ABSTRACT

LAMICA, AUSTIN. Assessing the Determinants of Interstate Softwood Roundwood Trade in the Southern United States: A Gravity Trade Model Approach (Under the direction of Dr. Rajan Parajuli).

Intraregional trade of forest products is a critical component of regional and sub-regional timber markets in terms of supply chain planning and investment decisions. Many factors influence the flow of timber products from state to state. This article investigates factors driving the flows of softwood sawlog and roundwood pulpwood in the US South. Based on a gravity trade modeling, I estimated the impacts of importing and exporting state's gross domestic product (GDP), distance, common border, softwood sawlog and pulpwood production, stumpage prices, pellet mill capacity, and major hurricane events on softwood roundwood trade between southeastern states. I applied various panel data models to estimate the sawlog and pulpwood trade models based on bi-annual data from 2011 to 2019. The results suggest that GDP, importer's sawlog production, distance, and common border are significant influential factors of bilateral sawlog trade. Similarly, GDP, importer's pulpwood production, distance, common border, stumpage prices, and pellet mill capacity were found to be significant determinants of unidirectional roundwood pulpwood trade. With this knowledge, forest managers and policy makers may be able to have a sense of the bilateral trade dynamics in regional and sub-regional markets in the US South. Further, these findings could provide useful policy guidelines in regulating timber markets, harvest scheduling, and interstate trade policies to reflect changing timber trade patterns within the region.

Keywords: gravity trade model, forest products, intra-regional trade, Hausman-Taylor estimator, pellet mill capacity

Assessing the Determinants of Interstate Softwood Roundwood Trade in the Southern United States: A Gravity Trade Model Approach

by
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DEDICATION

With dedication to my parents Lori Lamica-Nelson, Frank Lamica, and Keith Nelson, my grandmothers Dawn Lamica and Sally Wahl, my late grandfathers Frank Lamica Sr. and Herb (Chubby) Wahl, the late Vergil K. Faigle Jr., my fly fishing and fly tying mentor Allen Case, and my friends that will always be family…You know who are.

BIOGRAPHY

Austin Lamica was born and raised in the Catskill Mountains of Upstate New York, where he grew up hunting in the mountains and fishing the infamous Beaverkill and Delaware Rivers. These passions lead him to obtain a B.S. in Forest Resource Management, with minors in economics and applied statistics, from The State University of New York College of Environmental Science and Forestry. Upon completion of a M.S. in Forestry and Environmental Resources at North Carolina State University, with a minor in Economics, he will continue to a Ph.D. in Forestry and Environmental Resources, focusing on Applied Economics. His goal is to finish his Ph.D. and work in academia, undertaking forest economics research, and helping future cohorts of natural resources professionals explore their interests and careers.

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Introduction

Regional and sub-regional timber inventories are important factors for forest managers and policy makers to consider when making forest management, supply chain, and investment decisions. A vital part of these forest product industries are traded within the region. In the US South, the highest softwood producer in the nation (Howard and Liang, 2019), significant amounts of wood move across state lines. It was estimated that 25% of the total pulpwood consumption by the pulp industry and 12% of the sawlog consumption by the sawmill industry in the US South is transported from other states in the region (Polyakov and Teeter, 2007). This underscores the significance of interstate trade on sub-regional forest product markets accounting and projection and the importance of unidirectional trade dynamics between the states in this region.

The gravity trade model is the commonly applied theoretical foundation to assess the international trade of goods and services. This framework can offer insight into the sector and product level trade, as well as gives a broad economic background of trade (Morland et al., 2020). The roots of this model were developed from theories of gravitational physics. Simply, the gravity model of trade states that trade volume or value between two trading partners is inversely proportional to the distance between them and directly proportional to their economic masses (Tinbergen, 1962).

In the context of international forest products trade, previous studies analyzed promoting and resisting factors of trade in China (Zhang and Li, 2008, Zhang and Li, 2009, Nashrullah et al., 2020), Vietnam (Vu et al., 2020), and the US (Kang, 2003). Gravity models have also been used to assess trade patterns between the European Union (EU) and Central and Eastern European countries seeking access to the EU (Kangas and Niskanen, 2003), a more global context of pulp and paper (Hujula et al., 2013), determine Turkey's potential to join in the EU in terms of forest products trade (Akyuz et al., 2010), examine regulatory quality on India's forest products trade (Das et al., 2018), and project future global US wood products trade trends (Larson et al., 2018).

On a domestic and subregional level in the US, particularly in the US South, several studies on forest products have been conducted to assess timber inventories and regional and state-level timber market dynamics. For example, Daniels and Hyde (1986) estimated hardwood and softwood supply and demand equations for North Carolina hardwood and softwood stumpage. Newman (1987) presented an aggregate regional model of softwood solidwood and pulpwood stumpage markets in the US South for the period of 1950 to 1980. Carter (1992) assessed effects of supply and demand determinants on Texas's pine pulpwood stumpage market. In addition, Polyakov et al. (2005) analyzed factors influencing Alabama's pulpwood supply and demand. Liao and Zhang (2008) studied determinants of softwood production in the US south through comparing industrial and nonindustrial forestland ownerships. Parajuli and Chang (2015) estimated simultaneous supply and demand equations for Louisiana's softwood sawtimber market.

State and regional timber inventories are important for forest resource managers and policy makers to consider when making decisions regarding forest resource management, planning, and investment decisions. Past studies that built these types of models include the Georgia regional timber supply (GRITS) model (Cubbage et al., 1991), the DPSupply for Alabama (Teeter, 1994, Zhou, 1998), and the sub-regional timber supply (SRTS) model (Abt et al., 2000). Polyakov and Teeter (2007) argued that subregional modeling of timber supply and demand might be improved by accounting for spatial aspects of timber markets and interregional roundwood trade; thus, they assessed different forms of gravity trade models to predict future trade. Polyakov and Teeter's (2007) use of the gravity trade model in this context was the first application of this model that assessed interstate pulpwood trade in the US south.

The aim of this study is to assess various determinants that explain the interstate trade of softwood sawlog and pulpwood roundwood within the southeastern states in the US. To my knowledge, the only other assessment of intra-regional trade of forest products conducted in the US South using a gravity trade model was conducted by Polyakov and Teeter (2007). In my application, I drew from the theoretical foundations of the gravity model of international trade and estimated separate augmented gravity equations for exports and imports of softwood roundwood among the 13 southern states. I used the traditional model described by Tinbergen (1962). I included GDP of the importing and exporting states as a proxy for economic mass and distance between them as a proxy for transportation costs. Similar to Polyakov and Teeter (2007), I assessed timber trade flows within the US South and calculated weighted centers of production and consumption based on spatial state levels of harvesting production and mill locations. My analysis extended beyond Polyakov and Teeter (2007), as I focused on softwood sawlog and pulpwood roundwood trade, whereas their focus was softwood and hardwood pulpwood roundwood. I also followed the majority of gravity model literature on forest products trade and included a proxy for timber inventories.

My analyses incorporated softwood roundwood products only, as softwood production is dominant in the US South. To illustrate, in 2017, softwood volume represented 85% of wood production in the US South, making this region the highest softwood producer in the nation (Howard and Liang, 2019). Furthermore, similar to Hujula et al. (2013) and Tang et al. (2015), I implemented a Hausman-Taylor (HT) estimator, in addition to Ordinary Least Squares (OLS), Fixed Effects (FE), and Random Effects (RE) estimators, to capture any potential bias and heterogeneity in a panel data framework. Finally, I extended beyond most existing studies by adding an expanded set of explanatory variables that have not received much attention in previous studies or may be novel determinants. These included a storm variable to capture local effects of catastrophic hurricanes, which are common event shocks in our study region that cause timber damages, and a stumpage price coefficient, which captured the effects of timber market differentiation between states. Additionally, the more novel cumulative pellet mill capacity coefficient captured the effects of growing wood pellet demands on the production and supply of wood pellets from southern US states.

This study contributes to the forest products trade literature using a gravity approach, as well as the literature using the gravity model in intra-regional trade studies. Results of this study identify the determinants and their influences on the bilateral trade of softwood sawlog and pulpwood roundwood between states in the US south. These results may help explain the observed trends in interstate trade of softwood products within the US South. These results will also serve as indicators for forest managers and policy makers when making forest management, planning, and investment decisions. Understanding market forces and other factors that influence trade of softwood sawlog and pulpwood in the US south may allow managers and planners to have a better sense of unidirectional trade relations.

I structure this paper with the following framework. In the next section, I present a detailed review of the literature to discuss the theoretical background and framework of the gravity trade model and showcase other similar studies that were conducted to identify the research gap. Next, I describe the data and historical trade patterns and then describe the empirical strategies. Finally, I present and discuss the results of my findings and conclude with study limitations and future research.

Literature Review

<u>Broad Product Overview of Trade Analysis Using A Gravity Approach</u>

The gravity trade model has been applied to a number of different product types. For example, Koo et al. (1994) studied factors influencing the volume and direction of world meat trade, with particular interest on the effects of export promotion programs and import restriction policies. Estimation of their reduced form gravity equation was conducted with cross-sectional and time series data from 1983 to 1989, using different econometric methods. Results of a Hausman test indicated that the FE model was preferred (Koo et al., 1994). Their findings revealed that beef price, livestock production capacity, and meat quality differences were major determinants influencing meat export. The importing country's GDP, livestock production capacity, and trade-restricting policies also influenced meat imports (Koo et al., 1994). Finally, they concluded that long-term agreements, sharing a common border, and affiliation with an economic union significantly enhanced meat trade, while distance and animal disease were negative influencers (Koo et al., 1994).

Dascal et al. (2002) implemented the gravity model approach to analyze factors influencing volume of European Union (EU) wine exports and imports. In this analysis, the authors assessed the main factors affecting wine trade in 12 EU countries using pooled time series and cross-sectional data from 1989 to 1997. Gravity models were estimated using fixed effects (FE) and random effects (RE) estimators, and the Hausman test indicated the FE model was preferred (Dascal et al., 2002). FE estimation results revealed that GDP per capita of EU and importing countries, EU remoteness from its partner, exchange rate, EU wine production, and

EU membership were positive and significant influencers of export value, while export price negatively influenced value (Dascal et al., 2002). Additionally, EU and its partner GDP per capita and EU membership positively influenced import volume, and EU remoteness from partner, import price, exchange rate, and EU wine production negatively influenced imports (Dascal et al., 2002).

Jayasinghe and Sarker (2008) analyzed the effects of regional trade agreements, particularly the North American Free Trade Agreement (NAFTA), on the trade of six agrifood commodities (red meat, grains, vegetables, fruits, sugar, and oilseeds) from 1985 to 2000. Using an extended gravity model, they estimated the effects with pooled cross-sectional and time-series regression and generalized least squares methods (GLS) in three-year time frames (Jayasinghe and Sarker (2008). Due to heteroskedasticity, GLS was implemented as it controlled for this issue (Jayasinghe and Sarker, 2008). The main findings from their analysis were that NAFTA countries traded more agrifood products among themselves than with countries not in NAFTA, and there was presence of trade creation and diversion effects from the NAFTA agreement (Jayasinghe and Sarker, 2008).

Mendes dos Reis et al. (2020) studied the influences of logistic performances in Argentina, Brazil, and US soybean exports to their trade partners with an augmented gravity model approach. Their augmented gravity model specifications contained basic gravity terms, along with the addition of logistic performance indicators of the World Bank (Mendes dos Reis et al., 2020). Using panel data from 2012 to 2018, they estimated their gravity specification with OLS, FE, RE, and Poisson Pseudo – Maximum Likelihood (PPML) estimators (Mendes dos Reis et al., 2020). Hausman test results showed that the FE estimator was preferred over the RE estimator (Mendes dos Reis et al., 2020). Finally, the PPML estimator results were found to be somewhat equivalent to those of FE (Mendes dos Reis et al., 2020). They concluded that some logistic performance indicators are significantly important promoters of bilateral soybean trade, some were significantly negative, and some were insignificant (Mendes dos Reis et al., 2020). They also found that logistics infrastructure was an important promoter, distance was positive, and GDP had a low impact on soybean trade, indicating soybean trade may have been connected with factors other than those of a basic gravity model (Mendes dos Reis et al., 2020).

In the first study of its kind assessing intra-national trade impacts on mitigating climate change within a country, Dall'Erba et al. (2021) assessed the potential for US interstate trade to mitigate the negative impacts of climate change on crop profits in the US. Their study used independent variables of; common state border dummies, travel time, drought days in the export and import states, import and exporter GDP for farm and food manufacturing industries, a remoteness index of the import and export state, growing degree days, and total precipitation in the import and export states and a dependent variable of interstate flows of crops in its gravity model. The gravity model in the analysis does not follow a structural approach but that of a reduced-form approach. Their study estimated the gravity equation using fixed effect structures at the climatic zone. OLS and PPML estimators were used to estimate the parameters (Dall'Erba et al., 2021). Results of the estimations showed that travel time and exporter drought days are significant and negatively influence export crop flows, and importer drought days, importer and exporter GDP, exporter remoteness, and exporter precipitation are significant and positively influence export crop flows (Dall'Erba et al., 2021). The authors concluded that interstate US crop trade was expected to act as a $14.5 billion mitigation tool in the near future (Dall'Erba et al., 2021).

International Forest Products Trade Analysis Using a Gravity Approach

In 2020, the FAO estimated the annual world forest products export value at US$ 226.38 trillion and world import value at US$ 234.52 trillion, illustrating the value in forest products trade (FAO, 2022). With the growing trend of forest products trade, it is not surprising that this topic has received considerable attention from researchers.

One of the first studies that utilized a gravity approach in forest products trade was conducted by Buongiorno et al. (1980). In the study, the researchers implemented a gravity trade model to assess economic and political influences that determined multilateral trade flows of tropical hardwood logs from 1967 to 1973, as well as their changes in relative importance over time. Results of this gravity model indicated that shipping distance was the most significant factor of trade intensity, with size of the importing country, relative price in the importing and exporting countries, development level and wood availability of the exporter, total volume of trade between countries, and trade preferences from old colonial ties also being significant factors but to a lesser extent (Buongiorno et al., 1980). The relative importance of these variables, except the role of income per capita, were found to be stable throughout the study period (Buongiorno et al., 1980).

Kangas and Niskanen (2003) used a gravity model with log-linear transformations to study forest products trade patterns between the European Union (EU) and the Central and Eastern European (CEE) countries seeking access to the EU. . Their analysis used an augmented form of the gravity model where importer and exporter GDP, importer and exporter GDP per capita, distance, and dummies for whether trading partners shared a common land border and if the trade occurred between an EU country and a CEE country . Model estimations were conducted with OLS estimation techniques. Their findings were similar to those of other studies.

Distance, exporter and importer GDP, exporter per capita income, and east-west trade direction were significant determinants of trade between the EU and CEE countries, with distance and east-west direction being negative and GDP and exporter per capita income being positive. Additionally, they found that 66% of the variation in trade flows across countries was explained by their gravity trade model.

In the first few years of the data, China was the world's third largest wood importer, behind the US and Germany, and steadily rose in ranking until it became the world's largest importer in 2018 and remained so in 2019 (Worldbank, 2022). Additionally, China was the second largest wood exporter in the world throughout this time (Worldbank, 2022). With the consistent high volume and importance of wood products trade taking place in China, several studies have investigated China's forest products trade.

Zhang and Li (2008) investigated resisting and promoting determinants of China's pulp and paper trade using gravity trade models, separately, for imports and exports. The empirical specifications of the gravity models in their analysis predicted the value of imports or exports based on wood pulp production per capita, exchange rate, distance, real interest rates, importer/exporter population (economic mass proxy as there was multicollinearity between GDP and per capita resource endowment), Asia-Pacific Economic Cooperation (APEC) membership, World Trade Organization (WTO) membership, and policy shocks (Zhang and Li, 2008). To estimate the causal effect of these determinates on import and export value of pulp and paper the authors used panel data from 1995 to 2005, consisting of bilateral trade observations of China and its 24 major trading partners, and one-way fixed and random effects estimators (Zhang and Li, 2008). Based on a Hausman test, they found that the RE estimator was weakly preferred (Zhang and Li, 2008). Noteworthy results of the import gravity model suggested that real interest rate was inversely proportional to pulp and paper import value, while exporter population, APEC and WTO membership, and policy shocks were directly proportional to pulp and paper import value (Zhang and Li, 2008). Finally, significant results of the export gravity model suggested that wood pulp production per area, exchange rate, and distance were all inverse proportional to trade export values, while importer population, APEC and WTO memberships, and policy shocks were all proportional to export values (Zhang and Li, 2008).

Similar to Zhang and Li (2008), Zhang and Li (2009) investigated determinants of wood products trade between China and its major wood products trading partners but gave particular interest to the effects of its trading partners resource endowments and China's logging restriction policies. This study also estimated separate gravity models for import and export values. Independent variables assessed in the gravity equations included importer/exporter GDP (economic mass proxy), importer/exporter GDP per capita, distance, exchange rate of the trade partner, exchange rate volatility, roundwood production per capita, and dummies for APEC and WTO memberships, and logging restriction policies. To estimate the two specifications, the authors used panel data consisting of bilateral trade data for China and 22 of its major trade partners from 1995 to 2004. Pooled OLS, one-way and two-way fixed effects models, random effects models, and Poisson pseudo-maximum likelihood estimation (PPML) models were estimated. A Hausman test and Breusch-Pagan Lagrange multiplier test ratios suggested that the fixed effects model was superior to the random effects models; however, PPML was preferred as it corrected for heteroskedasticity (Zhang and Li, 2009). The PPML results tended to follow those of similar studies assessing China's forest products trade. The import model indicated that exporter GDP per capita had a negative relationship with imports. Exchange rate volatility, roundwood production per capita, and logging restriction policies all positively influenced pulp and paper exports. Distance, importer GDP per capita, exchange rate, exchange rate volatility, and roundwood production per capita negatively influenced exports, and APEC membership positively influenced imports (Zhang and Li, 2009).

Looking at a more country-specific study in terms of the EU, Akyuz et al. (2010) was interested in investigating the effects of various trade determinants to assess how well-prepared Turkey was to join the EU in terms of forest products trade and to determine Turkey's export potential as part of bilateral relations. Using a log-linearized gravity model, they estimated the effects of the importer and exporter GDP and population, distance, and dummy variables for common border, common language, and EU15 membership before the 2004 enlargement on export trade value (Akyuz et al., 2010). This model was fitted using panel data from 2000 to 2006 and OLS estimation techniques. Findings of the model estimation showed that the most significant variables in the study were importer and exporter GDP, which had a positive relation with bilateral trade value (US$ 1000) and distance, which had a negative relationship with trade value (Akyuz et al., 2010). Other variables found to have significant and positive impacts towards Turkey's bilateral trade were whether trading partners shared a common border and whether the country was an EU15 member before the 2004 enlargement (Akyuz et al., 2010). Finally, they concluded that Turkey's forest product exports (US$ 1000) to the EU was below the potential export value and average, and trade relations of forest products could be increased if Turkey joined the EU (Akyruz et al., 2010).

Another study looking at a more worldwide context of forest products trade using a gravity model was conducted by Hujala et al. (2013), where they modeled bilateral trade patterns of chemical pulp and recovered paper. This analysis focused on the three most exported raw materials in the global paper and paperboard production: bleached softwood kraft pulp (BSKP), bleached hardwood kraft pulp (BHKP), and recovered paper (RP) (Hujula et al., 2013). In their modeling, the authors augmented a simple gravity model with additional explanatory variables to capture supply and demand conditions in the exporting and importing countries. The full empirical gravity model for BSKP and RP after this augmentation contained a dependent variable of pulp exports (BSKP or RP) and independent variables of distance, a China importer dummy, GDP per capita (which serves as their variable for economic mass), population, forested area, the bilateral real exchange rate, a decade dummy, an interaction term of China and the decade dummy, and dummies for North America, northern Europe and Latin America and their interactions with the decade dummies (Hujula et al., 2013). The full empirical specification for RP was similar but included additional dummies for planted eucalyptus and acacia and their interaction with decade dummies (Hujula et al., 2013). When estimating the gravity models, they used FE, RE and HT estimators and the Hausman test (1978) to test the various combinations of estimators to determine the preferred model. Hausman test results revealed that the HT estimator was preferred over the RE estimator, thus model interpretation was centered on HT estimates (Hujula et al., 2013). From the HT estimator the most traditional gravity model variables (distance, population, GDP per capita, population) were significant but varied depending on the specific product (BSKP, BHKP, and RP) (Hujala et al., 2013). In addition, they found that changes in dynamics of the pulp and paper industry affect bilateral trade flows of BSKP, BHKP, and RP (Hujala et al., 2013).

Tang et al. (2015) also examined China's wood pulp and recovered paper imports using an augmented gravity model, and their findings followed those of Zhang and Li (2008). In this paper, two gravity equations were estimated (one for wood pulp imports and one for recovered paper imports). The empirical specification for the gravity model was expanded by adding explanatory variables that had trade-resisting effects on China's wood pulp and recovered paper imports (Tang et al., 2015). This produced a gravity equation with independent variables of GDP per capita of China and its exporting partner (economic development levels), distance between China and its trading partner (proxy for transportation costs), bilateral real exchange rate (relative price between countries), an APEC dummy, and a WTO dummy for China's recovered paper imports. The specification of wood pulp imports had the same independent variables, but with the addition of the exporting partner's pulpwood production per capita, as it was thought countries with higher pulpwood production produce and export more wood pulp (Tang et al., 2015). To estimate their gravity equations, the researchers log-linearized the models and used panel data from 1995 to 2012, with an HT (Hausman-Taylor) estimator (Tang et al., 2015). Additionally, FE and RE models were also estimated, and Hausman tests were implemented to test the superiority of the HT estimator (Tang et al., 2015). Results showed that the RE model is preferred over the FE model, but overidentification tests showed that the RE estimator may produce bias in estimation. Thus, they concluded that the HT model was the most efficient (Tang et al., 2015). Using the HT model results, the findings suggested that distance negatively influenced China's wood pulp and recovered paper imports, real exchange rate negatively influenced recovered paper imports, exporter pulp production positively influenced wood pulp imports, and China's and the export partner's GDPs and WTO membership both positively influenced wood pulp and recovered paper imports (Tang et al., 2015).

Buongiorno (2016) conducted a general review of regional forest products trade to test the generality of gravity models with large, complete datasets of, and the use of their results for, policy analysis and forecasting among the participating Trans-Pacific Partnership (TPP) countries: Australia, Canada, Chile, Brunei Darussalam, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore, the US and Vietnam. The study used panel data from 2005 to 2014 to estimate OLS, FE, and RE models of a differential gravity model to assess GDP of importers and exporters, distance, common border length, whether countries shared a common language, and other influential variables. Model estimation results showed that results for each product group for the various panel data estimation models were comparable. Empirical analysis concluded that wood and articles of wood were inelastic with respect to GDP of exporters but elastic with respect to importer's GDP. Additionally, pulp exports were elastic with respect to exporter's and importer's GDP, and paper was elastic with respect to importer GDP but inelastic with respect to exporters GDP. The policy analysis of TPP impact in the participating countries with the estimated elasticities (and projected long-term changes in GDP) showed that the largest impacts occurred in imports and exports from Vietnam and New Zealand, particularly for wood and articles of wood.

In India, Das et al. (2018) examined the relationship between regulatory quality of India's partner countries' exports and the value of forest products imports in India. This relationship was evaluated using a log-log augmented gravity trade model where trade agreements, distance, relative forest area of trading countries, GDP, and population made up the independent variables (Das et al., 2018). These independent variables were chosen as regulatory quality, trade agreements, and distance were considered as proxies of trade costs, GDP and population were considered as proxies for economic mass, and forested area was considered as a proxy for commodity prices (Das et al., 2018). To estimate their gravity equations to find effects of regulatory quality on India's forest products imports, the researchers used panel data from 2009 to 2013 and utilized multiple panel specifications, such as pooled ordinary least squares (POLS) regression, RE generalized least-squares (GLS), PPML, and a population average feasible generalized least-squares (FGLS) (Das et al., 2018). FE estimation techniques were decided not to be used in this analysis due to time-invariant variables in the model and the very subtle change over time in the regulatory quality variable (Das et al., 2018). Like many other studies of this nature, a Hausman test and Breusch-Pagan Lagrange multiplier were used to determine the preferred model. Their results found that regulatory quality positively affected wood pulp and paper and paperboard products but not fiberboard, veneer sheets, plywood, sawn wood, or industrial roundwood (Das et al., 2018). Results also suggested that distance, forest area of the partner country relative to India's forest area, GDP, population, and trade agreements were significant explanatory variables for the value of India's forest products imports (Das et al., 2018), which was consistent with other studies. To conclude, they mentioned that trade agreements do not necessarily mean free trade and that using simple dummy variables for the existence of trade deals between two countries may be too simplistic to identify effects on exports of products from each sector or the effects of removing trade barriers on exports (Das et al., 2018). Last remarks on this analysis by the authors were a call for more analysis on additional factors of institutional quality, as it influenced export performance (Das et al., 2018).

Forest products can be specifically defined by groups and analyzed as well, rather than analyzing by broader categories such as pulpwood or sawlog. In the case of China's forest products trade, Nashrullah et al. (2020) focused on import and export values of forest products groups 44 (wood, wood charcoal, and articles of wood), 47 (wood pulp/fibrous cellulose/recovered paper/paperboard), 48 (articles of pulp, paper, paperboard, paper and board), 49 (printed books, newspapers, pictures, other products), and 94 (furniture, bedding, mattresses, similar stuffed materials). Independent variables in their gravity model specification included GDP and population of China and its trading partner, distance, exporter foreign direct investment, exporter exchange rate, forested area of China and the exporter, and dummies for global and economic financial crisis, enacted countervailing and antidumping duties by the US and trade partners, Organization for Economic Co-operation and Development (OECD) membership, APEC membership, and common language (Nashrullah et al., 2020). Estimation was conducted with panel data from 2001 to 2018 using pooled OLS, FE, and RE estimators for a log-linearized version of their specification. Results showed that GDP and GDPC, distance, and population were significant determinants (Nashrullah et al., 2020). To verify all variables were stationary and the gravity model could be applied, a panel unit root test was conducted, and stationary variables were confirmed (Nashrullah et al., 2020). Additionally, they implemented a Hausman test to determine a preferred model and determined that FE was preferred for groups 44, 47, and 48 (exports) and 48, 49, 94 (imports), and RE was preferred for groups 49 and 94 (exports) and 44 and 47 (imports) (Nashrullah et al., 2020).

In the first study of its kind in Vietnam, Vu et al. (2020) assessed determinants of wood products trade value (US$ Millions) using the gravity model. Following many other similar studies in other regions, they used panel data from 2001 to 2006 to estimate augmented import and export value models separately, in the form of OLS, FE, and RE models. Implementing Hausman test and Breusch-Pagan Lagrange multiplier tests, the FE models were found to be preferred over the OLS and RE models (Vu et al., 2020). Results of the FE models showed that importer GDP, per capita income differential, importer openness, and trade agreements were the most significant determinants of Vietnam’s exports, while real exchange rate, importer population, and round wood per capita were still significant determinants of Vietnam’s exports but to a slightly lesser extent (Vu et al., 2020). In the case of the import model, importer and exporter GDP, per capita income differential, real exchange rate, importer, and exporter openness, roundwood per capita, and logging restrictions were the most significant determinants of Vietnam's imports, while importer and exporter population were significant to a lesser degree (Vu et al., 2020).

Forest Products Trade Analysis in the United States Using a Gravity Approach

The literature relating to assessments of forest products trade using a gravity approach have been applied in several contexts. For example, gravity trade models have been used to assess global trade of forest products (Hujula et al., (2013), Buongiorno (2016)), individual countries international forest products trade (Zhang and Li (2008), Das et al., (2018), Vu et al., (2020)), and trade agreement effects on forest products trade (Akyuz et al. (2010), Kangas and Niskanen, (2003)). Studies have also focused on assessments of the US's forest products trade with a gravity model. Kang (2003) assessed trade with particular international regions, Polyakov and Teeter (2007) modeled intraregional pulpwood trade in the US south, and Larson et al., (2018) modeled the US's international forest products trade.

In his dissertation, Kang (2003) analyzed trade flows of a single wood products commodity market to study significant determinants of US exports and imports from the EU, East Asia, Pacific Rim, and NAFTA. In this analysis, Kang (2003) modeled trade value using augmented gravity trade models for the total value of US imports and exports. After augmentation, the dependent variables used in estimation included exporter and importer income, exporter and importer income per capita, distance, a time trend, the real exchange rate, forest and woodland areas, and a language and NAFTA dummy (Kang, 2003). Model estimations for the log-linearized import and export gravity equations were conducted with panel data methods using one-way fixed effects, random effects, two-way fixed effects, and random effects over time for each region studied. Model preferences were tested with a Hausman test.

Findings of this analysis showed that a modified gravity model can be applied to single wood products markets and aligned with conventional gravity model attributes (Kang, 2003). Additionally, the Hausman test results implied that the two-way random effects models were preferred over the other estimation techniques (Kang, 2003). Two-way random effects models estimated in this study showed traditional effects of the determinants on US trade value: distance, exporter income per capita, real exchange rates, and lack of common language were significate and negative influencers of US imports and exports, and exporter income and forest and woodland area were significant and positive influencers (Kang, 2003). Finally, these results concluded that structural changes in US trade occurred after NAFTA came into effect (Kang, 2003).

Polyakov and Teeter (2007) examined roundwood pulpwood trade in the United States South, the largest wood basket in the world. In this study, they focused on bilateral trade flows, in cords, of softwood and hardwood pulpwood between states within the US South. To assess the adoptability of the gravity equations in the timber inventory projection problem, they implemented an augmented gravity model. Determinants assessed in the augmented gravity model included supply and demand in the importing and exporting states, distance between them, and a common border dummy (Polyakov and Teeter, 2007). Interestingly, they computed distance as a linear measure between the center of production in the exporting states and center of consumption in the importing states. Production centers were computed as a weighted average of county level timber production within a state, while consumption centers were computed as a weighted average of mill capacity within the state (Polyakov and Teeter, 2007). Using panel data from 1994 to 2002, they estimated nonlinear, log-linear, OLS, FE, and nonlinear FE models. Employing a Hausman test, they found that the FE and nonlinear FE models were the best predictors of interregional roundwood trade quantities (Polyakov and Teeter, 2007). The results of the FE and nonlinear FE models indicated that consumption in the importing state and production in the exporting state were positive and significant in both hardwood and softwood models, consumption in the exporting state and production in the importing state were significant and negative in the softwood model, distance was significant and negative in both hardwood and softwood models, and the border dummy was significant and positive in both hardwood and softwood models (Polyakov and Teeter, 2007).

Larson et al. (2018) also undertook modeling international trade of forest products with a gravity model and used the results to project future US exports. Specifically, they were interested in estimating the quantities (metric tons or cubic meters) of FAO item categories 1860 (paper and paper board), 1875 (wood pulp), and 1633 (non-coniferous sawnwood). They estimated a nonlinear gravity model with PPML techniques. Larson et al. (2018) argued estimating the model using this strategy addressed potential bias associated with truncation, when the data contains many zeros, and heteroskedasticity that often occurs when log-linearizing. The empirical gravity equation employed the most traditional determinants of trade: importer and exporter GDP and the distance between them. Estimation was conducted with panel data covering 13 product categories at a country-pair level from 1997 to 2014 using PPML techniques with three specifications: only year fixed effects, importer and exporter fixed effects, and an interaction of the fixed effects with year effects (Larson et al., 2018). Results of their analysis aligned with most gravity model studies. Importer and exporter GDP were found to be significant and proportional to trade volume, while distance was significant and inversely proportional to trade quantity for all categories of forest products assessed (Larson et al., 2018).

Finally, they concluded that their approach provided a new tool that can be used to make informed decisions of forest products trade (Larson et al., 2018).

This review of the literature demonstrated the broadness of the gravity models' application in terms of forest products trade assessment. Only one study specific to intraregional forest products trade in the US south has been conducted. This was done several years ago by Polyakov and Teeter (2007). This shows the knowledge gap existing in forest products trade dynamics between southern US states, and the factors that influence them. With factors such as new and expanding wood products markets, migration to and from the US south making up the largest regional migration flows in the US (US Census, 2019), and weather events, understanding current influential trade factors is critical to understanding trade trends.

My analysis contributes to the forest products trade literature using a gravity approach, as well as expands it by contributing to this knowledge gap. In this article, I aim to fill the knowledge gap associated with interstate forest products trade dynamics in the US south. I plan to accomplish this by employing a gravity model of trade for intraregional exports and imports of softwood sawlog and pulpwood in the US south. My gravity models take augmented forms to capture traditional supply and demand factors of GDP and distance, less studied factors of state timber prices and catastrophic hurricane events, and the more novel increasing pellet markets in the US south.

Methods

Data

Data used in this analysis were collected from several sources. The bi-annual unidirectional interstate trade flows and production of softwood pulpwood and sawlog roundwood, in thousand cubic feet, for the 13 southern US States, Alabama (AL), Arkansas (AR), Florida (FL), Georgia (GA), Kentucky (KY), Louisiana (LA), Mississippi (MS), North Carolina (NC), Oklahoma (OK), South Carolina (SC), Tennessee (TN), Texas (TX), and Virginia (VA) (Figure 1), were collected from the Forest Inventory Analysis's (FIA) Interactive Reporting Tool from 2011 to 2019 (USDA Forest Service, 2021). Data were collected bi-annually due to the available data published by the FIA TPO at the time, which was collected bi-annually until 2018. Starting in 2018, the FIA changed its data collection methods from bi-annual to annual collection.

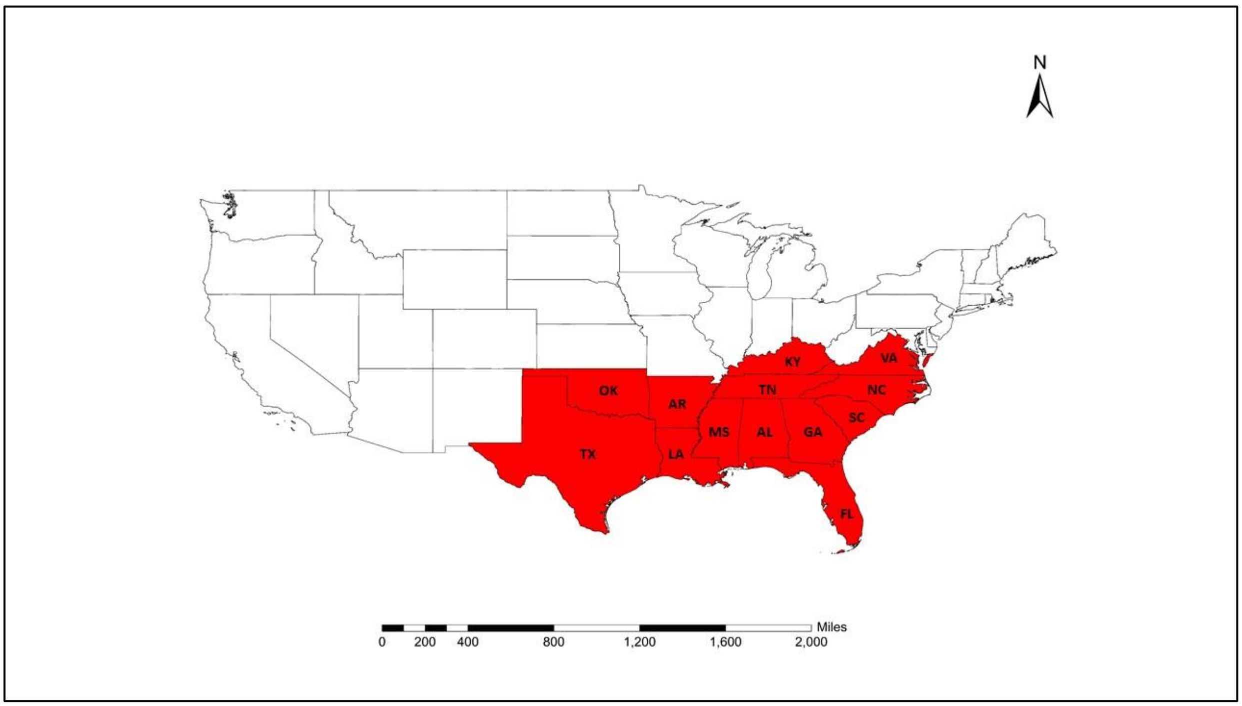

Figure 1. Map depicting the 13 US states included in the study region. We plotted the historical TPO export and import data to examine softwood sawlog (Figure 2) and pulpwood trade (Figure 3) trends across the US South.

The sawlog export data showed that MS was the leading state in softwood sawlog export quantity, in thousand cubic feet (MCF) to other states in the US South. GA, AL, and SC followed respectively. From 2011 to 2019, MS had the highest export quantity, in MCF, with the exception of AL having the highest in 2011, GA leading in 2018, and SC becoming the highest exporter in 2019. Generally, most of the states exported relatively stable quantities of sawlog MCF within the US South through out the study period; however, a few states had some trends of interest. In 2018, Figure 2 showed a spike in GA export quantity relative to 2017, then a sharp decline in 2019. The opposite occurred for MS. MS export quantity had a notable decrease in 2018, then increased back to typical levels in 2019. FL also had a significant increase in export quantity in 2017, and quantities remained more stable for the remainder of the study period. Notably, SC was the only state that experienced increasing sawlog export quantities for the entire study period. These increases were relatively significant as the state was on the lower end of the export trends in the beginning of the study but ended with the highest MCF quantityn the final obseravtion year.

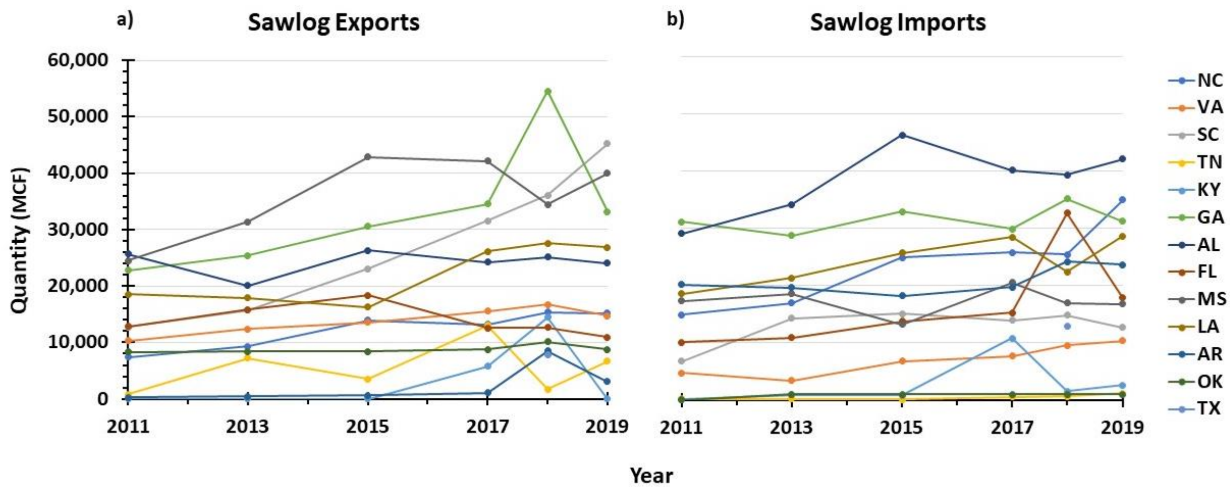

Figure 2. Softwood sawlog export (panel a) and import (panel b) trends for the 13 US South states. Trends are measured in the quantity, thousand cubic feet (MCF), exported from or imported to other states within the US South.

The sawlog import data showed that AL was the leading sawlog importer, in terms of the quantity, thousand qubic feet (MCF), of wood brought in from other states in the US South. With the exception of 2011 when GA had the higest import quantity, AL had the highest import quantity for the duration of the study period. GA was the next highest importer, with the exception of 2011 when it lead and in 2019, it was the second highest sawlog importer. Generally, most states had stable imports throughout the course of the study. Notable import changes occured in FL in 2018, when it had a significant increase in import quantity, and in NC. NC had a constant increase in import quantity throughout the study period and ended as the second higest importer, only falling behinde AL in 2019.

The pulpwood export data showed that MS, AL, and GA, respectivly, were the three major pulpwood exporting states in the US South, in terms of quantity, in MCF, exported to other states in the region. MS led all states in exports in each study year, with the exception of 2011 when AL lead. After 2011, AL remained the second highest importer, while GA remained the third highest. The remaining 10 states had significantly lower import quantities compared to MS, AL, and GA, and had stable export trends or minor declines, with the exception of SC who had increases and decreases in export quanities. Intrestingly, while MS and AL exports increased, GA decreased. The pulpwood export data showed that softwood pulpwood imports are dominated by GA and LA in the US South. Throughout the study period, these two states went back and forth as the leading pulpwood importer. FL was also a major importer early in the study period and was the second largest pulp importer in 2011. After 2011, however, FL decreased its pulp imports and stabilized them for the remainder of the study period to be the third largest pulpwood importer in the southern US. The remaining states in the region had relatively uniform and stable import quantities throughout the entire study period.

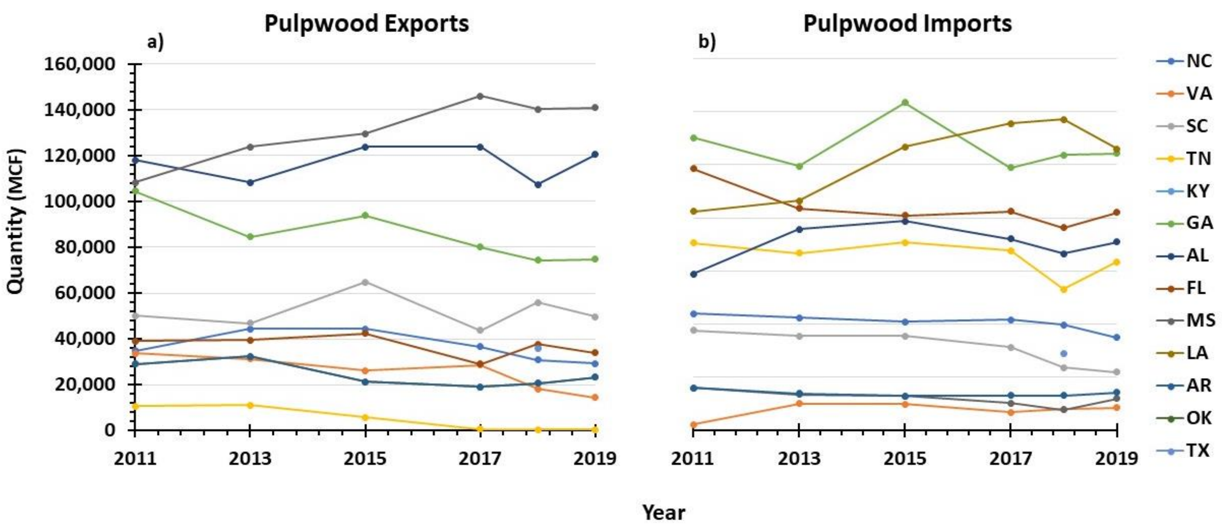

Figure 3. Softwood pulpwood export (panel a) and import (panel b) trends for the 13 US South states. Trends are measured in the quantity, thousand cubic feet (MCF), exported from or imported to other states within the US South.

These data trends offer a general sense of each state's softwood roundwood trading status, in terms of trade surpluses or deficits. A trade surplus occurs when a state's export quantity exceed import quantity (net exporter), while a trade deficit occurs when import quantity exceed export quantity (net importer). Figure 4 indicates this status for softwood sawlog trade status among the 13 southern states, while Figure 5 indicates the status for softwood pulpwood trade among the states.

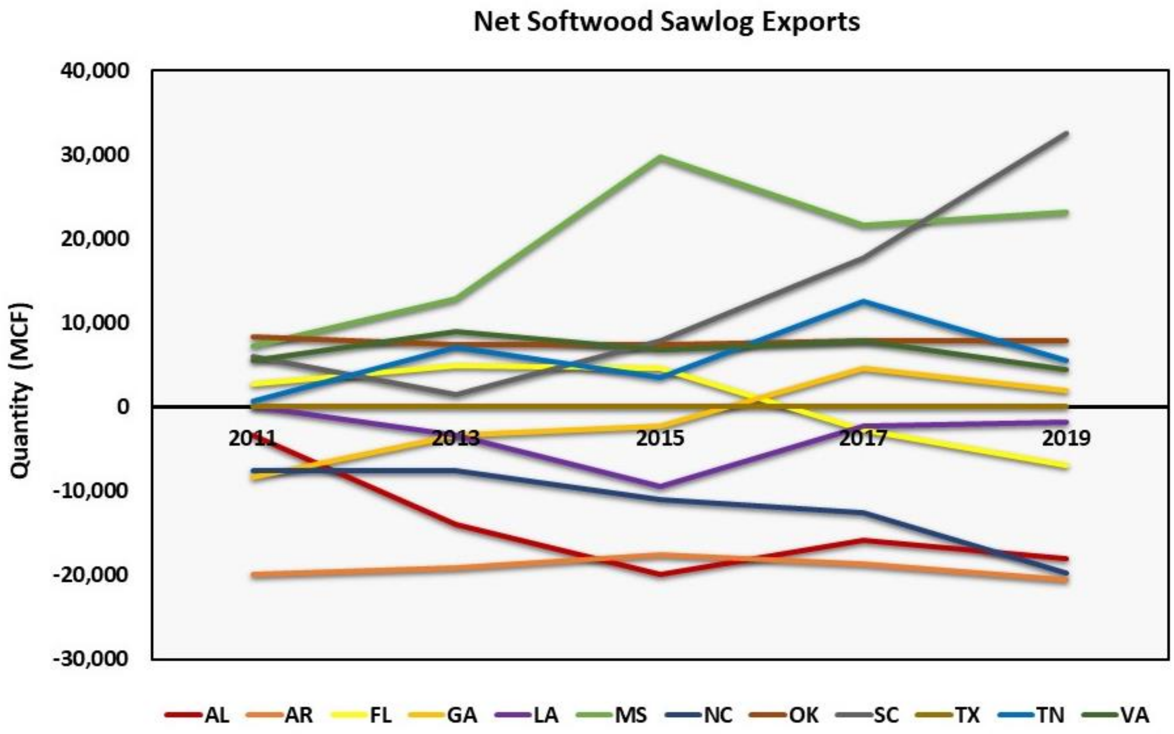

Figure 4. Net softwood sawlog export quantity, in thousand cubic feet (MCF), for the 13 states in the US South. Negative trends, below the 0 volume threshold, indicate a trade deficite, as sawlog import quantity exceed export quantity, and positive trends, above the 0 volume threshold, indicate a trade surplus, as sawlog export quantity exceed import quantity.

The net softwood sawlog export data revealed that MS, SC, TN, and VA had a trade surplus of softwood sawlog during the entire study period, while LA, NC, AL, and AR had trade deficits. Additionally, FL exihibted trade surpluses from 2011 to 2015 but trade deficits after 2015, while GA displayed trade dedeficits from 2011 to 2015 but trade surpluses after 2015. It is also interesting to note that SC experienced near constant and large increases in their net exports during the study period, indicating that they were either substantially increasing the quantity they export or decreasing the amount they import. Conversely, NC and AL had general decreasing net export trends during the study period, indicating that they were either increasing imports or decreasing exports. The remaining states had relativley stable net export or import trends. These trends showed that MS was the dominat net softwood sawlog exporter in the region, and AR was the dominant net softwood sawlog importer.

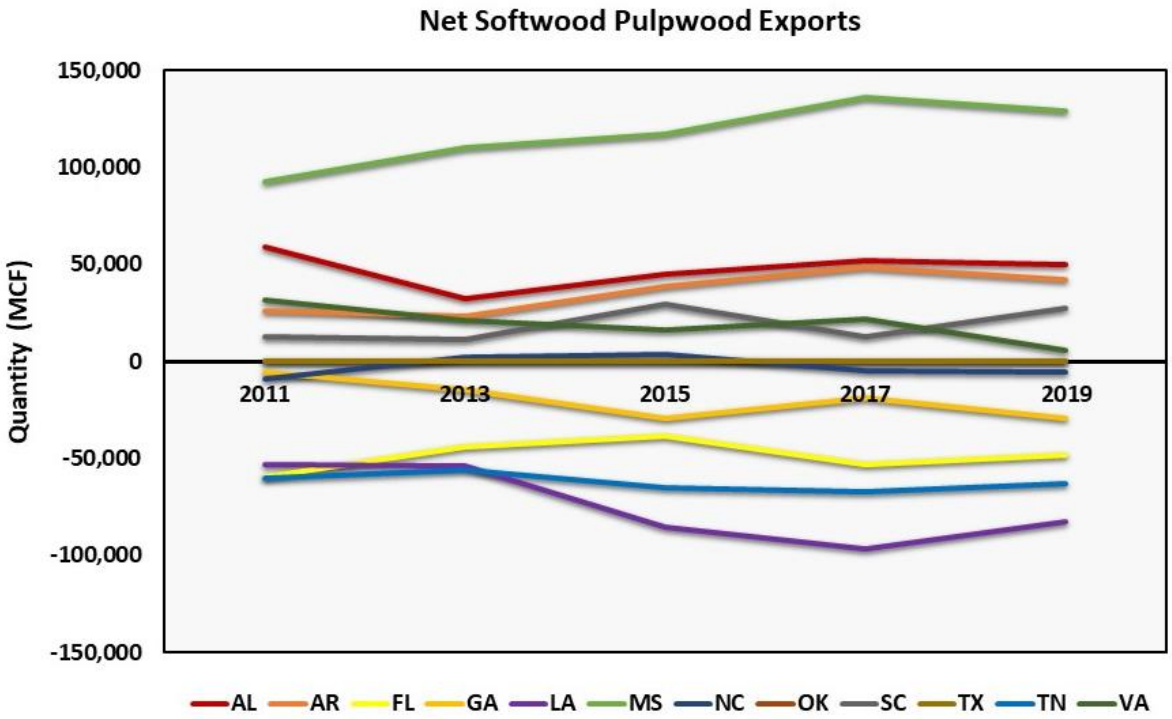

Figure 5. Net softwood pulpwood export quantity, in thousand cubic feet (MCF), for the 13 states in the US South. Negative trends indicate a trade deficite, as pulpwood import quantity exceed exports, and positive trends indicate a trade surplus, as pulpwood export quantity exceeds import quantity.

In terms of softwood pulpwood trade, the data indicated that MS, AL, AR, SC, and VA were net exporters of pulpwood and remained so throughout the study period, while GA, FL, LA, and TN were net importers. Interestingly, NC was the only state that experinced a change from a trade deficit to a surplus. In 2011, NC was a net pulpwood importer, then from 2013 through 2015, it changed to a net expoter, then finally changing back to a net importer for the remaining two years (2017 to 2019) in the study. It is also important to note that the net export/imports of NC remained close to zero throughout the study. In general, the net pulpwood export or import trends remained stable througout the study period. Additionally, the data showed that MS was the dominant net softwood pulpwood exporter in the US South, and exported substantially more softwood pulpwood than the other states in the region, while LA was the dominat net importer of softwood pulpwood.

Finally, the plotted TPO data showed in-state production, in thousand cubic feet (MCF), trends for softwood sawlog and pulpwood among the states in our study region. Figure 6 represents sawlog production trends throughout the study period. Figure 6 showed that most states had a relatively constant or slightly increasing trend in softwood sawlog production. From this trend, we can see that GA was the dominant producer in the south and produced more softwood sawlog quantity than any other state in the region. Following GA in softwood sawlog production was AL, with exception to 2018, when AR was the second highest producer. Interestingly, sawlog production in AR substantially grew between 2015 and 2018. Before 2015, NC was the third highest softwood sawlog producing state in the region. After 2015, however, MS became the third highest sawlog producer in the south. Another noteworthy trend in the production data was the sharp increase that occurred in sawlog production quantity in FL in 2018, followed by an almost equally as sharp decline in 2019. Throughout the study period, TN and KY were the lowest quantity softwood sawlog producing states in the region.

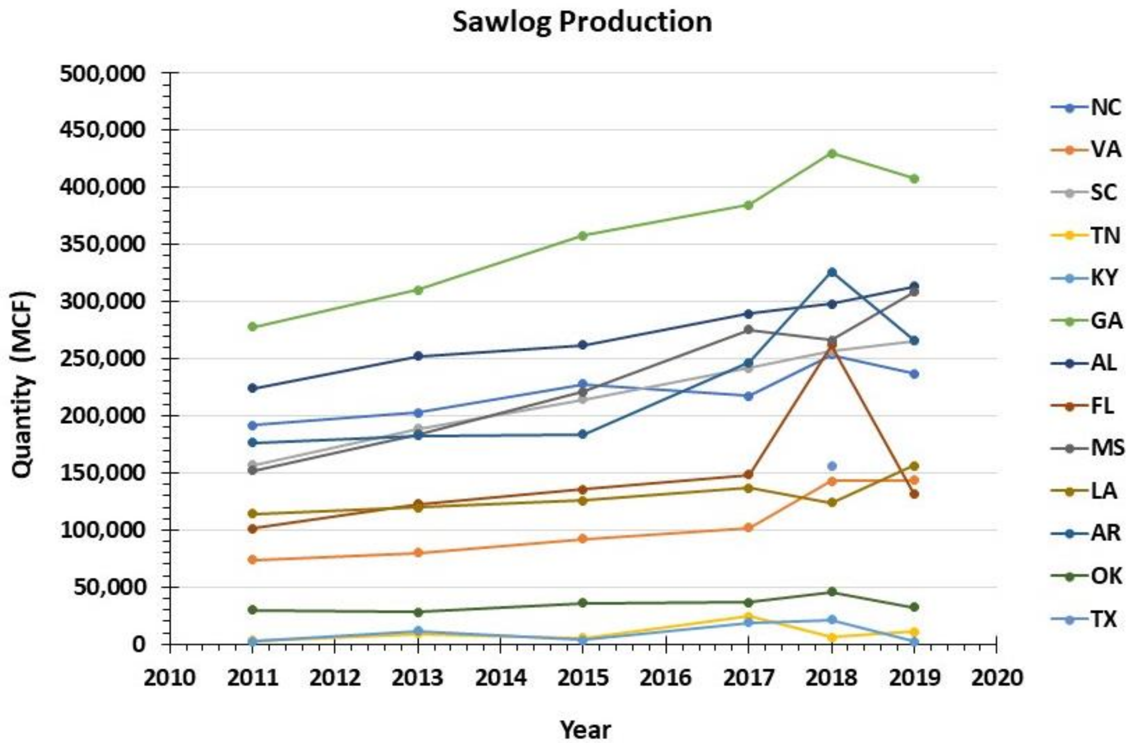

Figure 6. In-state production trends for softwood sawlog in, thousand cubic feet (MCF), for the 13 states in the US South during the study period of 2011-2019.

Figure 7 represents the in-state softwood pulpwood production trends, in MCF, that occurred in the southern US throughout the study period. Figure 7 showed that GA, AL, and MS, respectively, dominated the softwood pulpwood production in the US South. Meanwhile, TN had the lowest softwood pulpwood production for the duration of the study period. Additionally, Figure 7 shows that all states exhibited relatively stable softwood pulpwood production levels throughout the study period.

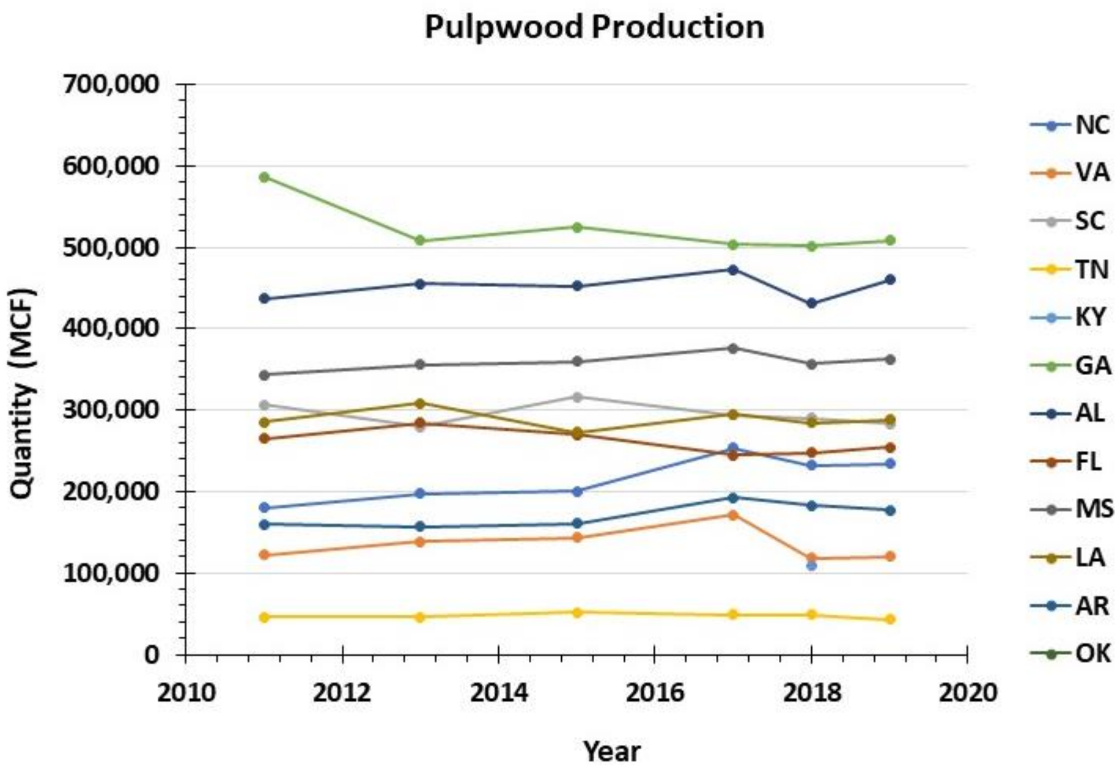

Figure 7. In-state production trends for softwood pulpwood, in thousand cubic feet (MCF), for the 13 states in the US South during the study period of 2011-2019.

Theoretical and Empirical Background of the Gravity Trade Model

The gravity model of international trade was first described by Dutch economist Jan Tinbergen in 1962 to explain the value of intra-industry trade in the monopolist competition model (Feenstra and Taylor, 2017). Tinbergen derived his theory of a gravity trade model based on Newton's 'Law of Universal Gravitation' (Kang, 2003), which states that "objects of greater mass and closer distances have a greater gravitational pull between them" (Feenstra and Taylor, 2017). Empirically, Newton's 'Law of Universal Gravitation' can be written as:

$$F_g = G * \frac{M_1 * M_2}{d^2}$$

where F_g is the force of gravity between two objects, G is a constant of magnitude of this relationship, M_1 is the mass of the first object, M_2 is the mass of the second object, and d is the distance between objects (Feenstra and Taylor, 2017).

Tinbergen's (1962) theory on trade is like Newton's gravity law described above. Tinbergen states that the amount of trade between two countries is directly proportional to their GDPs, which is the proxy used for the mass of a country, and inversely proportional to the distance between them, which he proposed as an approximation of transportation costs. Following Newton's empirical specification for gravitational force, Tinbergen's gravity model of trade takes the following form:

$$Trade = B * \frac{GDP_1 * GDP_2}{dist^n}$$

where *Trade* is the amount of trade between two countries (measured in imports, exports, or their average (net export), B is the gravity constant that reflects the effects of all factors, other than economic mass and distance, that influence trade volume, GDP_1 and GDP_2 are the gross domestic products (masses) of the two trading partners, and *dist* is the distance between them (Feenstra and Taylor, 2017).

Since described by Tinbergen (1962), the empirical specification of the gravity model of trade has been expanded by various subsequent studies. The first expansion was conducted by Pöyhönen (1963), who suggested the viability for trade estimations through the national incomes of two trading countries and the distance between them (Kang, 2003). Next, Linneman (1966) further expanded the traditional empirical specification by adding an explanatory variable for country population (Vu et al., 2020). Additionally, many studies since have implemented an augmented form of the traditional gravity model, where the augmented variables are specific to supply and demand conditions of the specific good being traded.

In my models assessing interstate softwood sawlog and pulpwood trade in the US South, I expanded the traditional gravity model of trade by adding explanatory variables to capture supply and demand factors in the exporting and importing states. The specification for my full augmented sawlog roundwood gravity equation is as follows:

$$yijt = \beta_0 + \beta_1(\ln distance) + \beta_2(\ln GDP_i) + \beta_3(\ln GDP_j) + \beta_4(\ln Prod_i) + \beta_5(\ln Prod_j) + \beta_6(Border) + \beta_7(Storm_i) + \beta_8(Storm_j) + \beta_9(Precip_i) + \beta_{10}(Precip_j) + \beta_{11}(Price_i) + \beta_{12}(Price_j) + \alpha_i + \varepsilon_{it} \quad \text{[Eq.1.1]}$$

The specification for my full augmented pulpwood roundwood gravity equation is as follows:

$$yijt = \beta_0 + \beta_1(\ln distance) + \beta_2(\ln GDP_i) + \beta_3(\ln GDP_j) + \beta_4(\ln Prod_i) + \beta_5(\ln Prod_j) + \beta_6(Border) + \beta_7(Storm_i) + \beta_8(Storm_j) + \beta_9(Precip_i) + \beta_{10}(Precip_j) + \beta_{11}(Price_i) + \beta_{12}(Price_j) + \beta_{13}(Pellet_i) + \beta_{14}(Pellet_j)\ \alpha_i + \varepsilon_{it} \quad \text{[Eq.1.2]}$$

Where, the dependent variable *yijt* is pulpwood (sawlog) export (import) quantity in thousand cubic feet (MCF) from export (import) state (i) to import (export) state (j) in year (t); *distance* is distance between trading pairs in year t; *GDP* is the gross state production in state i and j; *prod* is the softwood pulpwood (sawlog) production in state i and j; *border* is a dummy variable for whether the trading states share a common border; *Storm* is the number of category three and above hurricane events in state i and j; *Precip* is annual rainfall in states i and j in inches; *Price* is the softwood pulpwood (sawlog) price per ton; *Pellet* is the cumulative pellet mill capacity in state i and j at time t; α_i is the individual unobserved fixed effects; and ε_{it} is the error term.

In this study, I used panel data from 2011 to 2019 across the 13 southeastern states to estimate the relationship between trade determinants and softwood sawlog and pulpwood export and import volume. This panel consists of two-year time intervals (observations every other year), beginning with 2011 and ending in 2019, to maintain a balanced panel. OLS, FE, RE, and HT estimators were used to estimate natural log model specifications to investigate trade determinants and model softwood sawlog and pulpwood trade within the US South. I transformed these variables into a natural logarithm form to control for heteroskedasticity. Natural logarithm form models also allow coefficient estimates to be interpreted as elasticities (Jayasinghe and Sarker, 2008). To avoid multicollinearity, I dropped variables with high linear correlation. Because there is no absolute level of correlation that makes multicollinearity problematic (Wooldridge, 2015), I arbitrarily defined multicollinearity to be linear correlations greater than 0.5. Variables in the sawlog models with high linear correlations that were dropped are the catastrophic hurricanes in the importing state and precipitation variables in the exporting and importing states [Eq 1.3]. I also removed the production variables in the pulpwood models due to the high linear correlations between pulpwood production and cumulative pellet mill capacities. The final models are specified as:

$$yijt = \beta_0 + \beta_1(ln\ distance) + \beta_2(ln\ GDP_i) + \beta_3(ln\ GDP_j) + \beta_4(ln\ Prod_i) + \beta_5(ln\ Prod_j) + \beta_6(Border) + \beta_7(Storm_i) + \beta_{11}(Price_i) + \beta_{12}(Price_j) + \alpha_i + \varepsilon_{it} \quad \text{[Eq 1.3]}$$

$$yijt = \beta_0 + \beta_1(ln\ distance) + \beta_2(ln\ GDP_i) + \beta_3(ln\ GDP_j) + \beta_6(Border) + \beta_7(Storm_i) + \beta_{11}(Price_i) + \beta_{12}(Price_j) + \beta_{13}(Pellet_i) + \beta_{13}(Pellet_j) + \alpha_i + \varepsilon_{it} \quad \text{[Eq 1.4]}$$

Based on the theoretical foundations of the gravity trade model and results from similar studies, I hypothesized the expected signs on my estimated coefficients. I also provided a brief discussion on the theory behind my hypothesized signs. Table 1 summarizes these hypothesized signs for the gravity export and import model coefficients. Panel A represents the export model predictions, while Panel B represents the import model predictions.

Table 1. Expected signs of the coefficient estimates in the export gravity models of trade, and the theoretical reasoning behind each expectation. Panel A indicates the hypothesized signs of the export model, while Panel B represents those of the import model.

	A) Export Model		*B) Import Model*		*C) Citations*
Coefficient	**Sign**	**Theory**	**Sign**	**Theory**	
Distance	-	Transportation Costs.	-	Transportation Costs.	Tinbergen (1962)
Common Border	+	Relates to distance. Closer states will have better trade relations.	+	Relates to distance. Closer states will have better trade relations.	Kangas and Niskanen, (2003), Polyakov and Teeter (2007), Akyuz et al., 2010
Exporter GDP	+	Index of economic mass. Larger the economic mass, the more trade that occurs.	+	Index of economic mass. Larger the economic mass, the more trade that occurs.	Tinbergen (1962), Kangas and Niskanen, (2003)
Importer GDP	+	Index of economic mass. Larger the economic mass, the more trade that occurs.	+	Index of economic mass. Larger the economic mass, the more trade that occurs.	Tinbergen (1962), Kangas and Niskanen, (2003)
Exporter Production	+	Increased production increases inventory. Increases amount that can be exported.	+	Increased production increases inventory. Increases amount that can be exported.	Zhang and Li (2009), Tang et al. (2015)
Importer Production	-	Increased production increases inventory. Decreases the amount of imports needed.	-	Increased production increases inventory. Decreases the need to import.	Zhang and Li (2009)

Table 1 (continued).

Storms	-	Increases in storms increases timber and home damage. State will not export due to meeting its own demand increase.	-/+	Negative for pulpwood due to the glut of locally damaged timber overwhelming mills. Positive for sawlog due to increased demand for sawlog to rebuild.	N/A
Exporter Price	-	Increases in state's own market price will cause wood to be sold locally.	-	Increasing exporting state's market price will decrease imports due to exporters wanting to sell domestically.	Buongiorno et al. (1980)
Importer Price	+	Increases in the importing state's market price increases exports as wood is sold where the price is higher.	+	Increases in the importing state's stumpage price increases imports as exporters will sell where the price is higher.	Buongiorno et al. (1980)
Cumulative Pellet Mill Capacity	+/-	Negative for exports due to retention of wood. Positive for imports due to need to increase raw materials.	+/-	Positive for imports due to increased need for raw materials. Negative for exports due to state's needing to retain their pulpwood.	N/A

Trade Determinants

Distance was a linear measurement, in miles, from the exporting state's center of production to the importing state's center of consumption. Center of production for each product, in each state, was determined for every year in the study period by weighting the county level timber production with the x-y (longitude – latitude) coordinates of each county center. Center of consumption was computed using the same methodology as the center of production, except using the number of mills (either sawmill or pulpmill) in each county rather than county level timber production. County level timber production and mill data was obtained from TPO surveys. Distance was computed from the state's production and consumption centers due to the varying spatial and temporal patterns of timber harvesting operations. In the forest products industry, it is common for timber harvests to occur in different areas within a state from year to year, making the use of a weighted production and consumption center appropriate. Note in this study that the center of consumption remains constant. This is due to the use of the number of mills within a county, which remains stable in the data. Had mill capacity been used, then center of consumption would have varied temporally as well. State GDP, in chained millions of dollars, were obtained from the Bureau of Economic Analysis (BEA, 2021), while state populations were collected from the US Census Bureau (U.S. Census, 2021).

Catastrophic hurricanes that occurred during the study period were classified using the Saffir-Simpson Hurricane Wind Scales. The number of catastrophic hurricanes that occurred in a state within the study period was recorded from the National Oceanic and Atmospheric Administration's (NOAA) Historical Hurricane Tracks database (NOAA, 2022). Biannual state precipitation levels, which were not used in the models due to multicollinearity, were derived from NOAA's statewide time series data, which consisted of monthly rainfall in inches, for each year and state in the lower 48 US states from 1895 to 2019 (NOAA, 2021).

Stumpage price data for the export and import state were obtained from Forisk. The obtained prices were the average state level stumpage prices, and were obtained for softwood sawlog and pulpwood in each state and year in the study. Summary statistics for the export and import models are presented in Table 1. Panel A of Table 1 represents the export model, while Panel B represents the import model.

Table 2. Descriptive statistics of the variables used in the export and import gravity trade models.

A) Export Model	Mean	Std.Dev.	Minimum	Maximum	*B) Import Model*	Mean	Std.Dev.	Minimum	Maximum
Export(saw) (thousands cu.ft.)	3.54	5.31	0.00	24.73	Import(saw) (thousands cu.ft.)	3.75	5.39	0.00	24.78
Export(pulp) (thousands cu.ft.)	9.90	15.31	0.00	67.14	Import(pulp) (thousands cu.ft.)	10.49	15.56	0.00	67.14
Pop(i) (millions)	7.76	6.30	2.94	29.00	Pop(i) (millions)	7.12	4.25	2.94	21.50
Pop(j) (millions)	8.25	6.22	2.94	29.00	Pop(j) (millions)	7.99	6.40	2.94	29.00
GDP(i) (thousands)	365.27	350.53	98.77	1,764.36	GDP(i) (thousands)	318.73	195.52	98.77	963.26
GDP(j) (thousands)	387.98	345.11	98.77	1,764.36	GDP(j) (thousands)	376.38	357.42	98.77	1,764.36
Dist(saw) (miles)	258.66	113.97	111.92	673.31	Dist(saw) (miles)	263.18	115.43	111.92	673.31
Dist(pulp) (miles)	265.20	129.90	84.85	728.34	Dist(pulp) (miles)	271.04	130.92	84.85	728.34
SawProd(i) (thousands cu.ft.)	162.94	115.67	0.00	408.26	SawProd(i) (thousands cu.ft.)	180.59	111.88	2.42	408.26
SawProd(j) (thousands cu.ft.)	170.56	116.35	0.00	408.26	SawProd(j) (thousands cu.ft.)	165.19	117.18	0.00	408.26
PulpProd(i) (thousands cu.ft.)	239.32	175.20	0.00	586.48	PulpProd(i) (thousands cu.ft.)	256.86	163.47	0.00	586.48

Table 2 (continued).

PulpProd(j) (thousands cu.ft.)	242.59	169.43	0.00	586.48	PulpProd(j) (thousands cu.ft.)	244.39	176.64	0.00	586.48
Border	0.80				Border	0.78			
Storm(i)	0.30	0.64	0.00	2.00	Storm(i)	0.31	0.63	0.00	2.00
Storm(j)	0.30	0.61	0.00	2.00	Storm(j)	0.31	0.64	0.00	2.00
Precip(i) (inches)	53.99	10.59	14.70	68.06	Precip(i) (inches)	55.52	8.27	26.24	68.06
Precip(j) (inches)	53.98	10.44	14.70	68.06	Precip(j) (inches)	54.07	10.48	14.70	68.06
Sawprice(i) ($/ton)	12.08	1.82	7.71	16.07	Sawprice(i) ($/ton)	12.05	1.80	7.71	16.07
Sawprice(j) ($/ton)	12.17	1.82	7.71	16.07	Sawprice(j) ($/ton)	12.04	1.81	7.71	16.07
Pulpprice(i) ($/ton)	4.49	1.04	2.67	7.43	Pulpprice(i) ($/ton)	4.51	1.06	2.67	7.43
Pulpprice(j) ($/ton)	4.51	1.05	2.67	7.43	Pulpprice(j) ($/ton)	4.50	1.06	2.67	7.43
Pellet(i) (thousand tons)	536.45	594.95	0.00	2,448.00	Pellet(i) (M tons)	637.13	690.82	0.00	2,448.00
Pellet(j) (thousand tons)	626.23	674.81	0.00	2,448.00	Pellet(j) (M tons)	550.18	599.84	0.00	2,448.00
Observations	270				Observations	255			

Empirical Estimation Methods

Empirical estimation of Eq 1.3 and Eq 1.4 were conducted using STATA 17.0 software. When estimating panel data, it is common to estimate fixed effects (FE) and random effects (RE) estimators and formally test for statistically significant differences in coefficients on the time varying explanatory variables with the Hausman test (Wooldridge, 2015). The pooled ordinary least squares (OLS) estimator was estimated using STATA's *reg* command. Due to the analysis using panel data, the *xtreg* command was used to estimate the fixed effects (FE) and random effects (RE) estimators.

OLS estimates parameters by minimizing the sum of the squared residuals (Wooldridge, 2015). OLS, however, often ignores heterogeneity characteristics associated with bilateral trade relationships, causing heterogeneity bias (Serlenga and Shin, 2007). Thus, FE and RE estimators have become commonly used in panel data estimation. These methodologies are better suited for gravity model estimation, as they can model heterogeneity effects by including country-pair 'individual' effects (Serlenga and Shin, 2007).

FE estimators obtain unbiased results, if strict exogeneity assumptions on the explanatory variables are met (Wooldridge, 2015). FE estimators provides unbiased estimates by allowing for arbitrary correlation between α_i and the explanatory variables in any time period, generally making FE models preferred over RE models when estimating ceteris paribus (all else held equal) effects (Wooldridge, 2015). However, this eliminates any explanatory variables in the model that are time-invariant for all *i* and *t* through fixed effects transformations (Wooldridge, 2015). Because time-invariant parameters may be important factors in influencing trade, FE estimators may be insufficient in estimating gravity models. To alleviate this issue, RE estimators may be used.

RE estimators assume α_1 is uncorrelated with each of the explanatory variables in all time periods, allowing for time-invariant characteristics to be included (Wooldridge, 2015). This estimator is considered consistent, not unbiased, and asymptotically normally distributed as N becomes large with fixed T (Wooldridge, 2015). RE estimates, however, can be inconsistent due to correlation of some explanatory variables with unobserved bilateral effects (Hujula et al., 2013). In situations where the FE estimates cannot be used, and the RE model is found to be inconsistent, the Hausman-Taylor method (Hausman and Taylor 1981) may provide consistent estimations of gravity trade models.

Hausman and Taylor (1981) proposed an estimation method that corrects for correlation issues in RE estimators, while still allowing for time-invariant variables to be included in the model. The Hausman and Taylor (1981) (HT) estimator uses the model's own time-varying variables as instruments for the model's endogenous time-invariant variables, allowing it to include time-invariant variables and be more efficient than FE and RE estimators (Hausman and Taylor, 1981). The HT specifications for the sawlog and pulpwood models used different sets of endogenous variables as instruments. In the sawlog models, in-state production in the exporter and importer were used as instrumental variables, while export and importer cumulative pellet mill capacity values were instruments in the pulpwood models. The *xthtaylor* command in STATA was used to make the HT estimate.

The Hausman test (1978) tests for statistically significant differences in coefficient estimates of time-varying parameters (Wooldridge, 2015). This test was performed using STATA's *hausman* command for each combination of FE, RE, and HT models. The Hausman (1978) test was performed to test for the preferred model among the FE, RE, and HT estimators. My analysis implemented the Hausman (1978) test to: (1) test for the preferred FE or RE model,

(2) test the consistency of the HT estimator against the RE estimator, and (3) test the validity and endogeneity of the instrumented variables in the HT estimators.

Results

Export Models

Softwood Sawlog

Table 3 reports the OLS, FE, RE, and HT estimation results for the softwood sawlog export model. The Hausman test (Hausman, 1978) statistic from comparing the coefficient estimates of the FE and RE estimators is statistically insignificant at the 10% significance level, indicating that the RE model is the efficient and consistent estimator. Additionally, the Hausman test statistic from comparing the coefficient estimates of the FE and HT estimators are also statistically insignificant, indicating that the instruments are legitimate, and no other sources of correlation exists (Hujula et al., 2013). Finally, the Hausman test statistic from comparing the coefficient estimates of the HT and RE estimators are statistically significant at the 10% significance level, indicating that the HT model is the efficient estimator. This means that the instrumental variables are endogenous, as the HT estimation yields distinguishably better results compared to the RE estimates (Hujula et al., 2013). These results of the RE model being preferred over the FE and HT models are consistent with the findings of Tang et al. (2015). Being the HT model was found to be the preferred model, the interpretation of the softwood sawlog model results are centered on these estimates.

Table 3. Results of the OLS, FE, RE, and HT estimators of the gravity trade model for the interstate softwood sawlog export model in the US South.

	OLS	FE	RE	HT
Distance	-4.84***	-1.03	-4.05***	-3.56***
	(0.45)	(1.48)	(0.77)	(0.89)
GDP (Exporter)	0.79***	1.23	0.89*	1.33*
	(0.26)	(2.19)	(0.47)	(0.69)
GDP (Importer)	0.92***	-1.06	0.60	-0.09
	(0.27)	(2.11)	(0.48)	(0.69)
Production (Exporter)	0.19***	0.49*	0.22**	0.35
	(0.06)	(0.28)	(0.11)	(0.22)
Production (Importer)	0.73***	0.39	0.64***	0.38*
	(0.06)	(0.29)	(0.11)	(0.21)
Border	3.52***		3.83***	3.65***
	(0.46)		(0.89)	(1.12)
Storm (Exporter)	0.00	0.06	0.06	0.08
	(0.22)	(0.14)	(0.13)	(0.13)
Price (Exporter)	1.58	-0.81	0.03	-0.55
	(0.96)	(1.28)	(1.10)	(1.17)
Price (Importer)	0.43	0.30	0.12	0.68
	(1.03)	(1.29)	(1.12)	(1.21)
Constant	-8.35*	-0.45	-5.04	-2.80
	(4.94)	(20.33)	(8.22)	(9.94)
R^2	0.70	0.23	.69	
F	66.11	1.59		7.68
Observations	270	270	270	270
Hausman Test				
FE versus RE			10.50	
FE versus HT				6.58
RE versus HT				24.30

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Results from the HT model revealed that distance has a negative and statistically significant effect on the volume of softwood sawlog exports between states in the study region at the 1% significance level. The coefficient estimate of -3.56 associated with the distance between the center of production of the exporting state and the center of consumption in the importing state indicates that a 1% increase in distance leads to a 3.56% decrease in the quantity of softwood sawlog flows between the two trading states. Based on this, it was not surprising that the binary dummy variable proxy for whether two trading states shared a common border was positive and statistically significant at the 1% level. The positive coefficient estimates of 3.65 for the border dummy translates to two states sharing a common border will have greater sawlog trade quantities than states that do not share a common border.

The effect of state GDP on the volume of interstate sawlog shipment was found to be positive and statistically significant at the 10% significance level for the exporting state, but not significant for the importing state. The estimated coefficient for the exporting state was 1.33, which represents a 1.33% increase in the quantity of sawlog in response of a 1% increase in GDP.

The effect of state level production for softwood sawlog was found to be positive and insignificant for the exporting state and positive and significant at the 10% significance level for the importing state, which is the second most important determinant of sawlog trade. The associated coefficient estimate of 0.38 for the importing state's production states that a 1% increase in the importing state's sawlog production levels will result in an increase in the sawlog import quantity by 0.38%.

At traditional statistical significance levels, 1%, 5%, and 10%, the variable associated with the number of catastrophic hurricane events that occurred in the export state was found to be insignificant. Additionally, the price coefficients for softwood sawlog, in both the importing and exporting states, were determined to be insignificant determinants of sawlog exports.

Softwood Pulpwood Export Model

Table 4 reports the OLS, FE, RE, and HT estimation results for the softwood pulpwood export model. Comparing the estimation results between the FE and RE models, the Hausman test (1978) indicates the RE estimator is preferred over the FE estimator. The Hausman test also indicates an insignificant p-value in the tests between the FE and HT estimators and the RE and HT estimators. This concludes that additional sources of correlation do not seem to exist, and our instrumental variables of pellet mill capacities in the importing and exporting states are legitimate and endogenous (Hujula et al., 2013). Therefore, interpretations of the estimated softwood pulpwood import model are centered on the HT estimator.

Table 4. Results of the OLS, FE, RE, and HT estimators of the gravity trade model for the interstate softwood pulpwood export model in the US South.

	OLS	FE	RE	HT
Distance	-2.40***	-3.92*	-2.59**	-2.78**
	(0.59)	(2.35)	(1.11)	(1.31)
GDP (Importer)	-0.46	-2.66	-0.03	-0.20
	(0.34)	(2.17)	(0.61)	(0.73)
GDP (Exporter)	-0.66*	0.37	-0.48	-0.56
	(0.34)	(2.09)	(0.61)	(0.73)
Border	3.17***		2.92**	2.85
	(0.69)		(1.40)	(1.75)
Storm (Importer)	-0.37	-0.03	-0.07	-0.06
	(0.35)	(0.12)	(0.12)	(0.12)
Price (Importer)	2.01*	-1.25**	-1.30**	-1.38**
	(1.12)	(0.61)	(0.58)	(0.55)
Price (Exporter)	3.07***	1.71***	1.79***	1.79***
	(1.08)	(0.60)	(0.57)	(0.55)
Pellet Mill Capacity (Importer)	0.43***	-0.03	-0.00	-0.02
	(0.09)	(0.06)	(0.05)	(0.05)
Pellet Mill Capacity (Exporter)	0.29***	0.10*	0.08	0.08
	(0.09)	(0.05)	(0.05)	(0.05)
Constant	18.99***	54.20**	22.30*	26.73*
	(6.47)	(22.10)	(11.94)	(13.80)
R^2	0.38	0.03	.23	
F	17.60	2.537		3.32
Observations	270	270	270	270
Hausman Test				
FE versus RE			152.64***	5.39
FE versus HT				
RE versus HT				3.56

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As expected, distance between the center of consumption in the importing state and center of production in the exporting state was found to have a negative effect on the volume of trade between the two trading partners at the 5% significance level. The coefficient estimate of -2.78 associated with the distance parameter indicates that trade quantity decreases 2.78% for each 1% increase in roundwood pulpwood shipments between two trading states. Aligning with this finding is the binary variable associated with whether two trading states share a common border has a positive coefficient. This coefficient was estimated to be 2.85, which indicates that states sharing a common border will have 2.85% more pulpwood trade between them, compared to those that do not. Surprisingly, the border coefficient was found to be insignificant at traditional levels.

Estimated elasticities associated with the pulpwood prices in the importing and exporting states are in line with our expectations. These were found to be statistically significant at the 5% and 1% significance levels, respectively, and have signs in opposite directions. The coefficient of -1.38 on the importer's price suggests the importing state decreases the quantity of pulpwood it obtains from the exporter by 1.38% for each 1% increase in roundwood pulpwood stumpage prices. Conversely, the coefficient of 1.79 on the exporter pulpwood price indicates a 1% increase in stumpage price leads to a 1.79% increase in the quantity it exports.

The elasticities of the pellet mill capacities were found to be insignificant determinants of softwood pulpwood exports in the HT model. However, it should be noted that the p-value associated with the importer's pellet mill capacity is 0.103, which may not be high enough to conclude statistical insignificance of this determinant. It should also be mentioned that both exporter and importer pellet mill capacity coefficients are positive and statistically significant at the 1% level in the OLS specification, and the importer pellet mill capacity is positive and statistically significant at the 10% level in the FE specification.

Import Models

Softwood Sawlog

Table 5 reports the OLS, FE, RE, and HT estimation results for the softwood sawlog import model. The RE model was found to be the efficient estimator from the Hausman (1978) test, thus estimation interpretation is focused on these results. The Hausman test statistics also indicated our instruments of in-state softwood sawlog production in the exporter and importer are legitimate and endogenous and no other sources of correlation exist.

Table 5. Results of the OLS, FE, RE, and HT estimators of the gravity trade model for the interstate softwood sawlog import model in the US South.

	OLS	FE	RE	HT
Distance	-5.04^{***}	-2.61^{*}	-4.62^{***}	-4.43^{***}
	(0.46)	(1.57)	(0.80)	(0.88)
GDP (Importer)	1.21^{***}	-0.73	0.89^{*}	0.65
	(0.28)	(2.43)	(0.53)	(0.65)
GDP (Exporter)	0.61^{**}	0.75	0.67	0.87
	(0.26)	(2.34)	(0.48)	(0.62)
Production (Importer)	0.92^{***}	0.40	0.74^{***}	0.66^{***}
	(0.18)	(0.34)	(0.20)	(0.23)
Production (Exporter)	0.13^{**}	0.46^{*}	0.17	0.27
	(0.06)	(0.27)	(0.11)	(0.20)
Border	3.54^{***}		3.64^{***}	3.65^{***}
	(0.46)		(0.90)	(1.03)
Storm (Importer)	0.05	0.14	0.07	0.07
	(0.24)	(0.15)	(0.14)	(0.14)
Price (Importer)	-0.42	-0.09	-0.26	-0.12
	(1.53)	(1.32)	(1.23)	(1.24)
Price (Exporter)	1.32	-0.09	0.38	0.14
	(1.00)	(1.30)	(1.12)	(1.16)
Constant	-7.51	9.41	-3.17	-3.61
	(5.10)	(21.81)	(8.47)	(9.59)
R^2	0.68	0.35	.68	
F	58.36	1.88		10.73
Observations	255	255	255	255
Hausman Test				
FE versus RE			6.07	
FE versus HT				5.01
RE versus HT			1.02	

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The coefficient associated with the distance between trading states and whether they share a common border were found to be statistically significant in explaining sawlog imports and were found to have opposite effects on trade quantity. Distance was found to be negative, while sharing a state boundary was positive. The associated coefficient estimates of -4.62 for the distance variable indicates that a 1% increase in the distance between the center of production in the exporting state and center of consumption in the importing state decreases sawlog trade quantity , in MCF, by 4.62%. Conversely, the coefficient of 3.64 associated with the common border variable indicates that sharing a common border has a 3.64% increase in trade quantity between partners.

The effect of importer's GDP was found to significantly affect sawlog imports at the 10% level, while exporter GDP did not. In both cases, the coefficient estimates associated with GDP were positive, which was expected. In the case of importer's GDP, where effects are significant to sawlog exports, the associated coefficient estimate is 0.89, which indicates a 1% increase in importer GDP increases sawlog import volume by 0.89%.

The impact of softwood sawlog production in the exporting and importing states were both found to be positive. The effects of the importer's production are significant at the 1% level, whereas effects of exporter production are statistically insignificant. The 0.74 estimate of the coefficient that corresponds with importer production levels shows sawlog imports will increase 0.74% for each 1% increase in importer production levels.

Softwood Pulpwood

Table 6 reports the OLS, FE, RE, and HT estimation results for the softwood pulpwood import model. Hausman test (1978) results indicated that the HT estimator was found to be preferred, no additional sources of correlation exist, and our instrumental variables of pellet mill capacities in the importing and exporting states are legitimate and endogenous.

Table 6. Results of the OLS, FE, RE, and HT estimators of the gravity trade model for the interstate softwood pulpwood import model in the US South.

	OLS	FE	RE	HT
Distance	-4.33***	-5.03**	-4.13***	-4.20***
	(0.55)	(2.44)	(1.01)	(1.31)
GDP (Importer)	1.85***	1.33	1.65**	1.25
	(0.40)	(2.35)	(0.66)	(0.86)
GDP (Exporter)	-0.76**	-3.76	-0.54	-0.89
	(0.30)	(2.43)	(0.54)	(0.73)
Border	2.98***		3.20***	3.19*
	(0.61)		(1.19)	(1.66)
Storms (Importer)	-0.10	0.01	-0.05	-0.03
	(0.32)	(0.13)	(0.13)	(0.12)
Price (Importer)	0.30	1.87***	1.54**	1.70***
	(1.02)	(0.63)	(0.61)	(0.57)
Price (Exporter)	2.61***	-1.16*	-0.99*	-1.21**
	(0.97)	(0.63)	(0.59)	(0.56)
Pellet Mill Capacity (Importer)	0.23***	0.12**	0.09	0.09*
	(0.09)	(0.06)	(0.06)	(0.05)
Pellet Mill Capacity (Exporter)	0.29***	-0.03	-0.02	-0.05
	(0.08)	(0.06)	(0.06)	(0.06)
Constant	6.56	62.07***	10.71	20.62
	(5.86)	(23.10)	(10.72)	(13.63)
R^2	0.52	0.11	.42	
F	28.89	2.81		4.57

Table 6 (continued).

Observations	255	255	255	255
Hausman Test				
FE versus RE		35.99***		
FE versus HT				7.53
RE versus HT				7.20

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Distance between the center of consumption in the importing state and center of production in the exporting state was found to have a statistically significant inverse proportional effect on the volume of trade between the two trading partners at the 1% significance level. The coefficient estimates of -4.20 associated with the distance parameter indicates that trade quantity decreases 4.20% for each 1% increase softwood pulpwood must travel between trading partners. In line with the gravity trade model, the direction and significance of this coefficient followed our expectations. Aligning with this finding is the binary variable associated with whether two trading states share a common border is positive and statically significant at the 10% level. This coefficient estimate tells us that trade quantity of this product is 3.19% higher between states that share a common border, versus partners that do not.

The coefficients associated with the pulpwood stumpage prices in the importing and exporting states were found to be significant at the 1% and 5% levels, respectively. The positive coefficient of 1.70 on the importer's price suggests a state imports 1.70% more pulpwood quantity when it increases its price by 1%, while the negative coefficient of -1.21 associated with the exporter's price suggests that pulpwood trade quantity decreases by 1.21% for each 1% increase in the stumpage price in exporting states. The directions of the coefficients associated with importer and exporter prices followed our anticipated results for this model.

From the analysis, we find a 1% increase in the cumulative capacity of the importing state's pellet mills induces a 0.09% increase in softwood pulpwood import quantity. The coefficient associated with the importer's pellet mill capacity is significant at the 10% level, and the direction of the estimated coefficient aligned with our expectations. The coefficient associated with the exporter's capacity is insignificant at the even 10% level. However, it should be noted that the OLS specification yielded positive and statistically significant elasticities, at the 1% level, for both importer and exporter pellet mill capacities.

Discussion

The US South is a major producer of softwood timber products. Although studies have assessed international forest products trade, this is the first study since Polyakov and Teeter (2007) to assess intra-regional trade of forest products in the US South using the gravity trade model. This study uses panel data, with OLS, FE, RE, and HT estimation techniques, with the goal of estimating gravity trade equations to investigate various determinants of interstate softwood sawlog and pulpwood trade within the southeastern United States.

The results of the Hausman (1978) test statistics indicated that the RE estimator is preferred over the FE estimator in all models, except the pulpwood import model where FE is preferred. Hausman tests also indicated that the HT estimator is preferred over the FE estimator in all models, and is more efficient than the RE estimator in all models except the sawlog import model. These tests confirmed that no other correlation sources exist, and the instruments used are valid and endogenous.

Consistent with the theoretical foundation of the gravity trade model, the distance variable was found to be highly significant and negatively related to unidirectional softwood trade within the US South. Several similar studies assessing forest products trade (Polyakov and Teeter (2007), Hujula et al. (2013), Zhang and Li (2008)) also reported a similar result of a significant and negative distance coefficient. The significant, inverse relationship between distance and trade volume can be explained by distance being a proxy for transportation costs.

Timber transportation is a major challenge for the forest products sector, and trucking can account for up to 25% of timber delivery costs (Conrad IV, 2021). Increasing the distance products need to travel increases the cost it takes to transport them. In the context of wood products, a major component of total delivered costs is freight, which is highly correlated to diesel fuel, to transport the bulky feedstock (Forest2Market, 2014). Differences in cost and fuel efficiency are increased as a function of trucking distance (Väätäinen et al., 2020). Hence, increasing the distance roundwood must travel will increase fuel consumption and total delivered costs. This increase in transportation costs creates less incentive for trade between states that are located farther apart, as transportation costs would be greater compared to states located in a closer proximity to one another.

Additionally, in all major timber producing states, state weight limits for log trucks exceed federal interstate highway weight limits, often discouraging loaded log trucks from using interstate highways (Conrad IV, 2020). This discouragement of interstate highway use may influence truckers to seek alternative travel routes from harvest sites to delivery sites, which may increase distance and time traveled. If the distance and time traveled increases, the incurred cost of truck driver labor will simultaneously increase. This labor cost will increase due to increased hours, increased wages per hour for extra time, or a combination of the two.

Not surprisingly, the border dummy has the same level of significance and is positive in all models, except the pulpwood import model. This finding follows the results of Akyuz et al.

(2010) and Polyakov and Teeter (2007), who found distance to be a significant and positive trade determinant. Distance and border are often related as states that share a common border are often geographically closer than those that do not. This indicates two states sharing a common border will have increased trade relations, in the context of softwood sawlog and pulpwood, then those that do not. For example, NC and TX do not share a common border and are far apart, while NC and VA share a border and are close to each other. Based on this, NC is going to trade more with VA than TX.

In addition, sharing a common border may positively influence softwood sawlog and pulpwood trade volume due to similar feedstock availability. States that share a common border are generally located in geographically similar areas. Thus, important climatic conditions, such as temperature and precipitation, that influence forest composition types are often similar. This indicates these states likely have similar forest types (southern pines in the US South), which may increase trade volume by increasing the amount of available pine feedstock in the area.

Finally, sharing a border may increase trade volume due to mill procurement zones. Mills often have varying distances they will travel, depending on costs (Forest2Market, 2014) and mill inventory needs, to procure feedstock for the mill. Generally, these procurement zones will extend into more than one state (Forest2Market, 2014), rather than being dictated by state boundaries. Under circumstances of overlapping mill procurement zones and state boundaries, interstate trade is likely to increase due to mills obtaining wood from the neighboring state, which may be closer and cheaper for them to obtain than some areas in their own state.

Gross domestic product (GDP) was the original variable described by Tinbergen (1962) to account for the “mass” index described by his original gravity model framework derived from Newton’s law of gravity. Thus, our results of significant and positive coefficients for importer state GDP in the sawlog import and export model were not surprising. These findings also align with results of similar studies by Hujula et al. (2013), Tang et al. (2015), and Nashrullah et al. (2020), who all found GDP to be a positive, significant driver of trade.

State GDP is a significant trade driver, in part, due to what state GDP measures. State GDP is a measure of income factors, including labor and capital income and business taxes, and production costs (BEA, 2017).This statistic is often thought of as the best measure of a society's economic well-being (Mankiw, 2018). This explanation of GDP measure is indicative of how states with higher GDPs will have a greater "attraction force" of trade, and states with the larger GDPs will trade more. In the context of our model and forest products trade, increasing state GDP increases softwood sawlog and pulpwood imports and exports for this exact reason. As mentioned, as a state's GDP is higher, their output capacity and residents' income also rise. From this, we can reason those increases in a state's GDP will lead to an increase in the production levels of sawlog and pulpwood, as well as an increase in the demand for these products. In terms of sawlog exports, increasing production levels increase inventories, which may increase a state's available wood supply and ability to trade.

Regarding imports, increases in GDP may cause the increase in imports due to the increase in demand. Increases in incomes of those in the economy can be induced through two main channels, increases in the number of individuals earning income, increases in the income of the existing individuals, or a combination of these. This may drive demand for sawlog up due to increased need for housing and/or remodeling or expansion of existing structure, which commonly utilize materials processed from softwood sawlog (dimension lumber and plywood). Even though production may increase as a result from increased state GDP, a state may still have the need to import wood due to the demand factor. It may be a case where a state simply cannot keep up with demand using their own products, thus must import to meet the demand within the state. The reason behind why state GDP is not significant in the pulpwood models is less clear.

In the sawlog models, sawlog production in the importing states is found to be a significant driver of interstate trade in the US South. These results aligned well with those of Zhang and Li (2008), Zhang and Li (2009), Tang et al. (2015), Nashurella et al. (2020), and Das et al. (2018), who all found that forest areas, which are essentially forest endowment proxies, are significant determinants of bilateral trade of forest products. Contrary to our expectations, the coefficient estimates associated with the importing state's production in the sawlog model was positive.. Increasing supply leads to a lower price, resulting in lower timber trade if the production increased in the importing state.

One explanation for the contrary results of increased production in the importing state inducing trade increases is demand. Even though a state may increase its production of sawlog, it still may be unable to meet its own demand. For instance, states with major cities, such as Charlotte, NC and Atlanta, GA may be high demand regions With high populations, increasing migration from other US regions, and increasing infrastructure, these cities may increase demand for these products, and state level production may not be able to meet these demands at market prices and may require raw materials from outside sources to meet demand.

Another explanation for this contrary finding is bilateral trading. Many states will import these products from one state, while simultaneously exporting products to another state. In cases where demand does not have as strong of an influence, increased production allows a state to increase the amount it exports. In turn, this may increase the overall trading activity of the state. It should also be noted that the production levels of the exporting state are not significant drivers of sawlog trade. The positive sign on the associated exporting states' production levels coefficient is positive, indicating increased production increases trade volume. This makes sense, as increasing in-state production, the amount of standing timber harvested, increases roundwood inventories. This may allow for more roundwood availability, thus potential increased trade potential.

In both the import and export model frameworks, the price coefficient significantly influences pulpwood trade flows but not sawlog. In the pulpwood export model the exporter stumpage price has negative coefficient and the importer stumpage price has a negative coefficient. Conversely, in the pulpwood import model, exporter stumpage price is negative and importer stumpage price is positive. In context of the export model, it implies that as the market price, which is dictated by supply and demand, of pulpwood stumpage in the importing state increases the importing state increases the amount of pulpwood they harvest domestically, reducing the need to bring wood in from outside sources. Additionally, this also implies as the state's own market pulpwood stumpage price increases, pulpwood harvesting increases, increasing exports due to more quantity being available.

The interpretation of the estimated price coefficients in the pulpwood import model is similar to the export model's price coefficient interpretations that align with marketing principles. When the pulpwood stumpage price increase in the exporting state, the quantity harvested increases, decreasing the need for the export state to import pulpwood. If the pulpwood stumpage prices are increased in the importing states, there will be more incentive for timber trade because exporting states will be incentivized to sell wood to the importer. The export states will want to sell pulpwood roundwood where the market price is highest in order to gain the best potential profit margins.

The significance in price driving pulpwood trade but not sawlog trade may be due to the end-use product differentiation between them, which may cause competition for pine pulpwood to be high. Sawlogs are used to produce higher-value wood products, such as lumber and plywood (Forest2Market, 2014). Pulpwood, however, is a feedstock for a wider array of products, such as oriented strand board (OSB), pulp and paper products, packing materials, fluff pulp, and industrial wood pellets (Forest2Market, 2014, 2019). With a greater variety of pulpwood products, it is likely that there is more competition for pulpwood roundwood stumpage, compared to sawlog. Another explanation for the observed results of the price effect could be that while pine pulpwood prices have increased 47% since 2002, pine sawtimber prices have decreased 35% (Forest2Market, 2019). This trend in softwood pulpwood and sawtimber pricing is attributed to increased demand for pine pulpwood due to new markets and changing end-use products (Forest2Market, 2019). The major new and expanding markets for pulpwood and low valued woody feedstock that are influencing this trend include containerboard, fluff pulp, and industrial wood pellets (Forest2Market, 2019).

Our analysis has indicated that catastrophic hurricane events have no significant impact on softwood sawlog or pulpwood exports and imports. It may be the case that these results are insignificant due to a lagged effect from the storm. Perhaps, a few years after a hurricane, timber production levels may be reduced due to damages to standing timber inventories, increasing the need of timber from other states. Additionally, this insignificance may be attributed to the time scale of hurricane events. Hurricanes are often seasonal weather patterns occurring during a particular time of the year, with some hurricane seasons being worse than others. Major hurricanes often impact more than one state in US South, possibly hitting multiple states at different magnitudes. Coastal states, such as Louisiana, Texas, and Florida often see more frequent and intense hurricanes than inland states, such as Tennessee and Kentucky, as well. Finally, hurricane effects may not influence interstate trade in the US South due to timber damages. The timber damaged from the hurricane event is of lower value, thus is non-economical for trade.

Cumulative pellet mill capacity was found to be mostly insignificant in the HT estimation of the pulpwood models. The only significance of this variable was found in the importing state of the import model, which had a positive coefficient. The significance of the positive importer coefficient in the import model may be due to growing foreign consumption of industrial pellets (Galik and Abt,2015, Brandeis and Abt,2019). With the US south being a major producer of industrial wood pellets (Brandeis and Abt, 2019), wood pellet production and pulpwood roundwood trade may rise to meet the feedstock demand of larger scale production facilities, which are primarily located in the southeastern coastal region (Parajuli, 2021).

Conclusions

Regional and sub-regional timber markets and resource supply chains are crucial factors for timber managers and policy makers to consider when making forest management and investment decisions. With the significant amount of roundwood that crosses state lines in the US South in recent years, bilateral trade could play a vital role in characterizing these state and regional timber markets, procurement radii, and supply chain dynamics. Research related to the international exchange of goods has shown certain factors create trade barriers, resisting the volume or value of goods traded, while others promote them. The goal of my analysis is to investigate how various determinants related to the supply and demand of softwood sawlog and pulpwood influence bilateral trade of these products in the US South.

This analysis employs gravity trade models, with OLS, FE, RE, and HT estimation techniques as empirical strategies. The impacts of distance between trading partners, sharing a common border, state level GDP, softwood sawlog or pulpwood production and stumpage prices, and the number of catastrophic hurricanes that occurred in the importing and exporting states on bilateral trade volume of softwood sawlog and pulpwood were assessed separately. Study results suggested that the most traditional gravity model parameters of distance and GDP were significant and had the expected signs in both models. Distance was found to be inversely proportional to trade volume and GDP was found to be directly proportional to trade volume. This alignment with gravity model theory and similar study results indicated that the standard gravity trade model was successful in analyzing interstate trade flows within our study region.

Results of the softwood sawlog export model also suggested border, importing state sawlog production, and exporting state GDP to be influential drives of the interstate sawlog trade in the US South. Furthermore, the softwood pulpwood model results revealed that border, price, importing state pulpwood production, cumulative pellet mill capacity, and GDP are the influential determinants to its trade between southern states in the US.

It is important to note that the TPO's method of data collection, which is a survey based methodology, was changed in 2018 from biannual data collection to annual. Although likely not affecting empirical analysis, this change in data collection methods could potentially contribute to some of the observed differences in observed trends occurring in 2018.

This paper includes a limitation. In this study, I do not account for export or import quantities from other regions in the US or foreign nations. Exports and imports from other regions in the US outside the South are less likely to present validity threats due to the minimal quality of wood being exported to and imported from these regions. Export and import quantity from foreign nations may pose a greater threat to validity, however. Foreign exports and imports may influence the quantity of exports and imports between states in the US South due the major ports in the region existing on the states along the Atlantic coast.

This study opens the door for several follow-up analyses. The first may be to expand the inclusion of sawlog to include veneer logs, and pulpwood to include bioenergy products to determine if the results differ significantly from the results of this study. This was not included as sawlog, pulpwood, veneer, and bioenergy are reported separately in TPO datasets. Also, it would be interesting to use delivered wood prices rather than stumpage prices to determine if the results differ significantly from the results of this study. It may also be interesting to apply a similar modeling framework to the other major wood basket in the US, for instance in the Pacific Northwest to model intraregional trade occurring between states specific to that region. Similarly, this modeling strategy can be utilized to study hardwood timber trade. Additionally, it would be interesting to assess the dynamics of leakage, flows from regions outside the south, on forest product inventories in the South. Regions of particular interest of leakage may include the US Northeast, where production is focused on hardwoods, and international markets. The other interesting question would be to analyze how increasing foreign market demands may be influencing the trade of pulpwood and sawlogs between domestic states and regions.

Finally, the novel COVID-19 pandemic may present opportunities for researchers to assess the effects of the pandemic on domestic forest products trade. The pandemic had several effects on the forest products industry. Supply chain shortages, increased consumer demands, new business-related health and safety laws, US states with stay-at-home mandates, travel restrictions, and an increased incentive to substitute capital for labor, due to labor supply contractions could drive long-term alternations in trade patterns in this region. It may be of interest to assess how these pandemic-related factors may influence the US interstate trade of forest products.

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