the repeated measures of the data set, a two-stage random effects hedonic model is used. Below is a general random-effects model formulation,

$$y_i = X_i\alpha + Z_i b_i + e_i \qquad \text{Equation 3.2}$$

where *y* is the dependent variable,

α are fixed effects

b are random effects

and *i* is subject.

For the hedonic model used in explaining timber sale characteristics, the dependent variable is stumpage price, timber sale characteristics are fixed effects, and time and location are random effects.

DATA

The data is a longitudinal data set from Timber Mart-South. Timber Mart-South is a timber price reporting service covering 22 regions in 11 states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia) in the US South. Each state has prices for two regions by stumpage and delivered for different size and species of trees. Prices are reported as high, low, and average for eight products in each region. Timber Mart-South has price reports back to 1976. Timber Mart-South receives prices and market information from reporters who are engaged in the buying and selling of timber, both stumpage and delivered timber sales. The timber sale information from the reporters is in electronic format from 2003. The reported electronic timber sale data set from 2003 until 2012 is used in this chapter. Summary statistics for reported timber sales of pine sawtimber, pine chip-and-saw, and pine pulpwood from 2003 through 2012 are in Table 3.1, Table 3.2, and Table 3.3, respectively.

Table 3.1 Timber Mart-South Pine Sawtimber Timber Sale Summary Statistics

Variable	Description	Observations	Mean	Stand Dev	Min	Max
Dependent Variable						
PST.PRICE ($/Ton)	Pine Sawtimber Price	18,431	33.99	11.04	0.63	97.78
Independent Variable						
LUMPSUM_NEGOTIATED	Lump Sum Negotiated Sale (dummy variable)	183				
LUMPSUM_SEALEDBID	Lump Sum Sealed Bid Sale (dummy variable)	851				
PAC_NEG	Pay-as-Cut Negotiated Sale (dummy variable)	1,015				
PAC_SEALEDBID	Pay-as-Cut Sealed Bid Sale (dummy variable)	294				
NUMBER.BIDS	Number of Bids	5,928	3.53	3.12	1	35
BIDS^2	Number of Bids Squared	5,928	31.79	59.01	1	1225
THIN	Thin Harvest (dummy variable)	3,220				
CLEARCUT	Clearcut Harvest (dummy variable)	6,934				
ACRES	Sale Acres	6,882	121	303	1	20,973
ACRES^2	Sale Acres Squared	6,882	106,681	5,335,499	1	439,866,729

Table 3.2 Timber Mart-South Pine Chip-and-Saw Timber Sale Summary Statistics

Variable	Description	Observations	Mean	Stand Dev	Min	Max
Dependent Variable						
CNS.PRICE ($/Ton)	Pine Chip-and-Saw Price	21,979	18.83	5.72	0.05	65.3
Independent Variable						
LUMPSUM_NEGOTIATED	Lump Sum Negotiated Sale (dummy variable)	158				
LUMPSUM_SEALEDBID	Lump Sum Sealed Bid Sale (dummy variable)	742				
PAC_NEG	Pay-as-Cut Negotiated Sale (dummy variable)	1,293				
PAC_SEALEDBID	Pay-as-Cut Sealed Bid Sale (dummy variable)	393				
NUMBER.BIDS	Number of Bids	5,997	2.92	3.02	1	35
BIDS^2	Number of Bids Squared	5,997	30.25	5.4	1	1,225
THIN	Thin Harvest (dummy variable)	6,456				
CLEARCUT	Clearcut Harvest (dummy variable)	7,016				
ACRES	Sale Acres	7,263	135	310	1	20,973
ACRES^2	Sale Acres Squared	7,263	114,762	5,201,772	1	439,866,729

Table 3.3 Timber Mart-South Pine Pulpwood Timber Sale Summary Statistics

Variable	Description	Observations	Mean	Stand Dev	Min	Max
Dependent Variable						
PPW.PRICE ($/Ton)	Pine Pulpwood Price	32,546	8.83	3.34	0.25	46.83
Independent Variable						
LUMPSUM_NEGOTIATED	Lump Sum Negotiated Sale (dummy variable)	189				
LUMPSUM_SEALEDBID	Lump Sum Sealed Bid Sale (dummy variable)	837				
PAC_NEG	Pay-as-Cut Negotiated Sale (dummy variable)	2,340				
PAC_SEALEDBID	Pay-as-Cut Sealed Bid Sale (dummy variable)	610				
NUMBER.BIDS	Number of Bids	8,777	2.8	2.8	1	35
BIDS^2	Number of Bids Squared	8,777	15.71	42.8	1	1,225
THIN	Thin Harvest (dummy variable)	10,963				
CLEARCUT	Clearcut Harvest (dummy variable)	9,160				
ACRES	Sale Acres	10,359	132	268	1	20,973
ACRES^2	Sale Acres Squared	10,359	89,414	4,353,509	1	439,866,729

The data set is an unbalance panel of 56,542 records with 23 columns. The columns are year, quarter, state, county, area, stumpage/delivered, report type, pine sawtimber price, pine sawtimber volume, chip-n-saw price, chip-n-saw volume, pine pulpwood price, pine pulpwood volume, hardwood sawtimber price, hardwood sawtimber volume, reporter, sale type (lump sum or pay-as-cut), contract type (negotiated or sealed bid), acres, number of bids, and harvest type (clearcut, thin, or other). Of the 56,542 records, only 268 records have all the columns populated. If one considers prices for the respective products that have the sale characteristics of sale type, contract type, acres, number of bids, and harvest type, pine sawtimber has 2,042 records, pine chip-n-saw has 2,293 records, pine pulpwood has 3,500 records, hardwood sawtimber has 571 records, and hardwood pulpwood has 1,042 records. Using the reported prices and the sales characteristics, a hedonic model will show the marginal effect of the different sales characteristics.

In the data, there are 5,396 records that report the contract type as either lump sum or pay as cut. For these records, most clearcuts are reported as lump sum sales while most thinnings are reported as pay as cut sales. For lump sum sales, a seller receives one payment for all of the standing timber. In contrast for pay-as-cut sales, a seller receives a per unit price for the timber as it is harvested. Pay-as-cut is the preferred contract type for using a hedonic model because pay as cut prices are actual transacted prices as opposed to an estimated per unit price from a lump sum sale. Lump sum sales account for 1,719 of the 5,396 records in the data set and 1,391 of those records are for clearcut sales. Including lump sum sales in the model is not ideal, but excluding them reduces the number of observations, especially for clearcut records. Due to the limited data points from pay as cut observations, lump sum sales are also included in the model. In addition to increasing the sample size, there is precedent in previous research to employ hedonic models utilizing lump sum prices. Many of the articles referenced in the Literature Review section used lump sum sale and volume to estimate product values. Mathematically, the equation for a lump sum sale is,

Lump sum = Price per Unit x Volume Equation 3.3

Many journal articles authors solve for the unknown *Price per Unit* by rearranging the equation to,

Price per Unit = Lump sum / Volume Equation 3.4

Similarly, the reporters for Timber Mart-South lump sum sales provide a derived *Price per Unit* from the sale volume and lump sum value.

RESULTS

Timber sale characteristics effects were modeled for pine sawtimber stumpage prices, pine chip-and-saw stumpage prices, and pine pulpwood stumpage prices. The model's random error values were found to be homoskedastic but correlated. Without correcting the correlated errors, the significance tests for parameters are not correct and the estimates are not efficient. The error correlation was corrected by introducing an ARIMA(P=1,Q=1) structure for the random errors.

The number of observations in the respective models are 2,042 for pine sawtimber, 2,293 for pine chip-and-saw, and 3,500 for pine pulpwood. The majority of the timber sale characteristic variables were statistically significant at a 5% level. The summary results for pine sawtimber, pine chip-and-saw, and pine pulpwood can be found in Table 3.4, Table 3.5, and Table 3.6, respectively.

Table 3.4 Timber Sale Characteristics Effect on Pine Sawtimber Price Results

	Estimate	Std.Error	t-value	p-value
INTERCEPT	28.80527	0.96	29.96	0.00
LUMPSUM_SEALEDBID	-1.73019	0.71	-2.44	0.01
PAC_NEG	-3.12907	0.62	-5.08	0.00
PAC_SEALEDBID	-5.02255	0.87	-5.74	0.00
NUMBER.BIDS	0.63447	0.13	4.70	0.00
BIDS^2	-0.01524	0.01	-2.80	0.01
THIN	-3.08320	0.41	-7.61	0.00
ACRES	0.00852	0.00	2.60	0.01
ACRES^2	-0.00001	0.00	-1.30	0.19

Table 3.5 Timber Sale Characteristics Effect on Pine Chip-and-saw Price Results

	Estimate	Std.Error	t-value	p-value
INTERCEPT	16.90490	0.50	34.13	0.00
LUMPSUM_SEALEDBID	-0.61028	0.38	-1.63	0.10
PAC_NEG	-0.34698	0.33	-1.06	0.29
PAC_SEALEDBID	-1.16919	0.43	-2.73	0.01
NUMBER.BIDS	0.46631	0.07	6.72	0.00
BIDS^2	-0.01308	0.00	-4.81	0.00
THIN	-1.85442	0.18	-10.42	0.00
ACRES	0.00226	0.00	1.97	0.05
ACRES^2	-0.000002	0.00	-1.74	0.08

Table 3.6 Timber Sale Characteristics Effect on Pine Pulpwood Price Results

	Value	Std.Error	t-value	p-value
INTERCEPT	8.22601	0.33	24.81	0.00
LUMPSUM_SEALEDBID	-0.42554	0.25	-1.69	0.09
PAC_NEG	0.38836	0.22	1.79	0.07
PAC_SEALEDBID	0.47680	0.27	1.74	0.08
NUMBER.BIDS	0.30104	0.05	6.61	0.00
BIDS^2	-0.00548	0.00	-2.90	0.00
THIN	-0.60120	0.10	-5.77	0.00
ACRES	0.00174	0.00	3.07	0.00
ACRES^2	-0.000001	0.00	-2.35	0.02

Sale type and contract type were combined into a single dummy variable so timber sales variables are lump sum sealed bid, pay-as-cut sealed bid, lump sum negotiated, and pay-as-cut negotiated. This made the effect of the sale/contract combination explicit. The pine sawtimber marginal values for the sale and contract combinations are -1.73 for lump sum sealed bid sale, -3.12 for pay-as-cut negotiated sale, and -5.02 for pay-as-cut sealed bid. The pine chip-and-saw marginal values for the sale and contract combinations are -.61 for lump sum sealed bid sale, -.34 for pay-as-cut negotiated sale, and -1.16 for pay-as-cut sealed bid. The pine pulpwood marginal values for the sale and contract combinations are -.42 for lump sum/sealed bid sale, .38 for pay-as-cut negotiated sale, and .47 for pay-as-cut sealed bid.

The NUMBER.BIDS coefficient is .63 for pine sawtimber, .47 for pine chip-and-saw, and .30 for pine pulpwood. The result means that for each additional bidder participating in a timber transaction, the price per ton increases by $.63, $.47, and $.30

for pine sawtimber, pine chip-and-saw, and pine pulpwood, respectively. These marginal values as percent of stumpage price, where the stumpage price is represented by the intercept, are 2%, 3%, and 4% for pine sawtimber, pine chip-and-saw, and pine pulpwood, respectively. Additionally, the BIDS^2 coefficient is significant and negatively signed. This indicates that the stumpage price increases at a decreasing rate as more bidders participate in a timber sale.

The marginal value of thinning is represented by the THIN coefficient of -3.08 for pine sawtimber, -1.85 for pine chip-and-saw, and -.60 for pine pulpwood. These values represent a percent change price due to a thin harvest of -10.7% for pine sawtimber, -11% for pine chip-and-saw, and -7.3% for pine pulpwood compared to a clearcut harvest.

The ACRES coefficients are .0085 for pine sawtimber, .0022 for pine chip-and-saw, and .0017 for pine pulpwood. The ACRES^2 coefficients are small and negatively signed indicating that timber prices increase at a decreasing rate as the sale area increases. The ACRES^2 pine sawtimber and pine chip-and-saw coefficients are statistically significant at a 20% and 10% level, respectively.

DISCUSSION AND CONCLUSIONS

The results are as expected given previous research. These results are valuable to both buyers and sellers engaged in timber transactions because the results provide marginal values for several characteristics of timber sales. As expected the microeconomic factors represented by the modeled variables of contract sale type, number of bidders, sale size, and harvest type all are statistically significant in the hedonic timber price model.

Pay-as-cut sales had negative marginal values for solidwood products, pine sawtimber and chip-and-saw, while pine pulpwood had a positive marginal value for pay-as-cut sales. This may be due to that nearly twice as many pay-as-cut sales in the data are from thinnings. Generally, the silvicultural motivation of thinning pine stands in the US South is to increase the volume of the higher value solidwood products, pine sawtimber and pine chip-and-saw, at final harvest. So in a thinning operation, the removed pine sawtimber and pine-chip-and saw is generally lower quality than the residual pine sawtimber and pine chip-and-saw. Additionally, often sawmills pay less for younger wood from thinnings because of the poorer wood quality compared to older wood.

Negotiated sales had larger coefficients compared to sealed bid auctions, if only one bid is received. Assuming that negotiated bids only include one bidder, then as the number of bidders increase, the sealed bid becomes higher value depending on the product and contract type. For pine sawtimber, the sealed bid auction generated a higher price than a negotiated after four bidders. For pine chip-and-saw, the sealed bid auction generated a higher price than a negotiated after three bidders. For pine pulpwood, the sealed bid auction generated a higher price than a negotiated sale after two bidders.

The effect of oligopsonies and imperfect competition (Murray 1995) in many timber markets is highlighted by the significance of the number of bidders variable. The number of market participants effect on pricing can be seen by considering a Cournot equilibrium model (Varian 1992) where price is a function of elasticity of demand and market share. When there are few participants in a timber sale, a firm is able to take advantage of market inefficiencies and exercise oligopsony power. Alternatively, as the number of timber sale participants increase, the oligopsony market power decreases, and timber prices should increase. The increase in price as competition increases is consistent with an imperfect market with few buyers moving towards a more perfect market as more buyers participate. Many attributes effect the interest garnered and price paid in a timber sale, but the model result shows that an increase in prices can be expected from increasing the number of bidders.

When timber is sold as stumpage, the stumpage price is mostly a function of the delivered price to a mill destination less the cost of harvesting and hauling the wood. The total harvesting and haul costs are a combination of variable and fixed costs. A high fixed cost in a timber harvesting operation is the cost of time involved in moving and setting up harvesting equipment. As timber volume increases for a timber sale, the fixed cost of moving and setting up equipment is spread across more volume and the per unit average cost decreases. Assuming the variable cost of harvesting wood is close to constant, then as volume of wood harvested increases the average cost curve slopes downward towards the marginal cost curve. This reduction in cost is passed through the stumpage price function so that the stumpage price increases.

The increase in stumpage prices due to decreased costs at a decreasing rate attributable to economies of scale in timber harvesting operations is evidenced by the significance of the timber sale area variables, ACRES and ACRES^2. The total volume of timber harvested from a timber sale is generally a function of the acres associated with the timber sale, so that as timber sale volume increases as timber sale area increases. Sale area, ACRES, is a primary input for a timber sale volume production function. Area and the square of area, ACRES^2, are used as variables in the model to determine if price effect due to economy of scale cost savings increase or decrease at increasing or decreasing rates.

Harvest type coefficients show lower prices associated with thinning versus clearcut operations. This is expected because generally clearcuts are more cost efficient harvests than thinnings combined with solidwood products from thinnings are usually less desirable. Harvesting costs increase in thinnings because the equipment traverses more area to get an equal volume of wood and trees removed in thinnings are generally smaller than clearcuts so equipment must process more trees to get an equal volume as from a clearcut harvest. For solidwood products, pine sawtimber and pine chip-and-saw, the price decrease from thinnings is three and five times as much as for pulpwood, respectively. This is likely due to a lower wood quality pine sawtimber and pine chip-and-saw from thinnings. Silviculturally one generally thins a southern pine stand to increase the solidwood component at final harvest, so it is counter-productive to remove higher quality, final crop trees in a thin. Also, thinnings generally occur at younger ages than clearcuts so thinnings produce younger, less desirable solidwood.

This work provides marginal values for several timber sale characteristics. Both buyers and sellers of timber would benefit from considering these marginal values as they transact timber. Additionally, the results would be beneficial to entities that employ financial year budgets. Forecasting timber prices for budgets is an integral part of many timber companies and these results would allow those companies to better refine the budgeted prices based on the characteristics of the timber tracts that are budgeted to be sold in a given year. A timber company incorporating these results could reduce the price variance between budgeted and realized prices for timber sales.

A limitation to this investigation is the inclusion of lump sum sale values in the hedonic model. In lump sum sales, the individual product prices that are reported are estimated by the reporter and are not what is actually transacted per unit. Hedonic models perform best when using actual transacted prices as opposed to estimated prices. For this research, the increased number of observations gained by including the lump sales outweighed the fact that the lump sum prices are estimates.

In this work, the effects of difference price regions and time were treated as random effects. This chapter's results established the statistical significance and values associated with different timber sale characteristics. Interesting follow up questions include investigating if values for timber sale characteristics were statistically different between price regions. Also a question of interest would be whether the values changed over time.

CHAPTER 4

LONG-RUN SOFTWOOD SAWTIMBER PRICE RELATIONSHIP BETWEEN GEORGIA AND OREGON[3]

[3] Armstrong, M. and J. Siry. To be submitted to *Forest Science*

ABSTRACT

This essay tests for cointegration between the softwood sawtimber prices in a region in Georgia and a region in Oregon using the Engle and Granger test. The results of the test suggest that the softwood sawtimber prices in a region of Georgia and a region of Oregon are cointegrated. The consequence of this result is that one would expect the long-run price change between the respective regions in Georgia and Oregon to be similar.

INTRODUCTION

In the United States, the timber industry is concentrated in the US Pacific Northwest and US South regions. Combined, the US Pacific Northwest and US South regions account for approximately 78% of total wood volume removals and 85% of the total softwood volume removals (Oswalt 2012). Consequently, the majority of United States timberland investment management organizations (TIMOs) and timberland real estate investment trusts' (REITs) assets are in the US Pacific Northwest and US South regions.

Some TIMOS and REITS are isolated in either the US Pacific Northwest or the US South, but many TIMOs and REITs manage assets in both regions. Many of the largest TIMOs and REITS by acres manage assets in both regions. For these TIMOs and REITs, assets in geographically distant regions are driving investment returns.

In addition to being geographically distant, the characteristics of the timber assets in the US Pacific Northwest and US South are very different. The soils, topography, and climate are fundamentally different between the two regions. In both regions the primary commercial species group is softwoods, but there is no commercial species overlap between the two regions. Additionally, the biological growth rates and common silvicultural treatments are different between the two regions. Beyond the biological differences, there are economic differences such as logging costs, domestic markets, export markets, and end products. In summary, the differences between the two regions are significant.

In spite of the differences between the two timber producing regions, the price for softwood lumber, the primary high-value end products of timber, appear to be cointegrated (Yin and Baek 2005). Combining the national cointegration of lumber prices with the result that timber prices are cointegrated regionally with lumber prices (Ning and Sun 2014), the question of cointegration of national timber markets warrants examination. Using transitive properties, reason would follow that if southern timber prices were cointegrated with southern lumber prices and southern lumber prices were cointegrated with northwest lumber prices and northwest lumber prices were cointegrated with northwest timber prices, then southeast timber prices could be cointegrated with northwest timber prices. If northwestern and southern timber prices are cointegrated, then there are implications to expected returns and diversification for investments that span the two geographic regions.

LITERATURE REVIEW

There are many published articles dedicated to testing market integration in timber or timber product markets. The tests for market cointegration span regional timber markets and national lumber markets, but the literature review did not reveal any article testing for market integration between timber markets between the two largest wood producing regions in the United States.

Yin et al. (2002) tested the market cointegration of southern timber regions. The researchers used 13 pine sawtimber markets and 11 pine pulpwood markets from Timber Mart-South. Using the Johansen test and the Dicky-Fuller test it was determined that the US South timber market is not cointegrated. The 13 pine sawtimber regions were grouped into 4 regions. Similarly, the 11 pine pulpwood regions were also grouped into 4 regions. The pulpwood markets were more integrated than the sawtimber markets. The authors' opinion was that the southern timber markets were not cointegrated because of the bulky nature of the commodity.

Nagubadi (2001) investigated the hardwood stumpage markets in six states in the US South. First, the author investigated long-run price relationships by testing the cointegration of Timber Mart-South prices for hardwood pulpwood, mixed hardwood sawtimber, and oak sawtimber by utilizing both the Johansen test and Engle and Granger test. After using both tests, he concluded that the six states are not fully cointegrated for any of the three timber products. However, he concluded that hardwood sawtimber is closer to being cointegrated than hardwood pulpwood because the pair-wise Engle and Granger method showed that mixed hardwood sawtimber price was cointegrated in five of the six states. Second, he utilized an error correction model to examine short-run price relationships between the states.

Ning and Sun (2014) examined the vertical price integration between stumpage, delivered, and end product prices in the US Pacific Northwest and US South. The authors found that the stumpage and delivered prices were more integrated than delivered and lumber prices. Additionally, the US South had a stronger degree of vertical cointegration than the US Pacific Northwest. They used Oregon Department of

Forestry, Timber Mart-South, and Random Lengths for prices and determined cointegration by using the Johansen test and Engle and Granger test.

Yin and Caulfield (2002) used a Brownian motion model to investigate Timber Mart-South prices. This paper discusses the existence of two distinct time periods for the Timber Mart-South price series, with the demarcation roughly the late 1980's. The authors investigated real and nominal price growth rates and volatility for selected Timber Mart-South regions and products. The authors also compared prices between the US Pacific Northwest and US South, showing that sawtimber prices follow lumber prices due to the inputs high portion of final cost, and the lack of relationship between pulp/paper prices and pulpwood stumpage conversely due to pulpwood input being a small cost of the final product.

Several articles address the Law of One Price in the softwood lumber markets. Uri and Boyd (1990) , Jung and Doroodian (1994), and Yin and Baek (2005) all concluded that the US lumber market is cointegrated and so the Law of One Price holds. The authors came to the same conclusions after refining the methodology of the previous article. Uri and Boyd tested for market cointegration with Granger causality tests. Jung and Doroodian employed the Johansen test to confirm Uri and Boyd's conclusion. Yin and Baek raised issues with the Jung and Doroodian's interpretation of the Johansen procedure results. Consequently, Yin and Baek used more robust model structures in their tests along with using a more granular data set than the one used by Uri and Boyd, and Jung and Doroodian. Yin and Baek confirmed the conclusions of the previously published work.

Baek (2006) expanded the scope of his work with Yin to test the market cointegration of the North American lumber market. Baek concluded that the North American softwood lumber market is cointegrated. Additionally, he concluded that the North American softwood lumber market structurally shifted after US federal restrictions on timber harvesting in the US Pacific Northwest. Baek used Perron's method to test for the structural shift.

Nanang (2000) tested for Canadian softwood lumber market cointegration. Nanang tested five geographic regions and concluded that all the regional lumber markets had unit roots, but that the markets were not cointegrated when the Johansen test was applied.

Alavalapati et al. (1997) investigated the long-run and short-run price relationships in the Canadian wood pulp market. One of the main findings of the article was that the US and Canadian wood pulp markets were cointegrated so Law of One Price held.

Bingham et al. (2003) explored market cointegration for pulpwood and sawtimber in the US South. The authors utilized the Engle and Granger method to test for pair-wise cointegration for roundwood prices in Timber Mart-South regions. The tests results rejected the Law of One price for the US South roundwood markets being cointegrated. The results from the Engle and Granger tests were combined with distance, volume, and mill variables to produce a meta-regressions analysis. From these meta-regression results, the authors present visually contrived markets for sawtimber and pulpwood.

In summary, many articles exist showing national or international cointegration of wood products or regional cointegration of timber markets, but no articles were found during the literature review that present evidence of cointegration between regional timber markets. Providing evidence showing a cointegrated relationship between timber prices in the US Pacific Northwest and US South would be new information regarding timber markets.

DATA

The price series used in this research are delivered prices from Timber Mart-South and the Oregon Department of Forestry. Both price series are reported quarterly and begin in the late 1970's.

Timber Mart-South is a quarterly price series of multiple types of timber for 22 regions covering 11 states in the US South (Figure 4.1). The price series spans from the fourth quarter 1976 to current. Prices are gathered quarterly through use of a standardized survey to reporters. Reporters are individuals and companies who are engaged in frequent timber sales transactions. Prices are reported as average, Hi, and Lo. Hi and Lo are the 75^{th} and 25^{th} quartile respectively.

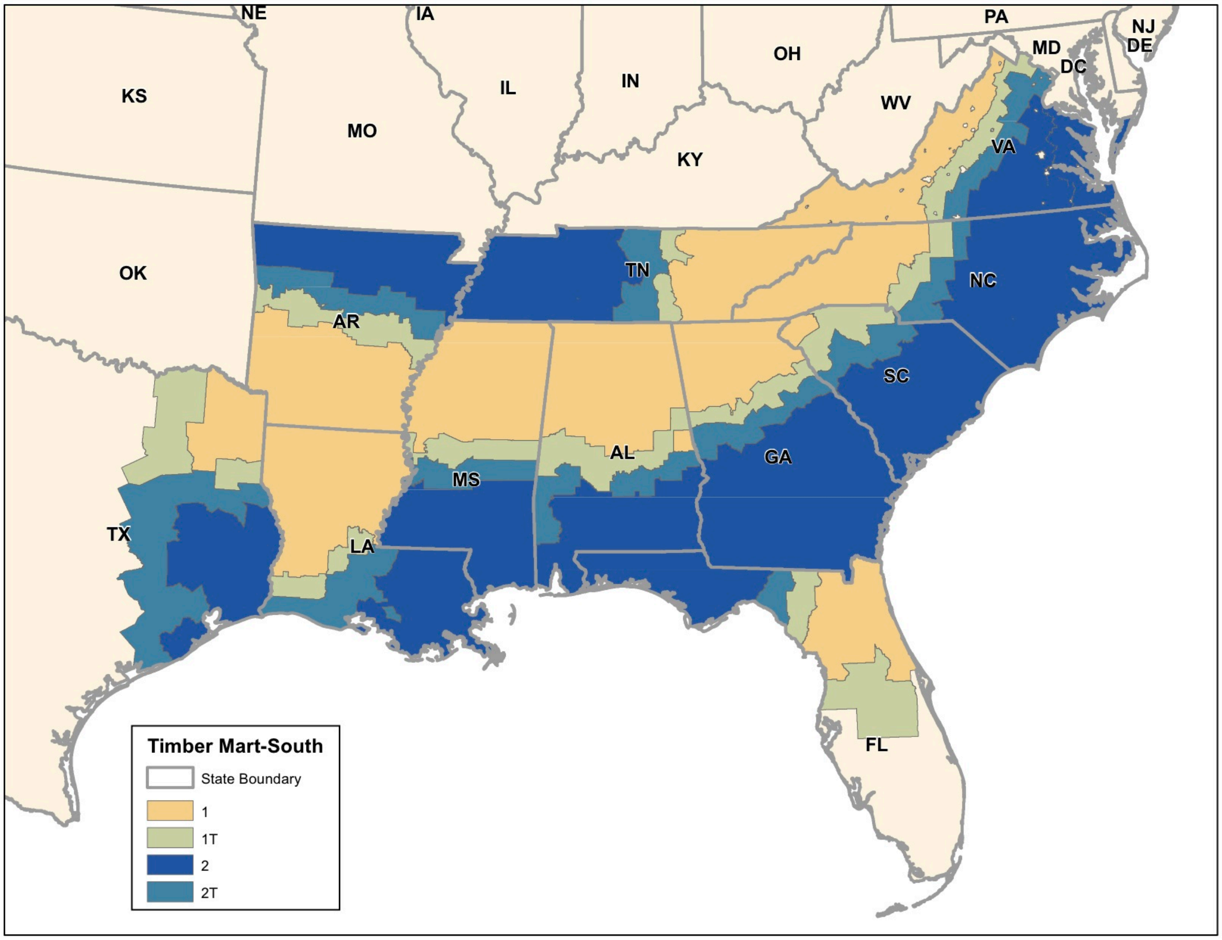
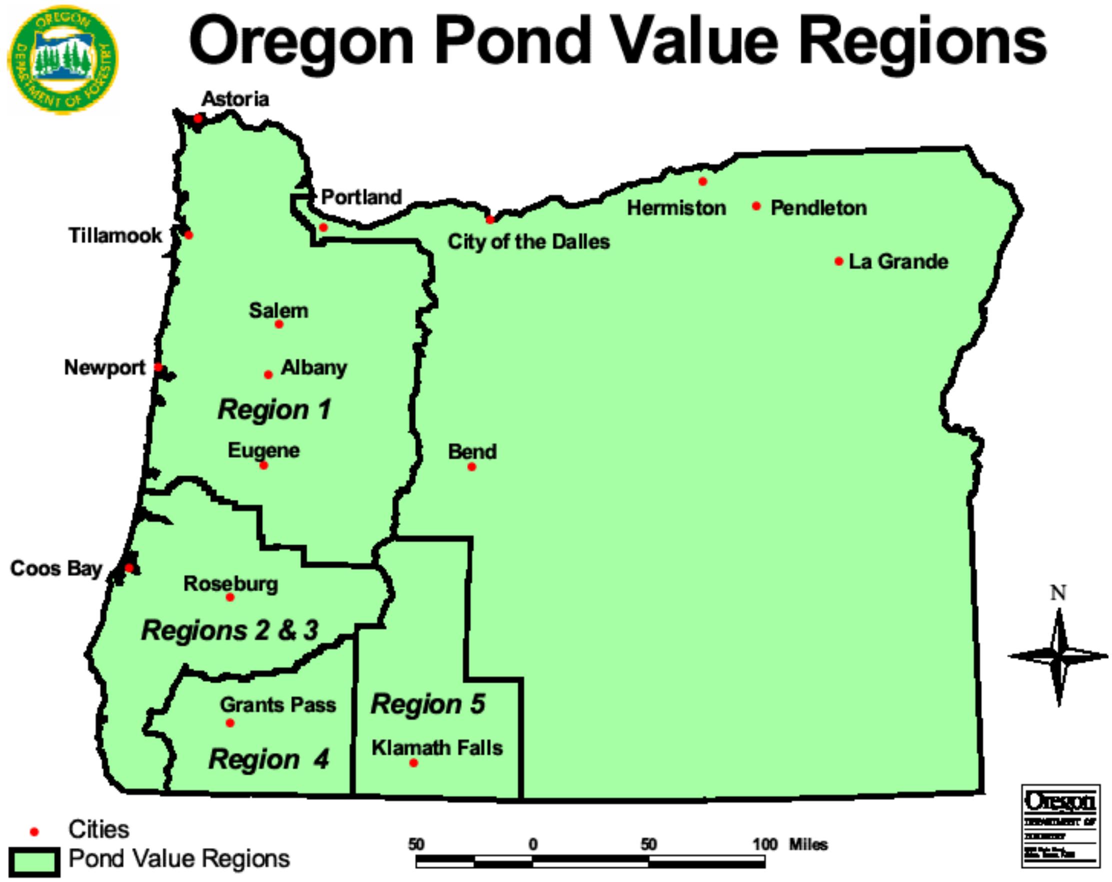


Figure 4.1 Timber Mart-South Timber Price Reporting Regions

Timber Mart-South provides stumpage and delivered prices for multiple products. The stumpage price is the price for a ton of wood in a standing tree. The delivered price is the price for a ton ($/Ton) of wood delivered to the gate of a processing facility. The delivered price includes the cost of harvesting and transporting the wood to a mill facility. Timber Mart-South provides these prices for pine pulpwood, pine chip-and-saw, pine sawtimber, pine poles, pine ply logs, mixed hardwood pulpwood, mixed hardwood sawtimber, oak sawtimber.

From 1980 through 1994, Timber Mart-South reported prices in Kentucky and Oklahoma. Currently, each state is divided into two regions. Prior to 1992, prices were reported for three regions per state, except Texas, which had two regions. In 1992, Timber Mart-South began reporting two regions per state. The region transformation generally consisted of combining regions one and two into region one and relabeling region three to region two. A table outlining the transformation from three to two regions is attached as Appendix A.

Oregon log prices for varying species and log grades are available from the Oregon Department of Forestry (ODF) from 1977 through 2014 by quarter. The species reported change across reporting regions and include Douglas-fir, western hemlock, spruce, western red cedar, red alder, sugar pine, ponderosa pine, incense cedar, and lodgepole pine. The prices are reported as delivered to mill, or pond price, in dollars per thousand board feet ($/MBF). Prices are currently available for 5 regions (Figure 4.2). From 1977 through 1981, the price series were grouped into 11 regions, but the reporting on several of the regions is not consistent. These 11 regions were rationalized into 5 regions where some regions were combined and some eastern regions were dropped.



Source: http://www.oregon.gov/odf/state_forests/timber_sales/docs/pvr.pdf 2015

Figure 4.2 ODF Pond Value Regions

The ODF time series has incomplete data for many quarters in regions 4 and 5 due to lack of market activity. Additionally, the number and type of log prices reported has changed over time. Descriptions of log grades can be found in Appendix D. From first quarter 1977 through third quarter 1981, prices were reported by diameter groupings and log grade. After third quarter 1981, the series stopped reporting by diameter grouping.

Cointegration between timber markets is more likely when timber markets transact more volume (Bingham et al. 2003). So to test for cointegration between the sawtimber markets in the US Pacific Northwest and US South, Timber Mart-South

Georgia region 2 and the ODF region 1 were selected because they represent the top softwood volume producing regions in the top two softwood volume producing states (Oswalt 2012). The specific softwood time series tested for cointegration are pine sawtimber delivered price from Timber Mart-South Georgia Region 2 and Douglas-fir #2 saw, western hemlock #2 saw, and western red cedar #2 saw from ODF Region 1. Summary statistics for the four price series are in Table 4.1.

Table 4.1 Summary Statistics for Softwood Sawtimber Prices from Timber Mart-South GA2 and ODF Region 1

Timber Product Price	Mean	Standard Deviation	Minimum	Maximum
GA Pine Sawtimber Delivered ($/ton)	45.04	11.68	24.8	66.04
OR Western Hemlock #2 ($/mbf)	373	114	180	665
OR Western Red Cedar #2 ($/mbf)	737	282	215	1175
OR Douglas-Fir #2 ($/mbf)	499	160	220	825

METHODS

Prior to testing for cointegration, one must establish the presence of unit roots in the individual time series. If the time series are stationary then there is no unit root. If there is no unit root, then the time series cannot be cointegrated.

After establishing the presence of a unit root, one can then test for cointegration. The Engle-Granger (1987) two-step method and the Johansen (1991) method were considered to test for cointegration. The Engle and Granger two-step method tests a pair of time series for cointegration, while the Johansen method is able to test multiple time series for cointegration. In spite of the limitation to only test a pair of time series, the Engle and Granger method was selected to test for cointegration because of its flexibility. The Engle and Granger method is capable of including information beyond the raw time series data, such as a time variable or a structural market shift.

Prior to testing for cointegration, a price series must first be tested for stationarity. The augmented Dickey-Fuller (ADF) tests for the presence of unit roots in the time series. For this chapter, the model formulation for the test is, as outlined by Greene (2003),

$$y_t = \mu + \beta t + \gamma y_{t-1} + \gamma_1 \Delta y_{t-1} + ... + \gamma_p \Delta y_{t-p} + \varepsilon_t \qquad \text{Equation 4.1}$$

Where,

y is price

μ is a constant

t is time

ρ is the lag factor

γ is the autoregressive coefficient

This formulation allows for trend and drift in the time series.

After establishing the presence of unit roots, one can then proceed to test whether the time series are cointegrated using the Engle and Granger. For the Engle and Granger two step method, one first sets up the cointegrating equation.

$$y_{1t} = \mu + \beta_1 t + \beta_2 y_{2t} + \varepsilon_t \qquad \text{Equation 4.2}$$

Where,

y is price

μ is a constant

t is time

Then, one tests for stationarity of the errors from the cointegrating equation 4.2. This is done using the ADF test on the residuals, rewriting the above equation as.

$$\varepsilon_t = y_{1t} - \mu - \beta_1 t - \beta_2 y_{2t} \qquad \text{Equation 4.3}$$

The ADF test null hypothesis is that the time series is nonstationary. If the null hypothesis is rejected, then the errors are stationary and consequently cointegrated.

RESULTS

There were visual trends in the delivered prices of southern yellow pine (Figure 4.3), Douglas-fir (Figure 4.4), western hemlock (Figure 4.5), and western red cedar (Figure 4.6).

Figure 4.3 Georgia Timber Mart-South Region 2 Southern Yellow Pine Delivered Price

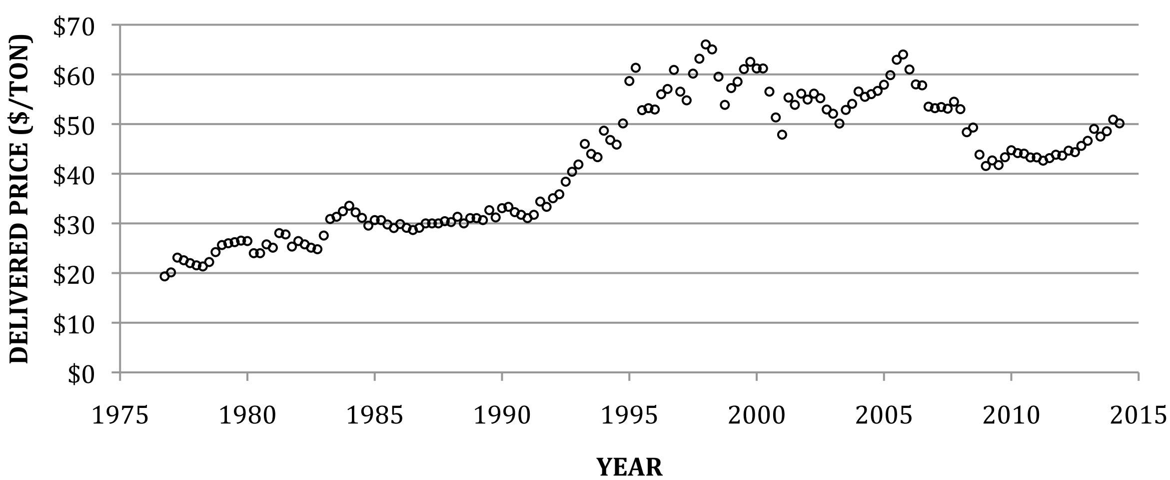


Figure 4.4 ODF Region 1 Douglas-fir #2 Saw Delivered Price

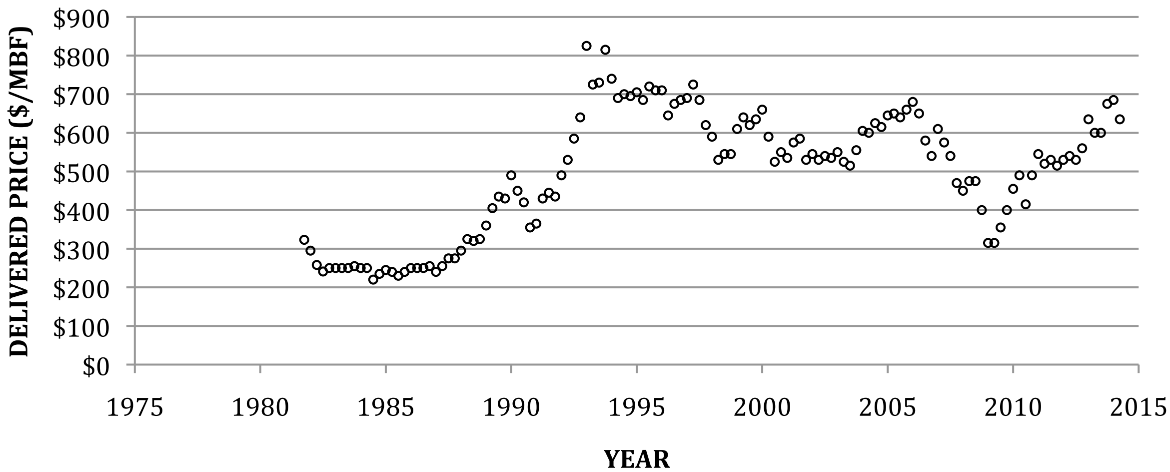


Figure 4.5 ODF Region 1 Western Hemlock #2 Saw Delivered Price

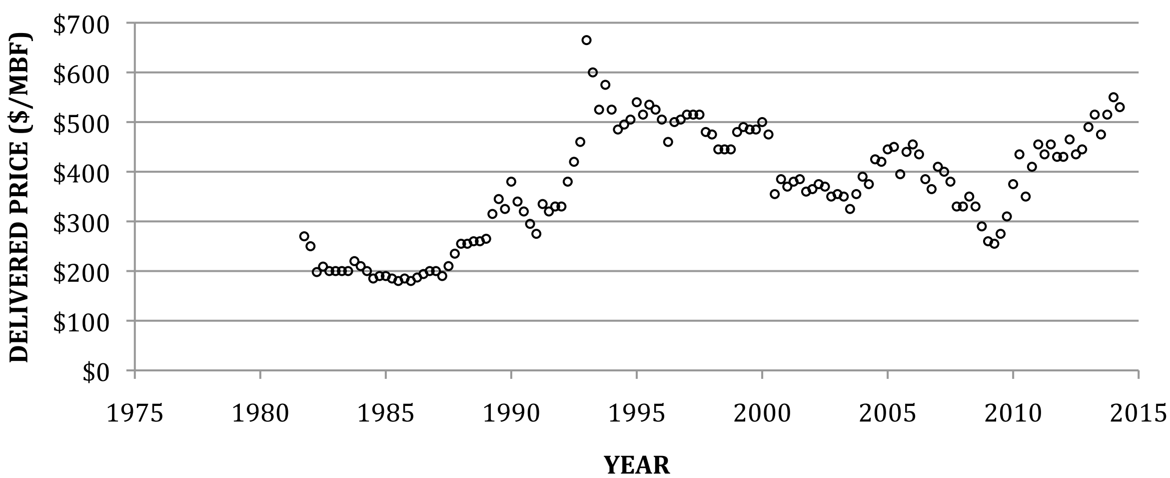
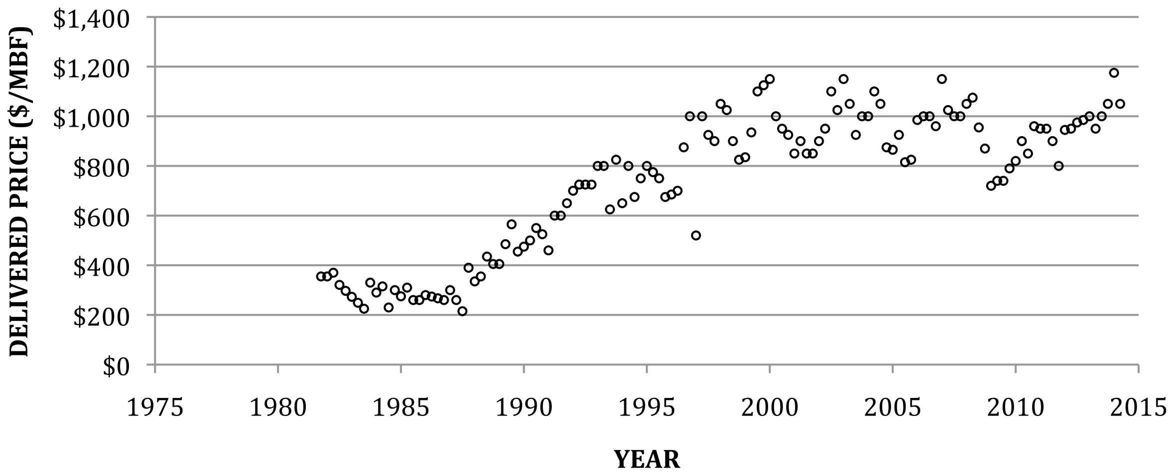
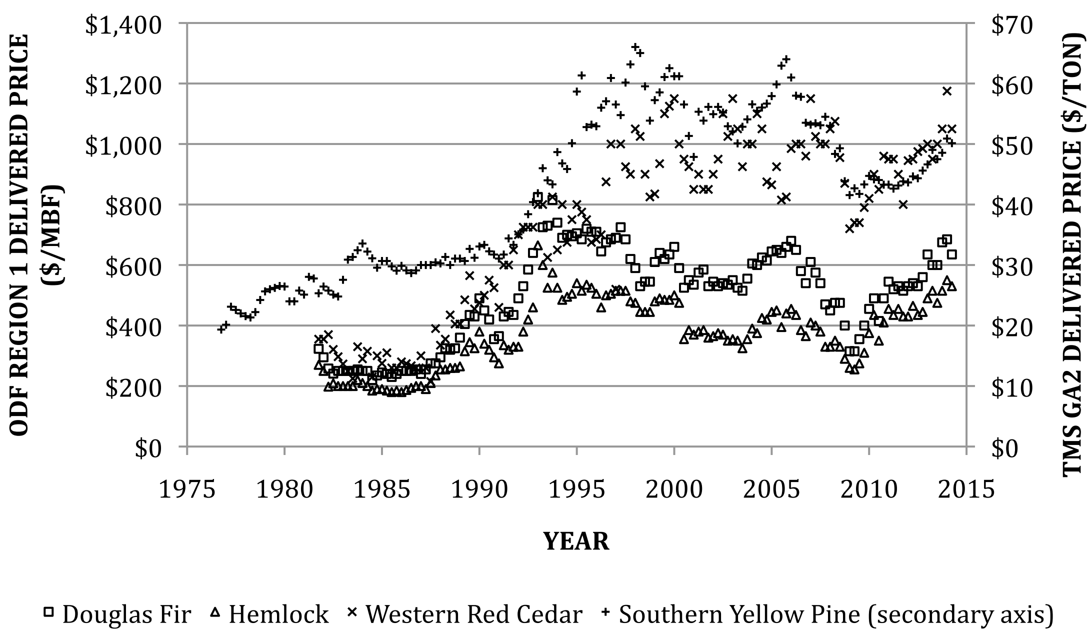


Figure 4.6 ODF Region 1 Western Red Cedar #2 Saw Delivered Price



In Figure 4.7, one can see the price series and their similarities. Note that the southern yellow pine price is on the secondary axis.

Figure 4.7 Timber Mart-South Georgia Region 2 and ODF Region 1 Delivered Sawtimber Prices



The delivered price time series were tested for stationarity by employing the ADF test that accounted for unit roots without drift or trend, with drift, and with drift and trend. Additionally, the ADF tests were performed including lags from zero through 5 quarters. Including lags variables were found to be statistically insignificant in testing for unit roots. All of the tests failed to reject the null hypothesis that the price series were nonstationary in the 12 combinations of the ADF tests. The ADF test statistics with no lag variables are reported for the delivered prices in Table 4.2.

Table 4.2 Unit Root Test Results

Delivered Log	Drift	Trend	ADF Test Statistic	Critical Value @ 5%
GA Pine Sawtimber Delivered	NO	NO	0.282	-1.95
OR Douglas-Fir #2	NO	NO	0.132	-1.95
OR Western Hemlock #2	NO	NO	0.229	-1.95
OR Western Red Cedar #2	NO	NO	0.393	-1.95
GA Pine Sawtimber Delivered	YES	NO	-1.794	-2.88
OR Douglas-Fir #2	YES	NO	-1.723	-2.88
OR Western Hemlock #2	YES	NO	-1.606	-2.88
OR Western Red Cedar #2	YES	NO	-1.432	-2.88
GA Pine Sawtimber Delivered	YES	YES	-1.683	-3.43
OR Douglas-Fir #2	YES	YES	-1.856	-3.43
OR Western Hemlock #2	YES	YES	-1.992	-3.43
OR Western Red Cedar #2	YES	YES	-2.689	-3.43

After establishing nonstationarity in the time series, one must test that the time series are integrated of the same order. To accomplish this, the four time series were first differenced and retested for stationarity using the ADF test. After first differencing, all of the ADF tests rejected the null hypothesis that the time series were nonstationary. This result shows that all the time series have a unit root, or integrated order of one.

After establishing the presence of a unit root, the first step of the Engle Granger cointegration test is to regress one price series on one another using ordinary least squares (OLS). A benefit of using the Engle Granger cointegration test compared to the Johansen test is the ability to include additional explanatory variables, such as a structural market shift. In 1990, the Northern Spotted Owl was listed under the Endangered Species Act (ESA). After 1990, harvests on public lands declined dramatically. A structural shift occurred in the US lumber market after the ESA listing of the Northern Spotted Owl and the decline in harvests on public land (Baek 2006). Given price transmission between delivered sawtimber prices and lumber prices in both the US South and US Pacific Northwest (Ning and Sun 2014), a structural shift dummy variable is included in the ordinary least squares regressions and is statistically significant (Table 4.3).

Table 4.3 Market Structural Shift Coefficient

Dependent Variable	Independent Variable	Structural Shift Coefficient	Pr(>|t|)
OR Western Hemlock #2	GA Pine Sawtimber Delivered	133.97	7.51E-09
OR Western Red Cedar #2	GA Pine Sawtimber Delivered	324.79	4.23E-14
OR Douglas-Fir #2	GA Pine Sawtimber Delivered	170.55	2.05E-09
GA Pine Sawtimber Delivered	OR Western Hemlock #2	13.37	2.43E-08
GA Pine Sawtimber Delivered	OR Western Red Cedar #2	4.45	0.0672
GA Pine Sawtimber Delivered	OR Douglas-Fir #2	9.41	5.33E-05

In the second step in the Engle Granger cointegration test, an ADF test was performed on the residuals from the ordinary least squares regressions in the first step. All of the combinations of Oregon delivered sawtimber prices with the Georgia delivered sawtimber prices are cointegrated because the ADF test rejects the null hypothesis that the OLS residuals are nonstationary. The test statistics from the ADF tests can be seen in Table 4.4.

Table 4.4 Engle Granger Cointegration Test Results

Dependent Variable	Independent Variable	Drift	Trend	ADF Test Statistic	Critical Value @ 5%
OR Western Hemlock #2	GA Pine Sawtimber Delivered	No	No	-2.9801	-1.95
OR Western Red Cedar #2	GA Pine Sawtimber Delivered	Yes	Yes	-5.2777	-3.43
OR Douglas-Fir #2	GA Pine Sawtimber Delivered	No	No	-3.0643	-1.95
GA Pine Sawtimber Delivered	OR Western Hemlock #2	No	No	-2.3768	-1.95
GA Pine Sawtimber Delivered	OR Western Red Cedar #2	No	No	-3.3403	-1.95
GA Pine Sawtimber Delivered	OR Douglas-Fir #2	No	No	-2.641	-1.95

DISCUSSION AND CONCLUSIONS

The result that the sawtimber prices from high timber production regions in the US Pacific Northwest and US South are cointegrated is important. A consequence of the prices being cointegrated is that the long-run investment return attributable to timber price changes should be the same. As previously mentioned in the introduction, there are many differing characteristics between an timberland investment in the US Pacific Northwest and US South, but the result of this chapter indicates that delivered sawtimber prices will not contribute a long-run diversifying effect to a timber investment specifically between Timber Mart-South Georgia Region 2 and ODF Region 1. This is an important consideration for timberland investors whose assets span different regions.

These findings allow that there are potentially more and geographically larger timber markets that could be cointegrated. Previous research showed that the US South timber market is not cointegrated as a whole, but rather grouped into subregions (Bingham et al. 2003; Yin et al. 2002). Conversely, no literature was encountered that investigated cointegration of timber markets in the US Pacific Northwest. There is opportunity to investigate cointegration of timber prices within the US Pacific Northwest timber markets and between larger timber markets in the US Pacific Northwest and US South.

Additionally, this research was limited to sawtimber because the ODF data did not include softwood pulpwood prices. It would be valuable to investigate whether the pulpwood markets between two regions are cointegrated. If one found that pulpwood was also cointegrated between the two regions, then long run timber investment returns attributable to two of the major timber product price changes would be the same.

The cointegration result from this chapter only pertains to the long-run relationship of prices. The evidence that the two regions are cointegrated provides little insight into short-run timber price relationships. Investigating the short-run price relationship between the US Pacific Northwest and US South may provide evidence suggesting short-run diversification benefits for investors that have assets in both regions.

Finally, one could use these results combined with short-run timber price relationships and long-run indicator price relationships to derive a short-run timber supply and demand model (Toppinen 1998). The resulting model could provide insight to expected future timber prices.

CHAPTER 5

The three essays in this dissertation examine timber prices using econometric methods. The first essay explored the relationship between softwood timber prices in the US South and temperature and precipitation. The second essay explored the effect of timber sale characteristics on softwood timber stumpage prices in the US South. The third essay explored the long-run softwood sawtimber price relationship between a region in Georgia and a region in Oregon. All three essays employed econometric models to analyze softwood timber prices.

In the first essay, a mixed effects panel model provided coefficient estimates for the effect of precipitation and temperature on timber prices in the US South. The data used in the econometric model was weather data from the National Oceanographic and Atmospheric Administration (NOAA) and timber prices from Timber Mart-South. In the model, time and geographic region were treated as random effects. The results of the model were as expected for both temperature and precipitation. For the temperature variable, both pine pulpwood and pine sawtimber prices have statistically significant inverse relationship with changes in temperature. The result is that as temperature increases then timber prices decrease, or conversely as temperature decreases then timber prices increase. For the precipitation variable, both pine pulpwood and pine sawtimber prices have similar statistically significant relationships with both changes in precipitation and changes in precipitation squared. The lag of the change in precipitation's effect on the timber prices is different between pine pulpwood and pine sawtimber, but both have statistically significant positive relationship with changes in precipitation. The relationship between precipitation and timber prices is increasing at a decreasing rate because of the inverse relationship between timber prices and precipitation squared. The results from this essay are useful for a variety of purposes including, buying and selling timber, preparing annual budgets, and modeling short-term timber supply and demand.

In the second essay, a random effects hedonic model provided coefficient estimates for the effects of timber sale characteristics on timber prices for pine sawtimber, pine chip-and-saw, and pine pulpwood in the US South. The data used in the econometric model was timber sale data collected and compiled by Timber Mart-South. In the model, geographic region and time were treated as random effects. The timber sale characteristics included in the model were sale type, number of bids, harvest type, and area harvested. For the timber sale type, lump sum sales exhibited more positive marginal price impact than per unit sales. Additionally for timber sale type, negotiated sales had more positive marginal price impact than sealed bid sales. However there was an interaction between sealed bid sales and number of bidders, so that the sealed bid sales had greater positive marginal price than negotiated sales after a number of bidders respective to pine sawtimber price, pine chip-and-saw price, and pine pulpwood price participated in a lump sum sale. The number of bidders and number of bidders squared coefficients in combination revealed that timber prices increased at a decreasing rate as the number of bidders increased. The type of harvest coefficient revealed that timber prices from thinning harvests yielded lower marginal timber prices than timber prices from clearcut harvests. Finally, the acre and acre squared coefficients illustrated that timber prices increase at a decreasing rate as the number of acres in a timber sale increases. Similar to the first essay, the results from essay two could be useful for a variety of purposes including buying and selling timber, preparing annual budgets, and modeling short-term timber supply and demand.

In the third essay, the long-run price relationship between softwood sawtimber delivered prices in a region of Georgia and a region of Oregon is explored. The two regions were selected because they represent the highest volume timber producing regions from the two highest softwood volume producing timber states. The data used in the econometric model is from the Oregon Department of Forestry and Timber Mart-South. The econometric model tests for the cointegration of southern yellow pine delivered sawtimber price with Douglas-fir, western hemlock, and western red cedar delivered sawtimber prices. The cointegration of the softwood sawtimber prices was determined using the Engle and Granger test. The econometric model included a statistically significant structural shift in the price series that coincided with a reduction in timber harvests from US Federal lands. The result of the Engle and Granger test was that southern yellow pine softwood sawtimber price from a region of Georgia and Douglas-fir, western hemlock, and western red cedar delivered sawtimber prices from a region of Oregon appear to be cointegrated. The consequence of the softwood sawtimber delivered prices being cointegrated is that one would expect the long-run price movements to be very similar. This result should be of interest to timberland owners and managers that market and manage timberland assets in Georgia and Oregon because the expected investment return attributable to long-run price changes would be similar. Additionally, one could use the result in short-run timber supply and demand modeling.

In conclusion, the three essays focusing on econometric analyses of timber prices in this dissertation provide new findings and results to the study of forestry. Not only are the findings and results new, but also they are relevant to the timberland investment industry and other entities transacting timber.

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APPENDIX A TIMBER MART-SOUTH PRICING REGION CONVERSION FROM

THREE REGIONS TO TWO REGIONS

State	HDPULP		HDSWT		OAKSWT		PPULP	
	1976-1991	1992-Present	1976-1991	1992-Present	1976-1991	1992-Present	1976-1991	1992-Present
AL1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1
AL2	3	2	3	2	3	2	3	2
AR1	Avg (1+3)	1	Avg (1+3)	1	Avg (1+3)	1	1	1
AR2	2	2	2	2	2	2	2	2
FL1	1	1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1
FL2	3	2	3	2	3	2	3	2
GA1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1
GA2	3	2	3	2	3	2	3	2
LA1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1	1	1
LA2	3	2	3	2	3	2	3	2
MS1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1	2	1
MS2	3	2	3	2	3	2	3	2
NC1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1
NC2	3	2	3	2	3	2	3	2
SC1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1
SC2	3	2	3	2	3	2	3	2
TN1	Avg(1+2)	1	Avg(1+2)	1	Avg(1+2)	1	Avg(1+2)	1
TN2	Avg(3+2)	2	Avg(3+2)	2	Avg(3+2)	2	Avg(3+2)	2
TX1	1	1	1	1	1	1	1	1
TX2	2	2	2	2	2	2	2	2
VA1	2	1	Avg(1+2)	1	Avg(1+2)	1	Avg (1+2)	1
VA2	3	2	3	2	3	2	3	2

State	CNS		PSWT		PPOL		PPLY	
	1976-1991	1992-Present	1976-1991	1992-Present	1976-1991	1992-Present	1976-1991	1992-Present
AL1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1
AL2	3	2	3	2	3	2	3	2
AR1	1	1	1	1	1	1	1	1
AR2	2	2	2	2	2	2	2	2
FL1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1	Avg (1+2)	1
FL2	3	2	3	2	3	2	3	2
GA1	Avg (1+2)	1	Avg (1+2)	1	2	1	Avg (1+2)	1
GA2	3	2	3	2	3	2	3	2
LA1	1	1	1	1	1	1	1	1
LA2	3	2	3	2	3	2	3	2
MS1	2	1	2	1	2	1	2	1
MS2	3	2	3	2	3	2	3	2
NC1	Avg (1+2)	1	Avg (1+2)	1	2	1	2	1
NC2	3	2	3	2	3	2	3	2
SC1	Avg (1+2)	1	Avg (1+2)	1	2	1	Avg (1+2)	1
SC2	3	2	3	2	3	2	3	2
TN1	Avg(1+2)	1	Avg(1+2)	1	Avg(1+2)	1	Avg(1+2)	1
TN2	Avg(3+2)	2	Avg(3+2)	2	Avg(3+2)	2	Avg(3+2)	2
TX1	1	1	1	1	1	1	1	1
TX2	2	2	2	2	2	2	2	2
VA1	Avg (1+2)	1	Avg (1+2)	1	2	1	2	1
VA2	3	2	3	2	3	2	3	2

APPENDIX B NATIONAL CLIMATIC DATA CENTER INDICES DESCRIPTIONS

1. Palmer Drought Severity Index (PDSI)

This is the monthly value (index) that is generated indicating the severity of a wet or dry spell. This index is based on the principles of a balance between moisture supply and demand. Man-made changes were not considered in this calculation. The index generally ranges from -6 to +6, with negative values denoting dry spells and positive values indicating wet spells. There are a few values in the magnitude of +7 or -7. PDSI values 0 to -.5 = normal; -0.5 to -1.0 = incipient drought; -1.0 to -2.0 = mild drought; -2.0 to -3.0 = moderate drought; -3.0 to -4.0 = severe drought; and greater than -4.0 = extreme drought. Similar adjectives are attached to positive values of wet spells. This is a meteorological drought index used to assess the severity of dry or wet spells of weather.

2. Palmer Hydrological Drought Index (PHDI)

This is the monthly value (index) generated monthly that indicates the severity of a wet or dry spell. This index is based on the principles of a balance between moisture supply and demand. Man-made changes such as increased irrigation, new reservoirs, and added industrial water use were not included in the computation of this index. The index generally ranges from -6 to +6, with negative values denoting dry spells, and positive values indicating wet spells. There are a few values in the magnitude of +7 or -7. PHDI values 0 to -0.5 = normal; -0.5 to -1.0 = incipient drought; -1.0 to - 2.0 = mild drought; -2.0 to -3.0 = moderate drought; -3.0 to -4.0 = severe drought; and greater than

-4.0 = extreme drought. Similar adjectives are attached to positive values of wet spells. This is a hydrological drought index used to assess long-term moisture supply.

3. Palmer "Z" Index (ZNDX)

This is the generated monthly Z values, and they can be expressed as the "Moisture Anomaly Index." Each monthly Z value is a measure of the departure from normal of the moisture climate for that month. This index can respond to a month of above-normal precipitation, even during periods of drought. Table 1 contains expected values of the Z index and other drought parameters. See Historical Climatology Series 3-6 through 3-9 for a detailed description of the drought indices.

4. Modified Palmer Drought Severity Index (PMDI)

This is a modification of the Palmer Drought Severity Index. The modification was made by the National Weather Service Climate Analysis Center for operational meteorological purposes. The Palmer drought program calculates three intermediate parallel index values each month. Only one value is selected as the PDSI drought index for the month. This selection is made internally by the program on the basis of probabilities. If the probability that a drought is over is 100%, then one index is used. If the probability that a wet spell is over is 100%, then another index is used. If the probability is between 0% and 100%, the third index is assigned to the PDSI. The modification (PMDI) incorporates a weighted average of the wet and dry index terms, using the probability as the weighting factor. (Thomas R. Heddinghause and Paul Sabol, 1991; "A Review of the Palmer Drought Severity Index and Where Do We Go From Here?," Proceedings of the Seventh Conference on Applied Climatology, pp. 242-246, American Meteorological Society, Boston, MA). The PMDI and PDSI will have the same value during an established drought or wet spell (i.e., when the probability is 100%), but they will have different values during transition periods.

5. Standardized Precipitation Index (SPxx)

This is a transformation of the probability of observing a given amount of precipitation in xx months. A zero index value reflects the median of the distribution of precipitation, a -3 indicates a very extreme dry spell, and a +3 indicates a very extreme wet spell. The more the index value departs from zero, the drier or wetter an event lasting xx months is when compared to the long-term climatology of the location. The index allows for comparison of precipitation observations at different locations with markedly different climates; an index value at one location expresses the same relative departure from median conditions at one location as at another location. It is calculated for different time scales since it is possible to experience dry conditions over one time scale while simultaneously experiencing wet conditions over a different time scale.

Table 1. Classes for Wet and Dry Periods

Approximate Cumulative Frequency %	Range PHDI	Category	Range Z
> 96	> 4.00	Extreme wetness	> 3.50
90-95	3.00, 3.99	Severe wetness	2.50, 3.49
73-89	1.50, 2.99	Mild to moderate wetness	1.00, 2.49
28-72	-1.49, 1.49	Near normal	-1.24, 0.99
11-27	-1.50, -2.99	Mild to moderate drought	-1.25, -1.99
5-10	-3.00, -3.99	Severe drought	-2.00, -2.74
< 4	<-4.00	Extreme drought	<-2.75

APPENDIX C UNION OF NATIONAL CLIMATIC DATA CENTER REGIONS WITH TIMBER MART-SOUTH PRICE REPORTING REGIONS

Timber Mart-South Region	National Climatic Data Center State	National Climatic Data Center Region
AL1	Alabama	1,2,3,4,5
AL2	Alabama	6,7,8
AR1	Arkansas	4,5,6,7,8,9
AR2	Arkansas	1,2,3
FL1	Florida	2
FL2	Florida	1
GA1	Georgia	1,2,3
GA2	Georgia	4,5,6,7,8,9
LA1	Louisiana	1,2,3,4,5,6,7
LA2	Louisiana	6,8,9
NC1	North Carolina	1,2
NC2	North Carolina	3,4,5,6,7,8
SC1	South Carolina	1,2
SC2	South Carolina	3,4,5,6,7
TN1	Tennessee	1,2
TN2	Tennessee	3,4
TX1	Texas	4
TX2	Texas	4
VA1	Virginia	5,6
VA2	Virginia	1,2,3,4

APPENDIX D OREGON DEPARTMENT OF FORESTRY LOG GRADE REFERENCE

Log Price Report.

1P = No. 1 Peeler (Plywood veneers; clear, uniform-colored, face stock veneer - 50%)

2P = No. 2 Peeler (Plywood veneers; clear, uniform-colored, face stock veneer - 35%)

3P = No. 3 Peeler (Plywood veneers; veneer center core, cross core, backs and better)

SM = Special Mill (Logs suitable for the manufacture of Select Merchantable & Better lumber grades - 65% or veneer center core, cross core, backs and better - 100%)

2S = No. 2 Sawmill DF (Logs suitable for the manufacture of Construction & Better lumber grades - 65%)

3S = No. 3 Sawmill DF (Logs suitable for the manufacture of Standard & Better lumber grades - 33%)

4S = No. 4 Sawmill DF (Logs not quite suitable for the manufacture of Construction & Better lumber grades - 33%)

1S = No. 1 Sawmill Pine (Old growth logs suitable for the manufacture of D Select & Better lumber grades - 50%)

2S = No. 2 Sawmill Pine (Old growth logs suitable for the manufacture of D Select & Better lumber grades - 35%)

3S = No. 3 Sawmill Pine (Old growth logs suitable for the manufacture of No. 2 Shop & Better lumber grades - 50%)

4S = No. 4 Sawmill Pine (Logs suitable for the manufacture of No. 2 Common & Better lumber grades - 50%)

5S = No. 5 Sawmill Pine (Logs 6" diameter suitable for the manufacture of No. 3 Common & Better lumber grades - 33%)

6S = No. 6 Sawmill Pine (Logs 5" diameter suitable for the manufacture of No. 3 Common & Better lumber grades - 33%)

SC = Special Peelable Cull (Logs that do not meet the minimum for Peeler or Sawlog grades, but are suitable for rotary cutting of Firm White Speck and Better veneer - 50%)

Utility = Utility Grade (Logs that do not meet the minimum for Peeler or Sawlog grades, but are suitable for the production of firm usable chips - 50%)

CR = Camp Run (Log production from the forest of the species or group of species being logged, that are better than Cull grade)

Pulp = Utility Grade (Suitable for reducing into wood fiber for use in the manufacture of paper and paper products; usually wood that is too small, of inferior quality, or the wrong species to be used for lumber or plywood)

Wormy =Wormy Cedar Logs (Not meeting requirements of 4S because of excessive worm holes)