Interregional Aspects of Timber Inventory Projections

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INTERREGIONAL ASPECTS OF TIMBER INVENTORY PROJECTIONS

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Vita

Maksym Polyakov, son of Oleksandr Polyakov and Lyudmyla Polyakova, was born on December 24, 1968 in Kyiv, Ukraine. He graduated from the Ukrainian Agricultural Academy with an Engineer of Forestry degree in 1992. After graduation he worked as an engineer and senior engineer at the State Forest Management Planning Institute for eight years. During the same period, with the support of the Swedish International Development Agency (SIDA) he pursued a study of land management at the Royal Institute of Technology, Stockholm, and graduated with a Master of Science in Land Management degree in 1999. In 1995 he began graduate study by correspondence at the Scientific Research Institute of the Ministry of Economy, Kyiv, Ukraine. He defended his dissertation and graduated with a Candidate of Economical Sciences degree in 1999. From 1999 to 2000 he worked part time as a lecturer at the Forestry Faculty of National Agricultural University, Kyiv, Ukraine. He entered graduate school at Auburn University in January 2001. He is married to Olena Polyakova and they have a son, Petro, and daughter Oksana.

DISSERTATION ABSTRACT

INTERREGIONAL ASPECTS OF TIMBER INVENTORY PROJECTIONS

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The overall goal of this study is to explore interregional aspects of modeling timber supply. Three separate papers are presented in this dissertation.

The first paper (Chapter 3) presents an econometric analysis of factors influencing demand and supply of pulpwood in Alabama. The softwood and hardwood pulpwood markets were modeled simultaneously as a partial equilibrium system, where equalities of supplies and demands determine prices. Estimation of the parameters was done using two-stage least squares. Price elasticities of supply were found to be similar to those previously reported for the U.S. South (Newman 1987, Carter 1992). The substitution role of sawtimber in hardwood pulpwood supply is consistent with findings for Sweden and the U.S. South (Brännlund et al. 1985, Newman 1987). Results indicate that softwood and hardwood demands are complementary and that a substitution relationship exists between Alabama and Mississippi pulpwood. Regression results can be used for short run predictions.

Four different specifications of a gravity model and a fixed gravity coefficient model were evaluated, and their capabilities to predict pulpwood trade were compared in Chapter 4. Root mean square error was used as a measure of models' predictive performances. The gravity model estimated using non-linear least squares (NLS) with fixed error methods (FEM) and the fixed gravity coefficient model (FGCM) showed the best results, while results for the FGCM were second best and this method is much easier to use.

In Chapter 5, an interregional trading model for stumpage products was developed that recognizes the importance of demand centers (centers of forest products manufacturing activity) and inventory in forecasting future harvests and trade flows. A gravity model was constructed that considers the relative position of each region vis-á-vis all others as a producer of stumpage and as a consumer of stumpage products. The fixed gravity coefficient model was incorporated in a multi-region version of DPSupply (Teeter 1994, Zhou and Teeter 1996, Zhou 1998) referred to as the Interregional DPSupply System (IDPS). Projections for growth, harvest and trade in forest products were made for the thirteen state southern region through 2025. Aggregate trends in inventory are similar to those reported in the Southern Forest Resource Assessment. Inventory trends by product (pulpwood, sawtimber) and type (hardwood, softwood) differ by state and are used to illustrate the advantages of explicitly recognizing interregional trade in the projection system.

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Chapter 1

Introduction

The South is the major timber production region in the United States. In 1997, nearly 58% of U.S. industrial roundwood and three-fourths of total U.S. pulpwood production was produced in the region (Howard 1999, p. 38). The forest sector is an important part of the Southern states' economy, producing 6% of its gross regional product. Forestry is the dominant land use in the U.S. South, occupying 56% of the land base (Wear and Greis 2002). A number of projections made in the 1970s and 1980s (e.g., Haynes and Adams 1985), as well as the 2000 USDA Forest Service Resource Planning Act (RPA) Assessment (Haynes et al. 2003) predicted an increasing share for the U.S. South both in timber growth and removals.

The constant interest in timber supply and environmental issues calls for more efforts to improve analyses and projections of forest resource trends. Furthermore, in recent years, there is a growing interest in information on timber supply in specific regions (states or parts of the states) and how is it affected by mill expansions, land use changes, and urbanization (Abt et al. 2000).

Location and availability of timber inventories determine location of timber industries. In turn, timber industries affect timber inventories, thus impacting themselves, as well as the local economies. Mutual interdependence of timber resources and timber industries occurs not only on a temporal basis, but also on a spatial scale. Demand for roundwood in most of the states is satisfied from the local resource base, as well as by transporting roundwood products from other states. Thus, interregional trade is an important determinant of roundwood markets in the U.S. South.

In this situation, single state timber supply models are too restrictive and may inappropriately indicate bottlenecks in future timber supply. At the same time, aggregating parts of a larger region into a single roundwood demand or supply market can hide local supply problems, providing little detail on the location of future inventory and harvest activity. Therefore, timber supply and demand modeling on a subregional (state) level requires accounting for the spatial aspects of timber markets, and in particular, interregional trade of roundwood products.

The overall goal of this study is to explore interregional aspects of modeling timber supply. Three separate papers are presented in this dissertation. The first paper investigates factors determining demand and supply for the pulpwood market of a single state (Alabama) in the broader context of a regional pulpwood market. The goal of the second paper is to compare the forecasting performance of various specifications of a gravity model and a fixed gravity coefficient model, and discuss their possible applications in interregional (subregional) timber inventory models. The third paper presents an interregional timber inventory projection model that recognizes the importance of demand centers, inventory dynamics, and trade flows in forecasting future inventories, growth, and harvests for the U.S. South by state and by product on an annual basis.

Chapter 2

Literature Review

This chapter reviews some of the existing literature on the topics analyzed in the following chapters. The first section discusses econometric modeling of roundwood markets. Section two reviews multi-regional input-output models. Next, the history and application of gravity models are discussed. Finally, the fourth section provides an overview of timber supply and demand projection models.

2.1 Econometric analysis of roundwood markets

There exists extensive literature devoted to the analysis of timber products markets. Two of the earliest were econometric studies by Gregory (1960) and McKillop (1967). Studies of roundwood product supply and demand were limited to analysis of a single product, for example, pulpwood (Leuschner 1973, Hetemäki and Kuuluvainen 1992), or several products simultaneously (Brännlund et al. 1985, Newman 1987). The scope of these studies varies from a national perspective (Brännlund et al. 1985, Hetemäki and Kuuluvainen 1992, Haynes and Adams 1985) to regional (Newman 1987, 1990) and subregional (Leuschner 1973, Adams 1975, Daniels and Hyde 1986, Carter 1992) markets.

The theoretical part of most empirical studies of timber markets is commonly based on contemporary neoclassical microeconomic theory. Supply and demand are considered simultaneously, therefore methods are employed which allow for systems of simultaneous equations. Common approaches include two stage least squares (2SLS) regression, or three stage least squares (3SLS) regression.

Leuschner (1973) conducted an econometric study of the aspen pulpwood market in Wisconsin based on data covering 1948 to 1969. He assumed that demand for pulpwood is not affected by price and is shifted by changes in pulpmill capacity. Supply is affected by price and shifted by the previous year market quantity and imports. A linear two stage least squares regression was used to estimate the model. All equation coefficients were found to be significant and had the expected signs. The elasticity of supply with respect to own price was estimated to be 2.6.

Brännlund et al. (1985) analyzed Swedish pulpwood and sawtimber markets based on time-series data covering 1953 to 1981 and assumed that the equality between demand and supply determines price in the sawtimber market, and that pulpwood prices are exogenously determined (because of specific features of the Swedish pulpwood market). A log-linear model specification was used. All estimated coefficients of the supply curves had signs consistent with the underlying theory, and most were statistically significant. The own supply price elasticity of pulpwood was estimated to be approximately 0.7.

Newman (1987) presented an aggregate regional model of the southern U.S. softwood solidwood (lumber + plywood) and pulpwood stumpage markets. This analysis considered direct substitution in output between these two products. A simple theoretical framework of the stumpage market allows the derivation of stumpage demand and supply within a profit maximization framework. Three-stage least squares regression techniques provided simultaneous parameter estimation of the market system.

The linear specification was used. The study quantified substantial asymmetries between the pulpwood and solid wood market structures with respect to both supply and demand. Price coefficients in pulpwood supply and demand equations were significant and had signs consistent with the theory. The own price supply and demand elasticities for the pulpwood market were estimated to be 0.23 and −0.43 respectively.

Carter (1992) presented a dynamic model of the Texas pulpwood stumpage market for the period 1964–1986. The ridge regression form of three-stage least squares was used in order to address problems of collinearity. A large significant supply elasticity was found with respect to income, larger than own price elasticity. The role of income is due to the fact that for nonindustrial private forest owners standing timber plays a role of a store of wealth that can be liquidated in the short run to meet income targets. The estimates of own price supply and demand elasticities using three-stage least squares were equal to 0.59 and −0.42 respectively.

All of the previous studies listed above dealt with softwood pulpwood (Carter 1992), softwood solidwood (pulpwood + lumber) (Brännlund et al. 1985, Newman 1987), or hardwood pulpwood (Leuschner 1973) markets. Nagubadi et al. (2001) analyzed interactions between softwood and hardwood pulpwood demands, but did not find any statistically significant substitution effect between hardwood and softwood in pulp production.

Few econometric studies of roundwood markets include spatial interrelationships in the analysis. Adams (1975) analyses the two-region pulpwood market of Wisconsin and Michigan-Minnesota. This analysis includes explicit treatment of pulpwood flows, market interaction within the region, and inventory-holding behavior at pulp mills. Following Leuschner (1973), demand in both regions was assumed to be perfectly inelastic, aggregate supply was equal to aggregate demand. Merz (1984) analyses the pulpwood markets of Wisconsin and the Michigan Upper Peninsula. Unlike in Adams (1975), transportation costs were taken into account in this two-region spatial equilibrium model. However, the study failed to provide conclusive evidence concerning the appropriateness of a two-region model. Finally, analyzing Texas softwood pulpwood, Carter (1992) used net softwood pulpwood export from Texas to other states as an endogenous variable.

2.2 Gravity Model

Spatial interaction models derived from gravitational physics have been used in the social sciences since the early 1940s (Isard 1960). These models have been employed to explain the determinants of different types of flows such as migrations, commuting, recreation traffic, trade, etc. In these models, the degree of interaction between two regions is strengthened by their "masses", represented usually by population or income, weakened by the "distance" between them, reflecting transportation costs, and influenced by other factors.

In the context of international trade, gravity models were first used independently by Tinbergen (1962) and Pöyhönen (1963), who argued that bilateral trade flows are influenced by the size of each country's Gross National Product (GNP) and the distance between them:

$$E_{ij} = \alpha_0 (Y_i)^{\alpha_1} (Y_j)^{\alpha_2} (D_{ij})^{\alpha_3} \tag{2.1}$$

where E_{ij} is the trade between countries i and j, Y_i is the GNP of country i, Y_j is the GNP of country j, and D_{ij} is the distance between countries i and j. Coefficients α_1

and α_2 are assumed to be positive, since the greater the sizes of the economies, the more intensive is trade, while α_3 is negative, because the large distance (high transportation costs) inhibit trade. The values of coefficients were estimated by performing log transformation and using ordinary least squares regression.

The gravity equation became a popular instrument for trade policy analysis. It was used to evaluate trade potential as well as the impact of various policy issues regarding international trade, such as trading groups, currency unions, quotas, or preferential treatment. Despite its widespread empirical use, there was a criticism that the gravity equation has no theoretical foundation, however a number of subsequent researchers have shown that it can be derived from baseline models of trade. Anderson (1979) showed that the gravity model should be consistent with the generalized trade share expenditure system models. Bergstrand (1985) derived the gravity model from the assumption of monopolistic competition and product differentiation.

While used widely to analyze international trade, including trade of forest products (Kangas and Niskanen 2003, Kang 2003), some studies have shown that cross-sectional gravity analysis gives very wide forecast interval spans around the predicted values, which makes it almost useless for estimating trade potentials (Breuss and Egger 1999).

A number of recent studies suggest that a panel framework has many advantages over the cross-section approach (Mátyás 1997, 1998, Egger 2000). It allows a researcher to capture the relationships between the relevant variables over a longer period and to reveal time invariant effects specific to the importer and exporter regions. Acording to (Mátyás 1997), econometric specification of the gravity model using panel data is a three-way fixed effect approach, where importer, exporter, and time fixed effects could be viewed as orthogonal vectors of dummy variables. From the economic point of view, the time effect capture the influence of business cycles, while importer and exporter effects capture general openness of a country to trade with the partners. Furthermore, Egger and Pfaffermayr (2003) argue that proper specification of a panel gravity model should include exporter-by-importer bilateral interaction effect, the product of importer and exporter fixed effects. The exporter-by-importer interaction effect accounts for any time invariant bilateral influences which lead to deviation from a country pair's "normal" propensity to trade. However, the use of bilateral interaction fixed effects makes time invariant variables, such as distance, border, etc. redundant. In order to estimate coefficients of time invariant variables, a number of studies use the Hausman and Taylor (1981) instrumental variable estimation technique (Egger and Pfaffermayr 2004, Serlenga and Shin 2004).

2.3 Interregional Trade in Multi-Regional Input-Output Models

Multi-regional input-output models are an extension of classical input-output models. They can be constructed by either adding a geographic dimension into an input-output model or by embedding an input-output mechanism into a multi-regional trading model. In this overview we will be interested in the multi-regional trading part of multi-regional input-output models.

Hua (1990) classified multi-regional input-output models into four types according to the way interregional coefficients of these models are calculated.The coefficients of Type 1 models are obtained by dividing each column of the interregional trade matrix of a good by total regional consumption. These are the most widely used column coefficient models (Moses 1955, Polenske 1970). In models of Type 2, or row coefficient models, coefficients are obtained by dividing each row of the matrix by regional production (Polenske 1970). Type 3 and Type 4 models, known also as potential or gravity coefficient models (Leontief and Strout 1963), assume that trade of a commodity i between regions g and h (X^i_{gh}) is proportional to the total supply of a commodity in the supply region (X^i_{go}) and total demand of a commodity in the demand region (X^i_{oh}):

$$X^i_{gh} = \frac{X^i_{go} X^i_{oh}}{X^i_{oo}} Q^i_{gh} \quad \forall\ i, g, h \tag{2.2}$$

where X^i_{oo} is the total amount of commodity i produced in an economy and Q^i_{gh} is the gravity coefficient. However, the coefficients in Type 3 models are determined from the base year data while coefficients in the Type 4 models are determined using exogenous variables, such as distance.

Leontief and Strout (1963) developed four methods to derive gravity coefficients. The *point estimate* is used when base-year statistics comprise information on regional inputs and outputs X^i_{go}, X^i_{oh}, as well as regional absorptions $X^i_{gh}, g = h$, and interregional flows $X^i_{gh}, g \neq h$. In this case gravity coefficients are computed directly from (2.2), the coefficients obtained by this method are used in Type 3 models.

The *exact solution* is used when interregional flows $X^i_{gh}, g \neq h$ are not available. In the system of equations with $3m$ known variables (X^i_{go}, X^i_{oh}, $X^i_{gh}, g = h$) it is not possible to determine $m^2 - m$ unknown variables ($Q^i_{gh}, g \neq h$).

In order to determine gravity coefficients, Leontief and Strout (1963) suggested the following:

$$Q^i_{gh} = (C^i_g + K^i_h) d^i_{gh} \delta^i_{gh} \quad \forall\ i, g, h; \quad g \neq h \tag{2.3}$$

where d^i_{gh} is the distance between regions g and h; δ^i_{gh} indicates whether trade between g and h exist; C^i_g is the relative position of region g as a producer; K^i_h is the relative position of region h as a consumer. Now $m^2 - m$ unknown variables $(Q^i_{gh},\ g \neq h)$ are expressed as a combination of $2m$ unknown (C^i_g and K^i_h) and $2m$ exogenous variables (d^i_{gh} and δ^i_{gh}) and the system could be solved when base year trade data are not available.

A least squares regression estimation procedure is used when interregional flows $X^i_{gh}, g \neq h$ are not available and works in a way similar to generating the "exact solution", but uses the least squares method instead of the system of linear equations.

The *simple solution* is what the name indicates.

$$X^i_{gh} = \frac{X^i_{go} X^i_{oh}}{X^i_{oo}} b \delta^i_{gh} \quad \forall\ i, g, h \tag{2.4}$$

where δ^i_{gh} denotes whether trade between two regions exists, and b is a gravity coefficient common for all the pairs of regions where trade exists. The data required to implement this model are regional inputs and outputs X^i_{go}, X^i_{oh}, and regional absorptions $X^i_{gh}, g = h$.

$$b = \frac{X^i_{oo} - \sum_{r=1}^{m} X^i_{rr}}{\sum_{g=1}^{m} \sum_{h=1}^{m} \frac{X^i_{go} X^i_{oh}}{X^i_{oo}}}, \quad \delta^i_{gh} = 0\ \forall\ g = h \tag{2.5}$$

The use of interregional trade coefficients in predictive models relies on their stability, which is the key assumption of multi-regional input-output models. Stability of interregional trade coefficients has been a concern since the early applications of these models (Moses 1955).

Polenske (1970) conducted a testing of row, column, and gravity fixed coefficient models within an input-output framework to estimate 1963 Japanese production. Among the methods used to estimate the gravity fixed coefficient, the point estimate method produced the coefficients that gave the lowest estimation errors. The overall predictive capability of the column coefficient and the point estimate gravity trade models produced comparable results, while the row coefficient method was least accurate.

2.4 Timber Supply and Demand Models

Approaches to modeling timber supply and demand can be classified from two points of view: how they model the timber product market (gap models, market models), and how they treat spatial aspects (non-spatial, quasi-spatial, and spatial models).

Gap models attempt to determine differences between demand for and supply of timber products assuming a predetermined price level. Demand, supply, and inventory are first projected independently, then demand is compared with supply, and conclusions are made about resulting prices (whether they will be lower or higher than assumed). Thus, price-quantity relationships are not used explicitly.

Market models are characterized by explicit functional representations of market processes which determine both price and quantity. Usually this is done by modeling the relationship between price, aggregate production, aggregate consumption, and aggregate timber inventory, by product, and, if applicable, by region. This approach requires determination of empirical coefficients of these relationships (elasticities). Examples of models using this approach are the Georgia Regional Timber

Supply model (GRITS) Cubbage et al. (1991), the Timber Assessment Market Model (TAMM) Adams and Haynes (1980, 1996), and the Subregional Timber Supply Model (SRTS) Abt et al. (2000). The alternative is to model growth of individual representative stands and the decisions of owners whether to cut, which, when combined with aggregated demand, allows derivation of regional supplies and price levels (Teeter 1994, Zhou 1998).

Non-spatial models are characterized by explicit functional representation of market processes which determine both price and quantity, but treat only one geographical region. Suppliers and purchasers are treated as if they participate in a single aggregate regional market. Usually these models are applied to a state or to regions of similar size. Examples of nonspatial models are GRITS for Georgia (Cubbage et al. 1991) and DPSupply for Alabama (Teeter 1994, Zhou 1998).

Quasi-spatial and spatial models address spatial dimensions of timber markets. In quasi-spatial models, spatial dimensions are modeled, but simplified: a) there is a connection between one supply region and one demand region; or b) there are many supply regions and one demand region, for exampple, SRTS (Abt et al. 2000).

Spatial models fully acknowledge the existence of multiple supply and demand regions. There are a number of regions separated by transportation costs. For each region and product there is a relationship between price, production and consumption. As a result, a competitive equilibrium exists for prices, amounts produced and consumed, and transportation costs between regions, so that the net return for each source is maximized and the distribution of products takes place at a minimum cost. An example of a spatial model at the national level is TAMM (Adams and Haynes 1980, 1996).

The Interregional Timber Supply Model (Holley et al. 1975) modeled the U.S. softwood market through 17 supply regions, 23 demand regions, and 11 aggregate final products. ITM considered production costs, wood conversion coefficients, and transportation costs. Given the forward projection of consumption in each demand region and starting with existing inventories and production capacities in each region, the model traced least cost, most efficient geographical patterns of industrial location and timber harvesting over time. Softwood inventory in each supply region was updated using the TRAS (Larson and Goforth 1970) growth model. The approach to handling the multi-regional market was Linear Programming (LP). A large scale LP transportation and harvesting/processing model minimized overall costs of meeting consumer requirements in a given time period. Although it does not incorporate the economic concept of supply and demand as determinants of quantity and price over time, it models effect of the market mechanism in meeting exogenous regional demands.

The Timber Assessment Market Model (Adams and Haynes 1980, 1996) modeled the U.S. softwood market considering 9 supply regions (including Canada), 6 demand regions, and 4 aggregate final products. Quantity and price of timber products in each region were determined as a result of the interaction of regional demand and supply as well as trade of timber from and to other regions. Coefficients of supply and demand equations (elasticities) were calculated using econometric models of demand and supply. Coefficients for lumber and plywood demand equations were estimated separately for each demand region. Demands for pulpwood and fuelwood were determined outside of the model, regional demands were obtained by disaggregation of national level demands. Coefficients for stumpage supply equations were estimated separately for public and private sectors in each region. The model does not distinguish between pulpwood and sawtimber stumpage. The TRAS system was used as a growth model in the early implementation of the system followed by the Aggregate Timberland Assessment System (ATLAS) more recently. Because reaching an equilibrium assumes changes in both prices and quantities, it is not possible to use LP techniques for interregional allocation. The model utilizes *Reactive Programming* which is an iterative procedure in which successive approximations to the equilibrium solution are computed. Despite the fact that it is one of most advanced and widely accepted timber supply models, it treats the U.S. South as one supply region and does not allow for analysis of subregional inventory changes, harvest shifts, and impacts of reallocation within the forest industry.

The Subregional Timber Supply Model for the U.S. South (Abt et al. 2000) works with 52 supply regions (for each FIA forest survey region), 2 ownership classes, and 5 management classes. Inventory is aggregated by 10-year age classes. Timber supply for each region is a function of price, inventory, and supply shifters. Aggregate demand is a function of price and demand shifters. SRTS takes exogenously determined aggregate regional harvest levels and solves for the implicit demand, price, and subregional harvest shifts. Assumptions imply a competitive market with regions and ownerships facing the same price trend, although levels could differ across subregions. There is no demand associated with a single point, instead demand is assumed to be mobile, either through shifts in procurement regions or new capacity, and is assumed to respond to regional differences in stumpage prices. In reality, the ability to reallocate production capacities could be not as elastic as this model assumes because of the barriers between subregions represented by distances and transportation costs, which are ignored in SRTS. Thus, it is not clear how the model will respond to an explicit change in subregional demand, e.g. resulting from closure of a pulpmill.

DPSupply (Teeter 1994, Zhou 1998) was used to analyze timber supply for Alabama, South Alabama, and Mississippi. The elementary growth and harvesting unit is a FIA sample plot. A network of FIA sample plots covers the territory with a grid size of approximately 3 miles. In DPSupply each FIA sample plot is assumed to represent one stand. This makes DPSupply different from most other models which deal with aggregated timber inventory. FIA sample plots were grouped by four management types (pine plantations, natural pine, oak-pine, and mixed hardwoods), two size classes, and two ownerships classes (industrial and non-industrial private). Public forests were not considered due to their insignificant share (less than 5%) in timber production. A *growth model* was developed using two consecutive FIA data sets. Unlike most of other models which consider only the volume of "growing stock", DPSupply operates with the volume of "live trees," which is about 10% greater than the volume of "growing stock", and the difference could be harvested as pulpwood. Growth and timber product distribution models were built for each management type and size class. Volume per acre and average diameter at breast height (dbh) in a given year are modeled as a function of volume and dbh in previous year: $V_{t+1} = V(V_t, D_t)$; $D_{t+1} = D(V_t, D_t)$.

Timber product distribution models estimated using a multinomial logit method (Teeter and Zhou 1999) are used to distribute the aggregate volume on potential harvest plots to product classes. The dynamic programming module uses a recursive procedure to determine optimal harvest decisions (clearcutting, thinning, or no action) for each combination of volume and dbh class, management type, ownership class, and stumpage price level. The assumption of this model is that forest owners manage their forests in order to maximize net present value. The projection module works in the following way. For each year of the projection period, this module “grows” each stand according to growth functions, and, given exogenous demand and an array of optimal decisions from the dynamic programming module, “harvests” the necessary number of stands using a linear programming procedure, and “regenerates” harvested stands. DPSupply used a different approach to model the timber products market than the previous two models, but it is non-spatial model, which limited its ability to analyze interregional aspects of roundwood markets.

CHAPTER 3

ECONOMETRIC ANALYSIS OF ALABAMA'S PULPWOOD MARKET

3.1 Introduction

The Southern timber market is the major source of both softwood and hardwood pulpwood in the U.S. This region accounts for 65 percent of total U.S. pulpwood production over the past ten years (Howard 2001). Currently, 94 pulpmills are operating and drawing wood from the 13 Southern States. Southern mills' pulping capacity of 123 thousand tons per day accounts for more than two-thirds of the nation's current pulping capacity (Johnson and Steppleton 2003). Alabama leads the South in total roundwood pulpwood production (10 million cords), number of mills (14), and is second only to Georgia in pulping capacity (18,605 tons per day) (Johnson and Steppleton 2003).

The constant interest in timber supply and environmental issues calls for more efforts to improve analyses and projections of forest resource trends. Furthermore, in recent years, interest has grown in understanding timber supply in specific regions (states or parts of states) and how mill expansions, land use changes, and urbanization affect supply (Abt et al. 2000). The determinants of wood supply and demand are important elements of timber inventory projection models.

The scope of previous studies of roundwood markets varies from a world perspective (Trømborg et al. 2000), to national (Brännlund et al. 1985, Hetemäki and

Kuuluvainen 1992, Adams 1975, Haynes and Adams 1985), and to regional (Daniels and Hyde 1986, Newman 1987, Carter 1992) markets.

Most empirical studies of timber markets are based on contemporary neoclassical microeconomic theory. Supply and demand are usually considered simultaneously, using a system of simultaneous equations. Common approaches include two stage least squares (2SLS) regression or three stage least squares (3SLS) regression (Brännlund et al. 1985, Newman 1987, Carter 1992).

Previous studies of pulpwood markets dealt with softwood pulpwood (Carter 1992), hardwood pulpwood (Leuschner 1973), and softwood solidwood (pulpwood + lumber) (Brännlund et al. 1985, Newman 1987). In the latter case, the mutual influence of pulpwood and sawtimber markets was taken into account by considering direct substitution in output between solidwood and pulpwood. To our knowledge, only Nagubadi et al. (2001) analyzed interactions between softwood and hardwood pulpwood demands, but did not find any statistically significant substitution effect between hardwood and softwood in pulp production. This paper attempts to estimate demand and supply elasticities as well as identify factors determining demand and supply for the Alabama pulpwood market. Analysis of hardwood and softwood pulpwood cross price demand elasticities as well as cross-regional price elasticities are added goals of the present analysis.

3.2 Pulpwood Market Model

The basic economic assumption used in the present model is that of equality of supply and demand for both softwood and hardwood pulpwood:

$$Q_t^S \equiv Q_t^{Sd} \equiv Q_t^{Ss} \tag{3.1}$$

$$Q_t^H \equiv Q_t^{Hd} \equiv Q_t^{Hs} \tag{3.2}$$

where Q_t^S is the quantity of softwood pulpwood stumpage in year t, Q_t^{Sd} and Q_t^{Ss} are respectively the quantities demanded and supplied in year t; Q_t^H is the quantity of hardwood pulpwood stumpage in year t, Q_t^{Hd} and Q_t^{Hs} are respectively the quantities of hardwood pulpwood demanded and supplied.

Stumpage demand is derived from its use to produce pulp. Pulpmills have high fixed costs, and consequently, mill managers must ensure that mills operate continuously (Leuschner 1973). Therefore, aggregated mill capacity is included in the list of explanatory variables of the pulpwood demand equations. Capacity is expected to be more significant in models of smaller markets (e.g., state as opposed to region or nation). Pulpwood demand and pulpmill capacity are expected to be positively related. At the aggregate level, the pulping industry consumes both softwood and hardwood pulpwood. Depending on how much the proportions of these inputs are allowed to vary, softwood and hardwood pulpwood may be either substitutes or complements. The own-price demand elasticity is expected to be negative, the expected sign of the price of the alternative input depends on whether softwood and hardwood pulpwood are substitutes or complements. Furthermore, consideration must be made that a significant proportion of pulpwood consumed by Alabama pulpmills comes from other states. We assume that imported pulpwood substitutes for pulpwood produced locally. To account for imported pulpwood we include pulpwood stumpage prices from Mississippi, the major exporter of both softwood and hardwood pulpwood to Alabama. Thus, demands for softwood and hardwood pulpwood are specified as follows:

$$Q_t^{Sd} = F(P_t^{Spw}, P_t^{Hpw}, P_t^{MSpw}, C_t) \tag{3.3}$$

$$Q_t^{Hd} = F(P_t^{Hpw}, P_t^{Spw}, P_t^{MHpw}, C_t) \tag{3.4}$$

where P_t^{Spw} and P_t^{Hpw} are, respectively, softwood and hardwood pulpwood stumpage prices in Alabama; P_t^{MSpw} and P_t^{MHpw} are, respectively, softwood and hardwood pulpwood stumpage prices in Mississippi; and C_t is the daily pulping capacity of Alabama's pulp industry in year t.

It is more difficult to derive the supply equations for pulpwood than the demand equations. Individual timber growers' production cost data are not readily available (Brännlund et al. 1985, Newman 1987) and expenses connected with production are distant in time. Pulpwood supply is a function of the revenues of forest management through its own price and the price of alternative outputs (sawtimber). The coefficients of the own price variable is expected to have a positive sign while the signs of coefficients for alternative product prices are unclear; they depend on the possibilities to switch to and from alternative products and on the dynamics of alternative product prices. Previous studies report a substitution relationship between pulpwood and sawtimber in pulpwood supply (Brännlund et al. 1985, Newman 1987, Carter 1992). It is reasonable to use standing softwood inventory as in Newman (1987), but data are only available at approximately ten-year intervals, and interpolation does not make much sense. Another consideration is that stumpage is bought, harvested, and sold to the pulp mills by a large number of small contractors who have limited financial resources and managerial skills. The volume sold in previous years would likely affect the current year's supply since high sales in previous years provide contractors with an incentive to stay in business and expand capacity (Leuschner 1973). Therefore, we assume a positive relationship between current year supply and previous year quantity (harvest). Thus, the supply equations may be specified as follows:

$$Q_t^{Ss} = F(P_t^{Spw}, P_t^{Sst}, Q_{t-1}^{Ss}) \tag{3.5}$$

$$Q_t^{Hs} = F(P_t^{Hpw}, P_t^{Hst}, Q_{t-1}^{Hs}) \tag{3.6}$$

where P_t^{Sst} and P_t^{Hst} are, respectively, softwood and hardwood sawtimber stumpage prices in year t, and Q_{t-1}^{Ss} and Q_{t-1}^{Hs} are, respectively, harvests of softwood and hardwood pulpwood in the previous year.

3.3 Data

The current analysis uses time series data from 1977 to 2001. All prices are deflated to the base year 1982 using the Bureau of Labor Statistics Producer Price Index for all commodities (`http://www.bls.gov/`). The quantity of pulpwood stumpage ($Q_t^S \equiv Q_t^{Sd} \equiv Q_t^{Ss}$, $Q_t^H \equiv Q_t^{Hd} \equiv Q_t^{Hs}$) is the total quantity in thousand cords of, respectively, softwood and hardwood roundwood pulpwood produced in Alabama. Pulping capacity (C_t) is annualized daily pulping capacity of Alabama's pulp and paper industry in thousands of tons. The sources of data on quantity of pulpwood stumpage and pulping capacity are the "Southern Pulpwood Production" reports, an annual report series from the USDA Forest Service Southern Research Station. Stumpage price data are from Timber Mart South (Norris Foundation 1977–2001). Annual prices of softwood pulpwood, softwood sawtimber, hardwood pulpwood, and hardwood sawtimber, (P_t^{Spw}, P_t^{MSpw}, P_t^{Sst}, P_t^{Hpw}, P_t^{MHpw}, P_t^{Hst}) were obtained by averaging statewide quarterly data; prices are expressed as real U.S. dollars per cord for pulpwood, and real U.S. dollars per thousand board feet for sawtimber.

3.4 Model Estimation and Results

The present model is a system of four simultaneous linear demand (3.3, 3.4) and supply (3.5, 3.6) equations with equilibrium constraints (3.1, 3.2). Supply and demand equations contain two endogenous variables, prices of softwood and hardwood pulpwood, furthermore, the supply equations contain lagged dependent variables. Due to the endogenous variables, the ordinary least squares (OLS) method provides inconsistent estimates of the coefficients (Gujarati 1988, p. 563). Both demand and supply equations are overidentified, which suggests we should use two stage least squares (2SLS) regression, as it produces consistent (but biased) parameter estimates for the system of simultaneous equations.

In order to perform 2SLS, it is necessary to create instrumental variables by regressing P_t^{Spw}, P_t^{Hpw} on all the exogenous variables (P_t^{MSpw}, P_t^{Sst}, Q_{t-1}^{Ss}, P_t^{MHpw}, P_t^{Hst}, Q_{t-1}^{Hs}, C_t), and use predicted values $\hat{P}_t^{Spw}$, $\hat{P}_t^{Hpw}$ in the following system of structural linear regression equations:

$$Q_t^S = \alpha_1 + \alpha_2 P_t^{Spw} + \alpha_3 P_t^{Hpw} + \alpha_4 P_t^{MSpw} + \alpha_5 C_t + \epsilon_{1t} \qquad (3.7)$$

$$Q_t^H = \beta_1 + \beta_2 P_t^{Hpw} + \beta_3 P_t^{Spw} + \beta_4 P_t^{MHpw} + \beta_5 C_t + \epsilon_{2t} \tag{3.8}$$

$$Q_t^S = \gamma_1 + \gamma_2 P_t^{Spw} + \gamma_3 P_t^{Sst} + \gamma_4 Q_{t-1}^{Ss} + \epsilon_{3t} \tag{3.9}$$

$$Q_t^H = \delta_1 + \delta_2 P_t^{Hpw} + \delta_3 P_t^{Hst} + \delta_4 Q_{t-1}^{Hs} + \epsilon_{4t} \tag{3.10}$$

where the α_i, β_i, γ_i, and δ_i are estimated coefficients and the ϵ_{it} are residuals from the estimation.

We used a linear regression form because it best accommodates the theoretical model (the effects are mostly additive) and is reported generally to perform better in this kind of situation (Newman 1987). The regression results for the structural (second stage) equations are presented in Table 3.1. The table also contains elasticities calculated at the means of the data.

The goodness of fit (as indicated by R^2) was high in all supply and demand equations (although its use as a measure of goodness of fit is not fully appropriate because in 2SLS it is not bounded between 0 and 1, it is still the best available measure of goodness of fit). The White (1980) test failed to reject the null hypothesis of homoscedasticity at reasonable levels of significance in all demand and supply equations indicating no heteroscedasticity is present.

The values of the Durbin-Watson statistics calculated for the demand equations suggest that no autocorrelation problem exists. Because a lagged dependent variable was used in the supply equations, the Durbin-Watson d statistic is not valid; therefore the Durbin h statistic was calculated instead. The value of the statistic suggests autocorrelation is present in the hardwood pulpwood supply equation. For both supply and demand equations, Newey-West autocorrelation consistent covariance matrices (Greene 2000) were calculated and the corrected standard errors appear in Table 3.1.

Table 3.1: The results of two stage least squares regression and elasticities of determinants of the Alabama pulpwood stumpage market 1977–2001

Equations		Coefficients	Value	Std. Error	p-value	Elasticity
Supply	Q_t^S	Intercept	-194.105	421.214	6.4E-01	
		$\hat{P}_t^{Spw}$	84.151	25.068	7.9E-04	0.35
		P_t^{Sst}	-0.258	2.094	9.0E-01	
		Q_{t-1}^{Ss}	0.713	0.134	1.2E-07	
		R^2	0.845			
		Durbin h	-0.761		2.2E+00	
	Q_t^H	Intercept	1322.984	476.849	5.5E-03	
		$\hat{P}_t^{Hpw}$	101.900	45.349	2.5E-02	0.35
		P_t^{Hst}	-13.219	4.502	3.3E-03	-0.42
		Q_{t-1}^{Hs}	0.619	0.191	1.2E-03	
		R^2	0.868			
		Durbin h	3.837		4.0E-04	
Demand	Q_t^S	Intercept	608.012	662.625	3.6E-01	
		$\hat{P}_t^{Spw}$	-416.868	135.929	2.2E-03	-1.72
		$\hat{P}_t^{Hpw}$	-264.151	97.834	6.9E-03	-0.57
		P_t^{MSpw}	518.983	149.793	5.3E-04	1.74
		C_t	0.342	0.072	2.4E-06	1.42
		R^2	0.660			
		D-W d	1.850			
	Q_t^H	Intercept	-3511.743	1060.74	9.3E-04	
		$\hat{P}_t^{Hpw}$	-226.081	83.610	6.9E-03	-0.77
		$\hat{P}_t^{Spw}$	4.146	15.404	7.9E-01	0.02
		P_t^{MHpw}	277.566	95.530	3.7E-03	0.70
		C_t	0.342	0.057	2.3E-09	2.26
		R^2	0.814			
		D-W d	1.899			

The own price coefficients in the demand equations are significant at the 1% level and have the expected signs. Hardwood and softwood pulpwood are shown to be complements in the softwood pulpwood demand equation; however, data do not support the same conclusion in the hardwood pulpwood demand equation. The latter is likely due to the fact that in paper production requiring a mix of softwood and hardwood pulp, softwood is typically used in larger proportion. Mississippi pulpwood appears to be a substitute for Alabama pulpwood in both softwood and hardwood demand equations. The own price elasticities have similar magnitudes (and opposite signs) as elasticities for Mississippi pulpwood prices (cross-price elasticities) in both softwood and hardwood demand equations. The estimated coefficients on the pulpmill capacity variable have the expected signs and are significant at the 1% level.

Estimated coefficients on all the variables in the supply equations are significant at the 1% level or higher, except the coefficients for own price in the hardwood pulpwood supply equation, which is significant at the 5 percent level, and for the price of softwood sawtimber in the softwood pulpwood supply equation, which is insignificant.[1] All the signs are consistent with underlying theory (estimated coefficients of pulpwood prices and lagged pulpwood quantities are positive, and the estimated coefficient of hardwood sawtimber price is negative), supporting the hypothesis about substitution between pulpwood and sawtimber in hardwood pulpwood supply. Due to the presence of lagged dependent variables in the supply equations, the elasticities should be interpreted as short-run elasticities. The softwood pulpwood own price

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[1] However, the coefficient of the price of softwood sawtimber price in the softwood pulpwood supply equation becomes significant and has a sign indicating substitution when the two last two years (2000, 2001) of the time series are removed.

elasticity is similar to elasticities estimated for the U.S. South by Newman (1987) and Carter (1992).

3.5 Discussion and Conclusion

This study presents an econometric analysis of pulpwood supply and demand for Alabama. It uses a two-stage least squares regression technique to estimate the system of four supply and demand equations.

The price elasticity of softwood pulpwood supply was found to be relatively low, but similar to those previously reported for the U.S. South (Newman 1987, Carter 1992). The price elasticity of hardwood pulpwood supply was comparable to the estimated price elasticity for softwood pulpwood. The substitution role of sawtimber price found for hardwood pulpwood supply corresponds with findings for Sweden and the U.S. South (Brännlund et al. 1985, Newman 1987, Carter 1992). This supports our hypothesis that, at least in hardwood pulpwood supply, sawtimber could be considered as an alternative output, or a substitute in production.

The existence of a substitution effect between Alabama and Mississippi pulpwood suggests that Alabama's pulpwood market and the pulpwood markets in neighboring states are tightly linked. This explains the approximate equality of absolute values of the own and cross-price elasticities in both softwood and hardwood pulpwood demands, as well as relatively high absolute values of own and cross-price elasticities in softwood pulpwood demand. This phenomenon may be more general than anticipated at the outset of this study, with imported pulpwood playing an important role in satisfying pulp and paper industry demands in relatively small regions. Another interesting finding is the complementary role of hardwood pulpwood in softwood pulpwood demand.

Chapter 4

Modeling Pulpwood Trade within the U.S. South

4.1 Introduction

Despite the fact that it is often uneconomic to transport raw materials such as wood long distances, significant volumes of roundwood products in the U.S. South are transported across state boundaries. Nearly 25% of the pulpwood consumed by the pulping industry and 12% of sawtimber consumed by the sawmilling industry of the southern states are transported from other states in the region (while less than 1% is imported from outside the U.S. South). Most state level econometric studies of supply and demand take trade into account as an exogenous variable. Creation of a model capable of predicting timber supply and demand on a local level requires an understanding of factors influencing trade of timber products between the states.

The main reason for the occurrence of cross-state roundwood trade is the pattern of locations of timber harvest and roundwood consumption, which is determined by the location of mills and location of inventory (for the pulpwood, see Figure 4.1). Roundwood consumption and production in each state occurs not at a single point, but in an area or group of points. Location of roundwood production areas (procurement regions) and concentrations of timber industry do not conform with state lines, which in some cases cross areas of concentration of consumption and production. At the same time, forest and industry statistics are aggregated by states. As a result we

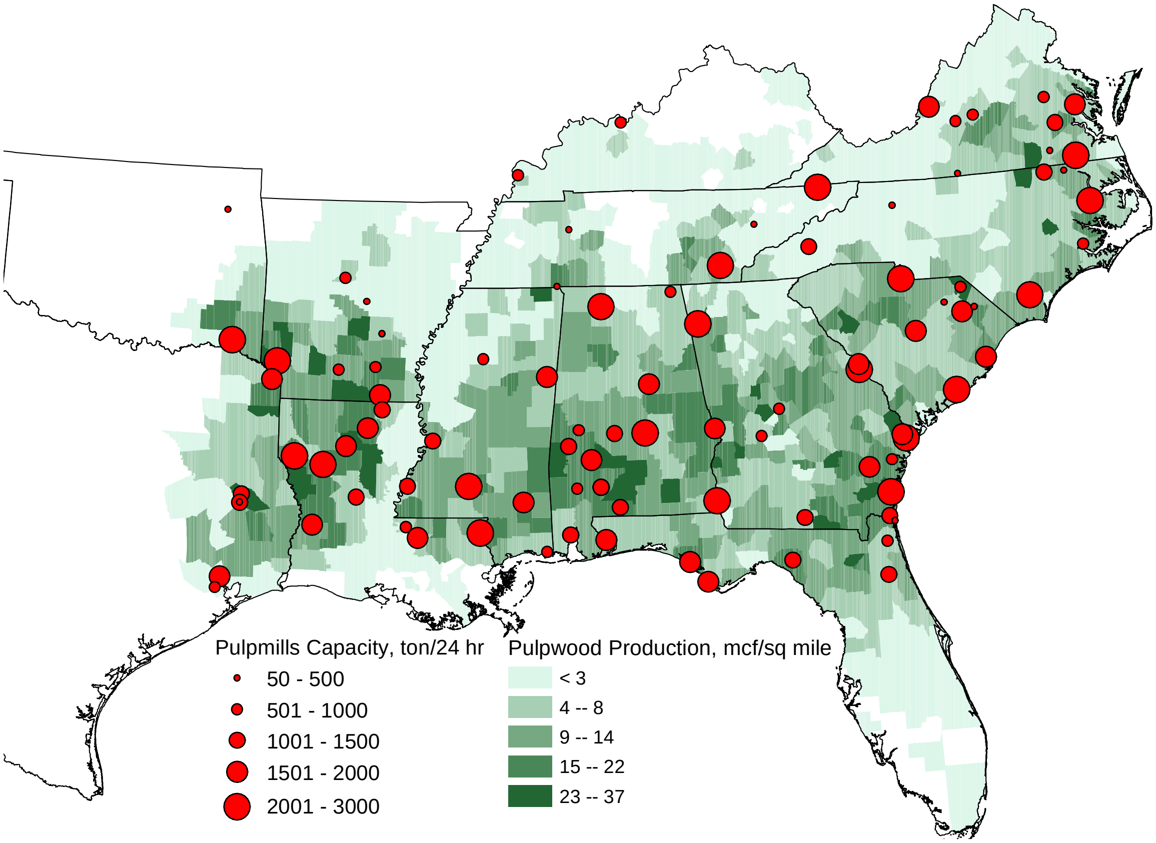

Figure 4.1: Pulpwood Production and Pulpmills Located in the South

observe trade across state boundaries (often in both directions — “cross-hauling”). Most such trade takes place between neighboring states, but a significant amount is traded between states that do not share a common border while the volume of trade between neighboring states vary greatly.

Several methods exist for regional interdependence analysis. Among them are fixed trade coefficient models (multiregional input-output models), gravity models, and linear programming models.

Modeling interregional trade using linear programming requires knowledge of a large number of parameters, including demand and supply prices and quantities in each of the demand and supply regions, as well as the costs of transportation between each pair of demand and supply regions. Under market conditions, prices and quantities are determined simultaneously as the result of the interaction of supply and demand in all regions, so the problem cannot easily be solved using a linear programming procedure.

In contrast to linear programming, gravity model and fixed coefficient methods, utilize existing data on interregional or international trade to obtain information about trading relationships between parties. This information could be used to predict future trade. In this study we will compare the forecasting performance regarding the pulpwood trade between states of the U.S. South for various specifications of a gravity model and a fixed gravity coefficient model, as well as discuss their possible applications in interregional (subregional) timber inventory models. The study is restricted to the analysis of pulpwood trade because of the greater amount of pulpwood trade in comparison to trade of other roundwood products, and because of the data availability.

4.2 Methods

4.2.1 Gravity Model

The general formulation of the standard gravity model is

$$X_{gh} = \beta_0 {M_g}^{\beta_1} {M_h}^{\beta_2} {D_{gh}}^{\beta_3},\ X_{gh} \geq 0,\ g \neq h,\ \beta_0 > 0,\ \beta_1 > 0,\ \beta_2 > 0,\ \beta_3 < 0, \quad (4.1)$$

where X_{gh} is the trade between exporting (g) and importing (h) regions, M_g is the size of the economy of the exporting region, M_h is the size of the economy of the importing region, D_{gh} is the distance between locations, and $\beta_0 \ldots \beta_3$ are the parameters to be estimated. Explanatory variables in this general gravity model could be viewed as representing three groups of factors, which determine trade between two regions. The size of the importing economy determines import demand (Tinbergen 1962). In empirical studies of international trade, size of the economy is usually represented by national income or income per capita. The size of the exporting economy represents a group of factors determining export supply. For this purpose, national output or output per capita is commonly used. The third group consist of factors that inhibit or facilitate trade between two economies. Distance, serving as a proxy for transportation costs, is the most common factor inhibiting trade (Tinbergen 1962). Other variables used in empirical studies are common borders, tariffs, preferential treatments, trade barriers or blocks, and language or cultural differences (Oguledo and MacPhee 1994).

The use of national or per capita output or income as proxies for export supply and import demand is understandable when aggregate trade is studied, especially in the case of international trade. When the trade of a single product is analyzed, the data on demand and supply of this product in individual regions could be readily available. Import demand is a function of total demand and total supply in the importing region. Export supply is a function of total supply and total demand in the exporting region.

The gravity model for trade of each of roundwood products between the states of the U.S. South in year t is specified in the following functional form:

$$X_{ght} = e^{\beta_0}(X_{got})^{\beta_1}(X_{ogt})^{\beta_2}(X_{oht})^{\beta_3}(X_{hot})^{\beta_4}(D_{gh})^{\beta_5}(e)^{\beta_6 B_{gh}} + \epsilon_{ght}, \qquad (4.2)$$

where X_{got} is the supply (production) of a product in the exporting state, X_{hot} is the supply (production) of a product in the importing state, X_{ogt} and X_{oht} are demands (consumptions) for a product in the exporting and importing states, and D_{gh} is the distance between the states, and B_{gh} is the border dummy taking value of 1 if states g and h share common border and 0 otherwise. Supply (production) and demand (consumption) are calculated from known traded and retained amounts of products for each of the states. Assuming that ϵ_{ght} is normally distributed with $E\left[\epsilon_{ght}\right] = 0$, the model could be estimated using Nonlinear Least Squares (NLS).

By taking logarithms of (4.2) and changing assumptions about the distribution and effect of the error term, this model could be estimated using Ordinary Least Squares (OLS), which is the most common way to estimate parameters of gravity models:

$$\ln X_{ght} = \beta_0 + \beta_1 \ln X_{got} + \beta_2 \ln X_{ogt} + \beta_3 \ln X_{oht} + \beta_4 \ln X_{hot} + \beta_5 \ln D_{gh} + \beta_6 B_{gh} + \epsilon_{ght} \tag{4.3}$$

While the vast majority of earlier applications of the gravity model used cross-sectional data, many recent studies emphasize the advantages of a panel approach (Mátyás 1997, 1998, Egger 2000, Egger and Pfaffermayr 2003). A panel framework allows to capture the relationships between the relevant variables over a longer period and to reveal time invariant effects specific to the cross-sectional units (importing region, exporting region and/or pairs of exporting and importing regions). Depending on the assumptions about structure of the error component, panel data models can be estimated using fixed effect and random effect models. According to the fixed effect model, group (cross-sectional or time) effects are treated as fixed parameters. In other words, groups have different intercepts. According to the random effect model, group effects are treated as a sample of a random drawing from the larger population and error component has different variation for different cross-sectional or time groups. Using a fixed effect model is a reasonable approach when the differences between units are viewed as parametric shifts of the regression function (Greene 2000), for example when analyzing trade flows between a predetermined set of trading partners. If the sample is randomly selected from the larger population of cross-sectional or time-series units, more appropriate is the random effect model, which allows one to extend inferences based on estimation results onto cross-sectional or time-series units outside the sample. This reasoning clearly speaks for the use of a fixed effect model to analyze roundwood products trade between states of the U.S. South, especially when the goal is the prediction of trade between these particular states.

It has been argued that the proper specification of a gravity model with panel data would include controls for time, importer, and exporter effects (Mátyás 1997). This is three-way panel specification containing two cross-sectional effects. The importer and exporter effects capture observable and unobservable country or region specific characteristics, while time effect captures common cyclical influences. Furthermore, Egger and Pfaffermayr (2003) suggest that interaction effect between importer and exporter main effects, which is the product of these two main effects, should be included in the model. They show that omission of importer-exporter interaction effect leads to bias in the estimates. From an economic point of view, the interaction effect of importing and exporting regions could be interpreted as the time invariant bilateral influences which lead to deviation from the "normal" propensity to trade for the pairs of regions (Egger and Pfaffermayr 2003).

The full set of dummy variables representing bilateral importer-exporter interaction effect is collinear with the full set of dummies representing main cross-sectional effects. In order to estimate regression, several dummies must be dropped. Because of bilateral interaction effect is the product of main cross-sectional effects, it contains all the information captured by both main cross-sectional effects. Thus, generalized three-way specification with importer, exporter, time, and bilateral interaction effects is identical to the two-way specification with time and bilateral effects only (Egger and Pfaffermayr 2003). Therefore, both exporter and importer main effects could be omitted. In addition to collinearity with main cross-sectional effects, bilateral interaction effect is collinear with time invariant variables like distance and common border. These variables should be also dropped from model. Thus, the panel specification for the gravity model (4.3) becomes

$$\ln X_{ght} = \beta_1 \ln X_{got} + \beta_2 \ln X_{ogt} + \beta_3 \ln X_{oht} + \beta_4 \ln X_{hot} + \tau_t + \delta_{gh} + \epsilon_{ght} \tag{4.4}$$

where τ_t are the time effects and δ_{gh} are bilateral importer-exporter effects. The corresponding specification without log-log transformation (to estimate the model using NLS) will be

$$X_{ght} = (X_{got})^{\beta_1} (X_{ogt})^{\beta_2} (X_{oht})^{\beta_3} (X_{hot})^{\beta_4} e^{\tau_t} e^{\delta_{gh}} + \epsilon_{ght} \tag{4.5}$$

4.2.2 Fixed Trade Coefficient Models

Fixed trade coefficient models are based on the following principle: the total interindustry demands (including the industry itself) and demands by final users equals the industry's output. These models were designed as rough and ready working tools capable of making effective use of limited amounts of factual information (Leontief and Strout 1963).

Interregional trade is accounted for using one of three models within the fixed trade coefficient framework: a column coefficient model, row coefficient model, or a gravity coefficient model.

The column coefficient model (Moses 1955, Polenske 1970) is based on the assumption that shipments of a commodity between two regions are proportional to total consumption of a commodity in the demand region. The row coefficient model assumes that shipments of a commodity between two regions are proportional to the total production of a commodity in the supply region. These models use a one way-approach (Hua 1990), because they relate trade to one of two factors. According to the gravity coefficient model (Leontief and Strout 1963), the amount of interregional trade is directly proportional to the total production and total consumption of a commodity in the supply and demand regions, respectively, and is inversely proportional to the total amount of a commodity produced in all regions. Because two orthogonal factors are used, this model could be described as employing a two-way approach (Hua 1990).

The amount of trade between the regions is expressed in the following ways according to column, row, and gravity coefficient models, respectively:

$$X^i_{gh} = X^i_{oh} C^i_{gh} \quad \forall\, i, g, h;\ g \neq h \tag{4.6}$$

$$X^i_{gh} = X^i_{go} R^i_{gh} \quad \forall\, i, g, h;\ g \neq h \tag{4.7}$$

$$X^i_{gh} = \frac{X^i_{go} X^i_{oh}}{X^i_{oo}} Q^i_{gh} \quad \forall\, i, g, h;\ g \neq h \tag{4.8}$$

where i is the commodity; g is the supply region; h is the demand region; X^i_{gh} is the amount of commodity i shipped from region g to region h; X^i_{go} is the amount of commodity produced in region g; X^i_{oh} is the amount of commodity consumed in region h; X^i_{oo} is the total amount of commodity i produced in an economy; C^i_{gh} is the column coefficient; R^i_{gh} is the row coefficient; and Q^i_{gh} is the gravity coefficient.

The empirical coefficients in the column and row coefficient models are calculated directly from the base-year data. Depending on assumptions about the nature of spatial interaction between supply and demand regions, gravity coefficients could be either extracted from the base-year data or determined using exogenous variables, for example, using one of the methods developed by Leontief and Strout (1963). In this study we will investigate the temporal stability of empirical gravity coefficients.

4.3 Data

We analyze bilateral trades of softwood and hardwood pulpwood between 13 states of the United States South (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia) over the period 1994–2002. Roundwood pulpwood and wood chips produced in the forest were taken into account, excluding pulpwood exported from the country. The amount of annual softwood and hardwood pulpwood trade, production, and consumption in cords were obtained from the annual reports “Southern Pulpwood Production” published by the Southern Research Station (Johnson and Steppleton 2003). The trade between each pair of states in both directions was accounted for separately. The datasets could be viewed as two matrices (softwood and hardwood pulpwood trade) with three dimensions: 13 exporting states, 13 importing states, and

9 years. Each of the matrices contain 1521 elements, of which 1404 elements represent volumes of trade between states and 117 elements are volumes retained by the states. Only the values representing trade between the states are used for modeling, however retained volumes are used to obtain states' production and consumption of hardwood and softwood pulpwood.

Euclidean distances in kilometers between exporting states' centers of inventory and importing states' centers of consumption were determined using ArcGIS® (geographic information system software from Environmental Systems Research Institute). Exporting states' centers of inventory were calculated separately for hardwoods and softwoods as centers of mass of counties for each of the states weighted, respectively, by softwood or hardwood inventory from the latest Forest Inventory and Analysis (FIA) data. Importing states' centers of consumption were calculated as centers of mass of pulpmills for each of the states weighted by mills' daily pulping capacity (Johnson and Steppleton 2003).

Descriptive statistics of the data used for the analysis of the pulpwood trade between the states of U.S. South are presented in Table 4.1.

4.4 Empirical Results

4.4.1 Gravity Model

Pulpwood trade flows between states of the U.S. South were estimated using several methodologies. First, for comparison purposes, the gravity models were estimated without specific effects, that is, assuming that intercept terms are constant for all 169 cross-sectional groups (which are importing-exporting pairs of states) and 9

Table 4.1: Descriptive statistics of the variables

Variables	Units	Mean	Std. Dev.	Minimum	Maximum
	Softwood pulpwood (n=1404)				
Production	cords	2410485	1691215	13894	6528057
Consumption	cords	2404647	1749286	4271	6268474
Trade	cords	46271	131861	0	950611
Distance	kilometers	765	376	178	1676
	Hardwood pulpwood (n=1404)				
Production	cords	1308856	918069	73111	4185204
Consumption	cords	1318555	1124607	52338	5486348
Trade	cords	33721	108824	0	1226806
Distance	kilometers	755	364	186	1669

time periods. Models were estimated using linear and nonlinear least squares methods, however White's test indicated severe heteroscedasticity problems. To obtain robust variance-covariance matrix, models were re-estimated using the Generalized Method of Moments (GMM) using Bartlett kernel with bandwidth parameter 1, which corresponds to the White estimator (SAS Institute, Inc. 1999, p. 733). Estimation results for the gravity equations using GMM are shown in Table 4.2.

All of the estimated regression coefficients have expected signs and most are highly significant. The only ones not significantly different from zero are the coefficient of demand in the exporting state and the coefficient of supply in the importing state in the log-linear model for hardwood pulpwood. Coefficients for the distance variable between exporting and importing states in the nonlinear model are not significantly different from -2, which is consistent with underlying gravity law of physics.

The R^2 values are higher for non-linear least squares models, however, these statistics could not be compared directly, because nonlinear models fit the original dependent variables, while log-linear models fit log-transformed dependent variables. The goodness of fit of models could be compared using measures such as Root Mean

Table 4.2: Estimation results for bilateral pulpwood trade between states of the U.S. South without specific effects (models (4.3) and (4.2))

Explanatory variables	Softwood		Hardwood	
	Log-linear	Nonlinear	Log-linear	Nonlinear
Intercept	9.73^{***}	-2.64^{*}	9.65^{***}	4.23^{***}
	(1.71)	(1.48)	(2.42)	(1.29)
Demand in importing state	1.33^{***}	2.07^{***}	0.57^{**}	1.84^{***}
	(0.23)	(0.20)	(0.16)	(0.15)
Supply in exporting state	0.98^{***}	1.88^{***}	0.69^{**}	0.80^{***}
	(0.23)	(0.26)	(0.20)	(0.14)
Demand in exporting state	-0.52^{**}	-0.98^{***}	-0.24	-0.33^{**}
	(0.22)	(0.23)	(0.16)	(0.13)
Supply in importing state	-0.79^{***}	-1.43^{***}	-0.03	-1.20^{***}
	(0.23)	(0.20)	(0.20)	(0.13)
Distance	-3.42^{***}	-2.11^{***}	-3.30^{***}	-1.95^{***}
	(0.22)	(0.18)	(0.25)	(0.17)
Border dummy	5.01^{***}	3.77^{***}	5.05^{***}	2.79^{***}
	(0.33)	(0.28)	(0.36)	(0.24)
R^2	0.71	0.77	0.66	0.86
$RMSE$		63753		41534
Adjusted $RMSE$	76366		58695	

Log-linear stands for log-transformed model linear in parameters.
Standard errors are reported in parentheses.
*** significant at 1%, ** significant at 5%, * significant at 10%.

Square Error ($RMSE$):

$$RMSE = \left[\frac{1}{N}\sum_{i-1}^{N}(y_i - \hat{y}_i)^2\right]^{\frac{1}{2}} \tag{4.9}$$

where y_i is the dependent variable and $\hat{y}_i$ is predicted dependent variable.

To obtain comparable $RMSE$, predicted dependent variables of the log-linear models ($\widehat{\ln y_i}$) should be reverse-transformed ($\hat{y}_i = e^{\widehat{\ln y_i}}$). However, when used to obtain mean response given values of the explanatory variables, reverse-transformed fitted linear models sometimes produce severely biased models (Miller 1984). In order for a detransformed estimator of a dependent variable to provide the mean response, it should be adjusted in the following way (Miller 1984):

$$\hat{y}_i = e^{\widehat{\ln y_i}} e^{1/2\hat{\sigma}^2} = e^{\hat{\boldsymbol{\beta}}'\mathbf{x}_i} e^{1/2\hat{\sigma}^2} \tag{4.10}$$

where $\widehat{\ln y_i}$ is the predicted transformed dependent variable, $\hat{\boldsymbol{\beta}}$ is an estimator of the coefficient vector, $\mathbf{x}_i$ is a vector of explanatory variables, and $\hat{\sigma}^2$ is an estimator of the regression variance.

For the log-linear models, we calculated adjusted Root Mean Square Error using a detransformed predicted dependent variable adjusted as in (4.10). Despite elimination of transformation bias, nonlinear models fit the data better than log-linear models. The reason is the multiplicative nature of the error term in log-linear models versus their additive nature in nonlinear models.

Next, we introduce individual bilateral and time effects into the models. Because of the nature of the data and objectives of the study, we consider the fixed effect model (FEM) appropriate as opposed to the random effect model (REM). The hypothesis that individual importer-exporter bilateral effects are equal for all groups is appropriately tested using an F ratio test. This test rejected equality of the individual effects for both hardwood and softwood at 1% level of significance.[1]

Estimation results for the FEM for a log-transformed linear gravity model and its nonlinear equivalent are presented in Table 4.3. A Breush-Pagan test indicated

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[1] Because of introduction of fixed effects into the model, time-invariant variables were removed from the model as collinear to the bilateral effects. Therefore, the use of F-test is not fully appropriate, need to use J-test (Davidson and MacKinnon 1981).

Table 4.3: Estimation results for bilateral pulpwood trade between states of the U.S. South with fixed bilateral and time effects (models (4.4) and (4.5))

Explanatory variables	Softwood		Hardwood	
	Log-linear	Nonlinear	Log-linear	Nonlinear
Demand in importing state	0.64***	2.10***	1.05***	1.85***
	(0.25)	(0.31)	(0.36)	(0.26)
Supply in exporting state	−0.17	1.42***	0.94**	0.92***
	(0.38)	(0.31)	(0.46)	(0.30)
Demand in exporting state	−0.08	−1.00***	−0.26	−0.50*
	(0.19)	(0.34)	(0.33)	(0.26)
Supply in importing state	0.09	−1.73***	−0.56	−1.00***
	(0.34)	(0.40)	(0.39)	(0.22)
R^2	0.89	0.96	0.84	0.98
$RMSE$		28144		17608
Adjusted $RMSE$	40114		30794	

Log-linear stands for log-transformed model linear in parameters.
Bilateral and time effects are omitted from the table.
Standard errors are reported in parentheses.
*** significant at 1%, ** significant at 5%, * significant at 10%.

the presence of heteroscedasticity, therefore the models were estimated using the Generalized Method of Moments.

Introduction of fixed bilateral and time effects improved the goodness of fit for both the log-transformed linear model and the nonlinear model as indicated by R^2 and $RMSE$ measures. Similarly to the case without specific effects, nonlinear models have better goodness of fit than log-transformed linear models. At the same time, for log-transformed linear models, the introduction of fixed bilateral and time effects made estimates of many explanatory variables not significantly different from zero (supply in exporting state, demand in exporting state, supply in importing state for softwood pulpwood trade), or significantly changed the estimates (demand in importing state for both softwood and hardwood pulpwood trade). For nonlinear models, all coefficient estimates remained significant and did not significantly change due to introduction of the fixed bilateral and time effects.

4.4.2 Fixed Gravity Coefficient Model

The fundamental assumption of input-output and interregional input-output analysis is the stability of technical input coefficients and trade coefficients. We will test the stability of gravity coefficients calculated by the "Point Estimate" procedure.

When actual trade data are available for the number of periods under study, we can obtain a set of gravity coefficients for each period:

$$Q^i_{ght} = \frac{X^i_{oot} X^i_{ght}}{X^i_{got} X^i_{oht}} \quad \forall\ i, g, h, t;\ g \neq h \tag{4.11}$$

where t is time period.

Individual year gravity coefficients could be thought of as having variation in three dimensions: exporter region, importer region, and time period (these are main effects). Furthermore, interactions among the main effects allow us to specify three additional dimensions of variation. The remaining variation is attributed to random error. The individual gravity coefficients could be partitioned in the following way:

$$Q_{ght} = \gamma_g + \eta_h + \tau_t + (\gamma\eta)_{gh} + (\gamma\tau)_{gt} + (\eta\tau)_{ht} + \epsilon_{ght} \tag{4.12}$$

where γ_g, η_h, and τ_t are main effects; $(\gamma\eta)_{gh}$, $(\gamma\tau)_{gt}$, and $(\eta\tau)_{ht}$ are interaction effects; and ϵ_{ght} is random error. Importer effect, exporter effect, and importer-exporter interaction effect could be viewed as comprising time indifferent gravity coefficients ($Q_{gh} = \gamma_g + \eta_h + (\gamma\eta)_{gh}$). If gravity coefficients are stable, most variation of Q_{ght}

Table 4.4: Analysis of variance with main and bilateral interaction effects of the fixed gravity coefficients for the pulpwood trade between states of the U.S. South during period 1994–2002

Source	Degrees of Freedom	Partial Sum of Squares	
		Softwood	Hardwood
Model	356	3937.6***	1619.9***
		(11.1)	(20.4)
Exporter effect γ_g	12	195.1***	72.6***
		(18.3)	(27.0)
Importer effect η_h	12	226.4***	73.1***
		(21.2)	(27.2)
Time effect τ_t	8	9.7	2.7
		(1.4)	(1.5)
Exporter and Importer effect $(\gamma\eta)_{gh}$	131	3329.9***	1423.8***
		(28.6)	(48.5)
Exporter and Time effect $(\gamma\tau)_{gt}$	96	85.0	19.3
		(1.0)	(0.9)
Importer and Time effect $(\eta\tau)_{ht}$	96	91.5	28.3**
		(1.1)	(1.3)
Residual	1048	931.1	234.7
Total	1404	4868.7	1854.6

F-values are reported in parentheses.
*** significant at 1%, ** significant at 5%, * significant at 10%.

should be explained by γ_g, η_h, and $(\gamma\eta)_{gh}$, while effect of τ_t should be small and statistically insignificant. Interpretation of $(\gamma\tau)_{gt}$ and $(\eta\tau)_{ht}$ is not clear, however their low significance would verify stability of gravity coefficients.

Table 4.4 presents results of the analysis of variance of gravity coefficients calculated for hardwood and softwood pulpwood trade between thirteen Southern states during the period 1994–2002. The importer-exporter interaction effects explain the largest part of variation of the gravity coefficients. The exporter effect, the importer effect, and the interaction between two effects are highly significant explanatory variables, and account for more than 95% of explained variation in both softwood and hardwood trade models. At the same time, time effect accounts for less than one-quarter of one percent of the explained variations and is insignificant for both softwood and hardwood trade gravity coefficients. Among time and importer or exporter interaction effects, only the importer-time interaction effect for the hardwood gravity coefficient is significant at 5% level. All this allows us to conclude that there is considerable stability of fixed gravity coefficients for softwood and hardwood pulpwood trade.

4.5 Simulation Results

To test the predictive capability of the models being studied, we performed simulations using existing data. Similarly to Bergkvist (2000), we randomly selected approximately 80% of the observations into the training set, the remaining observations comprised the test set. Using the training set, we estimated coefficients for each of four regression models and calculated average fixed gravity coefficients. Pulpwood trade quantities were predicted for the test set, and Root Mean Square Errors (RMSE) were calculated. This procedure was repeated five times. RMSEs obtained in simulation, as well as averages and standard deviations for each of the models are presented in Table 4.5.

The nonlinear gravity equation with fixed effects has the lowest RMSE, followed by the fixed gravity coefficient method and linear regression with fixed effects. Regressions without fixed effects have significantly worse results, while results of methods with fixed effects are overlapping, if standard deviations are taken into account.

Table 4.5: Root Mean Square Error (RMSE) for the different models and five different training and learning sets

Test	Products	Models				
		OLS	NLS	OLS FEM	NLS FEM	FGCM
1	Hardwood	57761	38621	39218	23444	27806
	Softwood	73659	61984	33076	22909	28675
2	Hardwood	77750	47191	26288	21633	23181
	Softwood	83898	65453	34370	39005	33813
3	Hardwood	71919	44957	25143	17564	25371
	Softwood	72157	60591	37871	32975	33070
4	Hardwood	57323	39071	31417	19315	21795
	Softwood	60962	43180	29187	29294	31965
5	Hardwood	41874	34720	26681	16215	24839
	Softwood	63095	52863	27980	27105	28032
Means	Hardwood	61325	40912	29749	19634	24598
	Softwood	70754	56814	32497	30258	31111
Standard deviations	Hardwood	14045	5069	5811	2941	2281
	Softwood	9189	8904	4003	6099	2612

4.6 Discussion and Conclusion

We have compared five different methods regarding their ability to predict trade of roundwood pulpwood between thirteen states of the U.S. South. For the gravity model, nonlinear estimation methods perform better than log-transformed OLS because there is no transformation bias. Fixed effect estimation yields significantly better results because distance and other observable variables are not capable of capturing all factors influencing propensity to trade between two localities. Fixed gravity coefficients are stable in time, and the method using fixed gravity coefficients provides the second best results. We would recommend the gravity model estimated using non-linear least squares method with fixed importer-exporter interaction effects or the fixed gravity coefficient model to forecast interregional roundwood trade. However, the fixed gravity coefficient method is much simpler and easier to use.

CHAPTER 5

INCORPORATING INTERSTATE TRADE IN A MULTI-REGION TIMBER INVENTORY PROJECTION SYSTEM

5.1 Introduction

This chapter describes an interregional timber inventory projection model that recognizes the importance of demand centers (centers of forest products manufacturing activity), inventory dynamics, and trade flows in forecasting future harvests. The model adapted work by Teeter et al. (1989), who modeled interindustry trade and highlighted the interdependence of producing regions. Drawing from that work, a gravity model was constructed that considers the relative position of each region vis-á-vis all others as a producer of stumpage and as a consumer of stumpage products. As a result, the model allows for changes in the harvest levels among regions to accommodate imbalances in inventory, changes in production capacity, and transportation costs from the source of the raw material to manufacturing facilities.

5.2 An Interregional DPSupply Model with Stochastic Prices

5.2.1 Overview of the Model

The Interregional DPSupply (IDPS) model utilizes a combination of normative and positive approaches (Wear and Parks 1994) to modeling timber supply. It models growth and optimal management decisions on the level of individual representative stands (FIA sample plots). As the model progresses through time, stands are evaluated each year and, on the basis of maximizing land expectation value (LEV), a recommendation is made to thin, conduct a final harvest, or leave the stand at a given stumpage price level. Stands are evaluated over a range of stumpage price levels and the stands recommended for harvest at any particular price level constitute aggregated supply at that price level. The system models the supply of four roundwood products: softwood pulpwood, softwood sawtimber, hardwood pulpwood, and hardwood sawtimber. Demands for individual products within demand regions are allocated to the supply regions using a modified gravity coefficient method. Within supply regions, demands are allocated among the set of forest plots recommended for harvesting using a linear programming procedure.

At the core of the IDPS model are three main components: a dynamic programming (DP) model for determining optimal harvesting decisions, a linear programming (LP) harvesting model, and an interregional trade model (see Figure 5.1). These models depend on several auxiliary models, including growth models, product distribution models, and information on area transition probabilities to account for changes in forest area by type over time. Extending DPSupply (Teeter 1994, Zhou and Teeter 1996, Zhou 1998) to incorporate the 13-state southern region requires accounting for regional differences in growth, the anticipated products from representative stands and area change. To accomplish this goal, the region was delineated according to physiographic regions (five) similar to those identified by Bailey (1995) and included the coastal plain, the piedmont and mid-coastal plain, the mountains and interior plateaus, the Mississippi alluvial basin, and the western piedmont and mid-coastal plain regions. Using FIA data from the counties in each region, regional

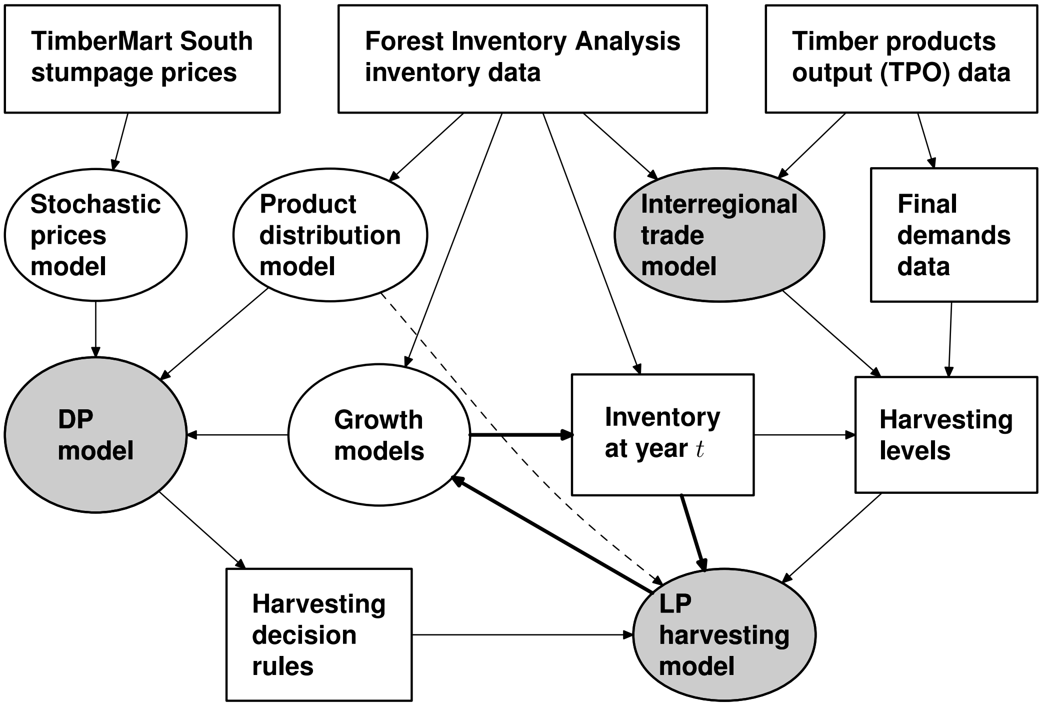

Figure 5.1: Interregional DPSupply system

growth models and product distribution models were constructed for each of 5 key forest management types: planted pine, natural pine, oak-pine, lowland hardwood and upland hardwood for each of the physiographic regions by owner class. The growth models were constructed using methods similar to those used in Zhou (1998). Product distribution models to allocate the projected volumes on each plot to each potential product class were constructed following multinomial logit methods outlined by Teeter and Zhou (1999).

5.2.2 Data

Development of an interregional DPSupply model for the U.S. South and performing simulations requires the following data:

- Forest Inventory Analysis (FIA) inventory data by sample plot for each of 13 states. The data were obtained from the USDA Forest Service website and included the following inventories: Alabama-2000, Arkansas-1995, Florida-1995, Georgia-1997, Kentucky-1988, Louisiana-1991, Mississippi-1994, North Carolina-1990, Oklahoma-1993, South Carolina-1993, Tennessee-1999, Texas-1992, and Virginia-1992.

- Timber Product Output (TPO) data on production, consumption and trade of major timber products for each of the U.S. South states. The data were obtained from bulletins of the USDA Forest Service Southern Research Station (e.g., Johnson and Steppleton 2001, Bentley et al. 2002, Johnson and Brown 2002), and from the TPO website.

- Stumpage price data, collected by Timber Mart-South (Norris Foundation 1977–2001).

5.2.3 Modeling future trading activity in forest products

As an economy develops, goods produced in one region are often sold in another region of the country. Several groups of methods exist for regional interdependence analysis. One group includes fixed trade coefficient models (multiregional input-output models), and another includes linear programming models.

Application of linear programming in the context of spatial models requires a large number of parameters to support the analytical mechanisms of interregional trade. These parameters include demand and supply prices and quantities in each of the demand and supply regions, as well as the costs of transportation between each pair of demand and supply regions. Unless prices and quantities in demand and supply regions are exogenous to the model (e.g., Holley et al. 1975), the problem cannot be solved using linear programming procedures. This difficulty was overcome to an extent by using reactive programming, an iterative procedure that computes the equilibrium solution using a series of successive approximations (Adams and Haynes 1980, 1996).

There are a few other obstacles to using linear programming for modeling interregional trade. The trading regions are more or less extended areas, so the average distances between them do not represent the actual diversity of trade flows (Leontief and Strout 1963). Furthermore, the transportation distances of roundwood products are of a similar order of magnitude as the size of the trading regions. As result, transportation costs could not be determined with the accuracy necessary for the application of linear programming procedures. Finally, yet importantly, cross-hauling, or simultaneous shipment of a homogeneous commodity in both directions, is difficult to incorporate into linear programming models (Polenske 1980).

Due to the above listed reasons we chose not to use a linear programming approach to model interregional trade. Instead, we base modelling of the roundwood trade between the states of the U.S. South on fixed trade coefficient models, which utilize empirical trade relationships between the industries and regions themselves. These models are based on the assumption that the total output of interindustry demands (including the industry itself), plus demands by final users plus exports equal the industry's output. Fixed trade coefficient models were designed as rough and ready working tools capable of making effective use of limited amounts of information (Leontief and Strout 1963). In forest economics, these models were used by Teeter et al. (1989).

Interregional trade is accounted for using one of three models within the fixed trade coefficient framework: a column coefficient model, row coefficient model (these models use a one-way approach), or a gravity coefficient model (a two-way approach).

The column coefficient model (Moses 1955, Polenske 1970) is based on the assumption that shipments of a commodity between two regions are proportional to total consumption of the commodity in the demand region. The row coefficient model assumes that shipments of a commodity between two regions are proportional to total production of the commodity in the supply region. The assumptions behind one-way approach models (trade is a function of demand or supply) seem very simplistic, however, the column coefficient model has been widely used due to its consistency with the input-output framework.

According to the gravity coefficient model (Leontief and Strout 1963), the amount of interregional trade is proportional to the total production and total consumption of the commodity in, respectively, the supply and demand regions, and is inversely proportional to the total amount of the commodity produced in all regions

$$X^i_{gh} = \frac{X^i_{go} X^i_{oh}}{X^i_{oo}} Q^i_{gh} \tag{5.1}$$

where i, g, h are the product (i), production (g), and consumption regions (h); X^i_{go} is the amount of product i shipped from region g to h; X^i_{oh} is the amount of product i shipped to region h from all regions; X^i_{go} is the amount of product i shipped to all regions from region g; X^i_{oo} is the total amount of commodity i produced in an economy; and Q^i_{gh} is the gravity coefficient. Depending on the assumptions about the nature of spatial interaction between the supply and demand regions, gravity coefficients could be either extracted from the base-year data or determined using exogenous variables. Leontief and Strout (1963) developed four methods to derive gravity coefficients within these two general approaches.

We selected the gravity coefficient method because it allows us to model trading relationships more realistically by capturing interaction effects of the supply and demand regions. The availability of data on the production, consumption and trade of roundwood products between U.S. Southern states allows us to use the point estimate procedure (Leontief and Strout 1963) to determine gravity coefficients from the base year data. Direct application of the point estimate procedure, however would not allow us to model the trade dynamics that result from changes in timber inventories of producing states. An adaptation of the procedure was necessary.

Recall that the gravity coefficient method assumes that trade between two regions is proportional to the total production of the commodity in the supply region. However, the elasticity of roundwood supply with respect to the timber inventory is commonly assumed equal to 1 (Binkley 1987, Abt et al. 2000), or, in other words, roundwood supply is proportional to inventory. Consequently, it is reasonable to assume that the shipments of roundwood product i from region g to region h are proportional to the amount of wood available for harvest in region g. Now the amount of timber product traded will be:

$$X^i_{gh} = \frac{I^i_g X^i_{oh}}{X^i_{oo}} \hat{Q}^i_{gh} \tag{5.2}$$

where $\hat{Q}^i_{gh}$ is the "modified" gravity coefficient and I^i_g is the amount of timber product i available in supply region g.

Assuming the "modified" gravity coefficients remain stable (stability of technological and interregional coefficients is the basic assumption of input-output and multiregional input-output models), the model allows prediction of harvest and trading levels in each forest product for future periods, based on the regional demands and the amounts of wood available for harvesting each year of the prediction.

5.2.4 Harvest Decisions

The assumption of the dynamic programming component of the IDPS model is that forest owners manage their forests in order to maximize net present value over an infinite series of rotations. Although the importance of this objective for NIPF owners has often been questioned, work by Newman and Wear (1993) supports the basic assumption. Another assumption of IDPS is that forest owners bear replanting costs at the beginning of the rotation and receive income when thinning occurs or at the end of the rotation, when they sell stumpage. Because replanting is assumed only for pine plantations, for all other forest types income at final harvest is the only component of the cash flow. The immediate return from thinning or final harvest is evaluated (using product distribution models) for each of the five levels of stumpage prices. The range of possible price levels, as well as average ratios between the stumpage prices of four roundwood products considered in the model, are calculated from Timber Mart-South historical data (Norris Foundation 1977–2001). Stumpage prices fluctuate over time, therefore expectations of future prices influence forest owners' decisions about when to harvest. For this reason, a stochastic pricing element, similar to the one developed by Teeter et al. (1993), was incorporated in the IDPS model to produce more realistic outcomes, i.e., owners are more willing to offer timber for sale when the price is higher because of the expectation that it will fall in the future.

The general backward recursive equation for the dynamic model can be expressed as:

$$\begin{aligned} V_t &= \max_k \Big\{ \Pi_t \left(P_t, d_t, v_t, k, o_l, f_m, r_n \right) \\ &+ \beta E[V^*_{t+1} \left(P_{t+1}, d_{t+1}(k), v_{t+1}(k), o_l, f_m, r_n \right) | P_t] \Big\} \\ &\forall \quad P, o_l, f_m, r_n; l = 1, 2; m = 1, \ldots, 5; n = 1, \ldots, 5 \end{aligned} \tag{5.3}$$

where V is the value function (\$/acre), k is the decision variable — management decision at time t (clearcut, thinning, selective harvest, or no action); d is the stand's diameter at breast height (183 0.1 inch classes); v is the stand's volume (209 25 cf/ac classes), P is the level of the stumpage prices (5 levels from \$1.70/cf to \$4.10/cf); o_l is the ownership class (non-industrial private or industry); f_m is the forest management type (planted pine, natural pine, oak-pine, lowland or upland hardwood); r_n is the physiographic region (the coastal plain, the piedmont and mid-coastal plain, the mountains and interior plateaus, the Mississippi alluvial basin, and the western piedmont and mid-coastal plain); Π is the immediate net return of management decision k (\$); β is the discounting factor (we used 5% interest rate for NIPF and 7% for the industry); and E is an expectations operator of random future prices P_{t+1} conditional on current prices P_t.

The output of the dynamic programming model is a matrix, which provides the optimal management decision for each combination of dbh and volume within each ownership class, forest management type and physiographic region, and at each of the stumpage price levels. The lowest price level, at which the optimal decision for the given stand would be harvesting or thinning, could be interpreted as the producer's (forest owner's) reservation price.

The IDPS harvesting module provides an interface between the inventory data, growth models, product distribution models, DP decision matrix and the interregional forest products trade model. For each year of the projection period, the volumes of timber products available for harvesting are generated using the initial inventory of a given year, a matrix of optimal harvesting decisions obtained from the dynamic program, and product distribution models derived from the region plot data. Harvest levels for each product in each state are determined using available inventory, final demands, and the interregional trade coefficients produced by the interregional trade model. The linear programming model then allocates the harvest request (demand) for each product in each state among the stands available for harvesting by choosing those stands, which have an appropriate mix of products and could be harvested at the lowest price:

$$
\begin{aligned}
\min_{s_{gj}} \quad & \sum_{g=1}^{G}\sum_{j=1}^{N_g} p_{gj} s_{gj} \\
\text{s.t.} \quad & \sum_{j=1}^{N_g} v_{gj}^{i} s_{gj} = \sum_{h=1}^{H} \frac{X_{oh}^{i} \sum_{j=1}^{N_g} v_{gj}^{i} S_{gj}}{\sum_{h=1}^{H} X_{oh}^{i}} \hat{Q}_{gh}^{i} \quad \forall \quad g, i \\
& 0 \leq s_{gj} \leq S_{gj} \qquad\qquad\qquad\qquad \forall \quad g, i
\end{aligned}
\tag{5.4}
$$

where s_{gj} is the area of stand j in the supply state g to be selected for harvesting or thinning (decision variable); p_{gj} is the reservation stumpage price (\$/acre) for the stand j in the supply state g; v_{gj}^{i} is the volume of product i on the stand j (cubic feet/acre); X^i_{oh} is the demand for product i in the demand state h; S_{gj} is the area of stand j; and $\hat{Q}^i_{gh}$ is the 'modified' gravity coefficient calculated from the base year trade data.

5.2.5 Area Change

Area change in the projection system uses the method similar to one utilized by Zhou et al. (2003) in their Scenario 1, which is to derive the changes of land use and forest management type from the historical FIA data. The method has three integrated components:

1. acres gained by each forest management type from non-timberland
2. acres lost by each forest management type to non-timber land
3. acres gained/lost by one management type through transition from/to another management type

In order to model 1) and 2), all FIA plots were selected which had non-timber land as the previous land use type and one of five forest management types as the current land use type, or those having one of the five forest management types as the old land use type and non-timber land as the current land use type. Plots representing public ownership were not included in this analysis. These plots were grouped by forest inventory unit. For each forest inventory unit, loss and gain by forest management type were calculated. Based on the length of a unit's survey period, annual gain was calculated and future gain was modeled by annually adding the appropriate proportion of acres to each forest management type by FIA unit. Net loss was modeled by adjusting (decreasing) the area of timberland annually. Timberland area was uniformly reduced across the region to reflect the effect of streamside management zones based on the finding of Wu (1994).

To model transitions between forest management types, all FIA plots where harvesting took place during the survey period were selected. The probability of transition was modeled using a multinomial logit model. The probability of transition to one of five forest management types (planted pine, natural pine, oak-pine, lowland hardwood and upland hardwood) was assumed to be a function of the old (previous survey) forest management type and the ownership class associated with the plot. Transition probabilities were calculated for each forest management type by physiographic region. During simulation, each harvested plot was partitioned into several new plots of different management types depending on the plot's pre-harvest forest management type and ownership class, with new plot areas determined proportionally according to the values of the transition probabilities.

5.3 Results

5.3.1 Inventory adjustment

As previously mentioned, the most recent FIA inventory data were collected in different years for different states, ranging from 1988 (Kentucky) to 2000 (Alabama). The consequence of using this kind of base data is that results of projections could be biased (inventory could be underestimated) if those state inventories were used as initial conditions for projections. One of the features of this study is that timber inventory data were adjusted from the year of latest FIA to the base year, 2000 using the IDPS model. We used Southern Pulpwood Production annual reports (Johnson and Steppleton 2001) and interpolated data from Timber Product Output reports (Johnson and Wells 1999) to determine annual harvest levels for these adjustments.

5.3.2 Inventory projections

We examined three different scenarios regarding future patterns of consumption (by firms) of wood products in the southern region using the IDPS model. These scenarios are: 1) no change in the level of forest products consumption from its level in 2000, 2) a 0.5% annual increase in consumption of forest products, and 3) a 1% annual increase in consumption. The first scenario was used to contrast the other two. The 0.5% annual increase scenario, considered here as the base case scenario, is consistent with the U.S. demand increase expected by Trømborg et al. (2000), and with the EL (elastic demand, low increase of plantation growth rate) scenario of the Southern Forest Resource Assessment (Wear and Greis 2002). In the last case, despite an assumed 1.6% annual outward shift of timber demand, the removals level during the period 2000–2025 increased 0.60% annually due to assumptions of elastic timber demand. The 1.0% increase consumption scenario reflects trends similar to those shown by the IH (inelastic demand, high plantation growth rate increase) of the Southern Forest Resource Assessment (Wear and Greis 2002), which shows 1.03% annual increase of removals during the period 2000–2025.

Figures 5.2 and 5.3 illustrate, respectively, softwood and hardwood inventory projections for the entire southern region under three removals scenarios. The projections are shown by product (pulpwood and sawtimber). Total softwood inventory is projected to increase 34%, 24%, and 15% under 0%, 0.5%, and 1.0% scenarios, respectively, between 2000 and 2025 with pulpwood inventories peaking in 2004 and

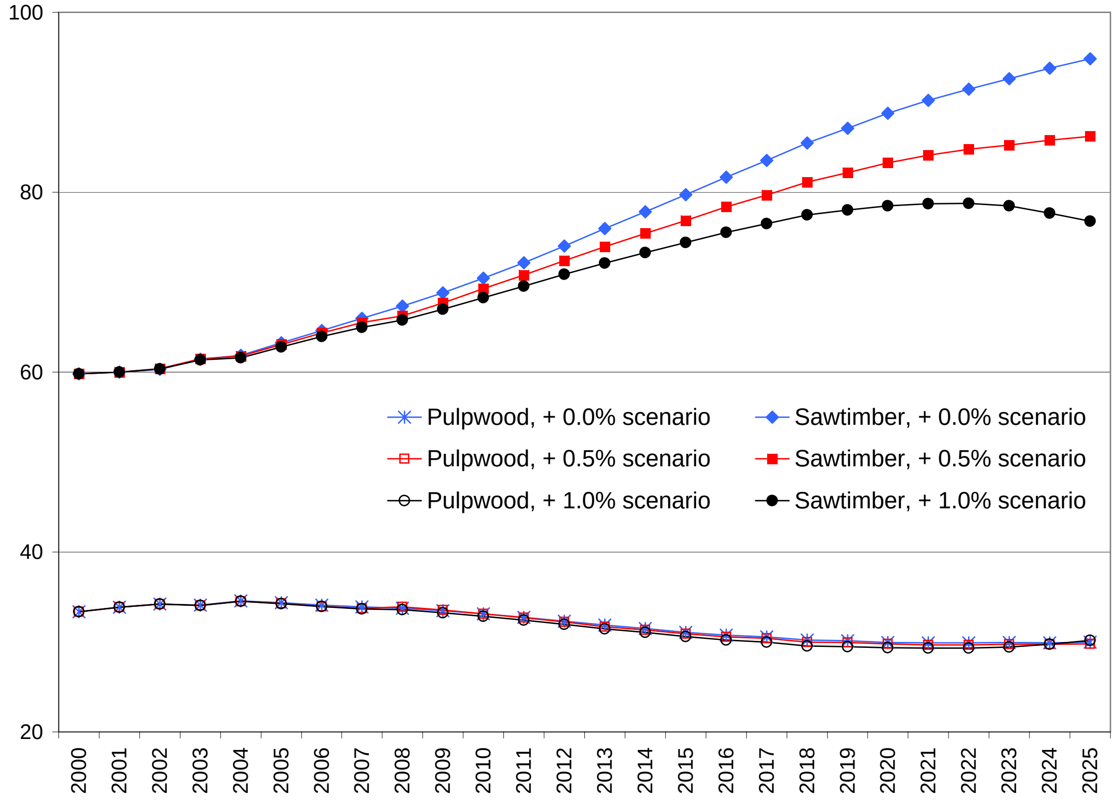

Figure 5.2: Softwood inventory projections for the 13-state southern region under three harvest increase scenarios, 2000-2025, billion cubic feet

ultimately declining about 10% below their 2000 levels under all of the scenarios. Softwood sawtimber is generally expected to increase throughout the projection period. Under 1.0% annual removals increase scenario, however, softwood sawtimber trends downwards during the last four years of projection period.

Total hardwood inventories are projected to increase 14%, 11%, and 7% under 0%, 0.5%, and 1.0% scenarios. Pulpwood inventories are projected to remain approximately unchanged over the period under the constant removals level scenario and

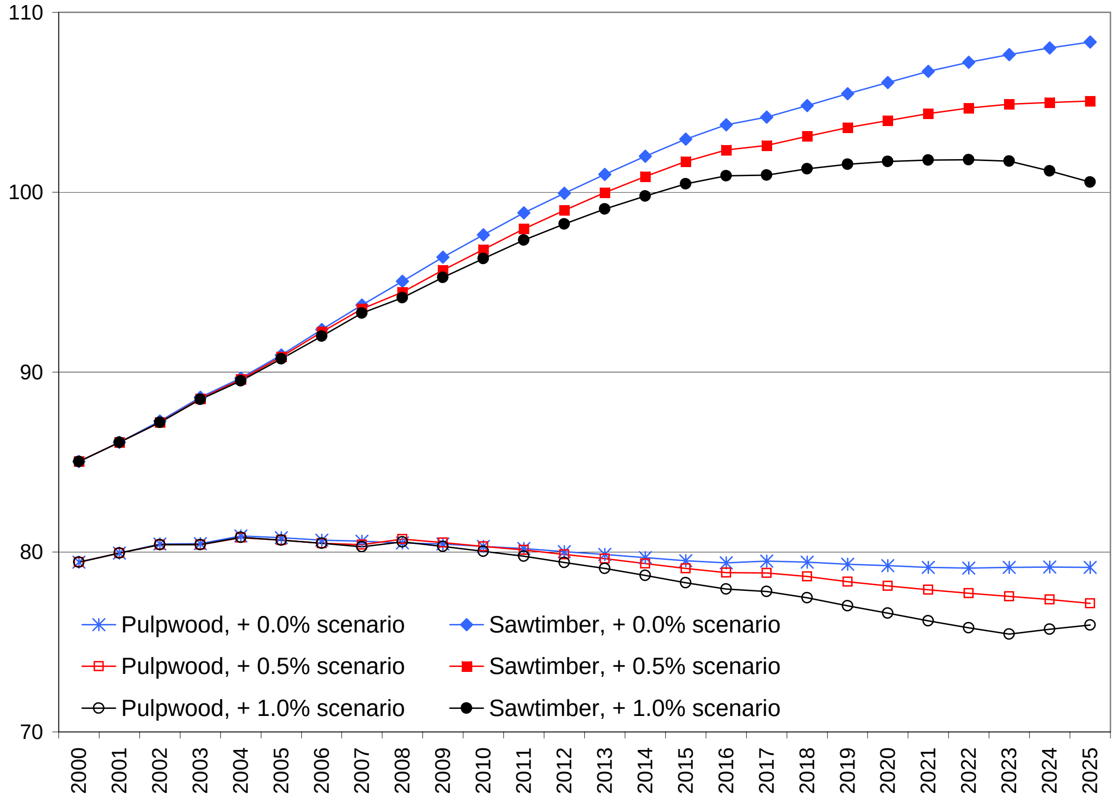

Figure 5.3: Softwood inventory projections for the 13-state southern region under three harvest increase scenarios, 2000-2025, billion cubic feet

will decline about 3% and 4% under 0.5% and 1.0% annual removals increase scenarios. Sawtimber inventories show net increases throughout the projection period, with the increases slowing down under the 0% and 0.5% removals increase scenarios, and declining during the last four years of the projection period under the 1.0% removals increase scenario.

On an individual state basis however, a much different future is projected in some cases. In Virginia and North Carolina, significant declines in softwood pulpwood inventories are projected (−40% and −34% respectively) for the Base Case. In North

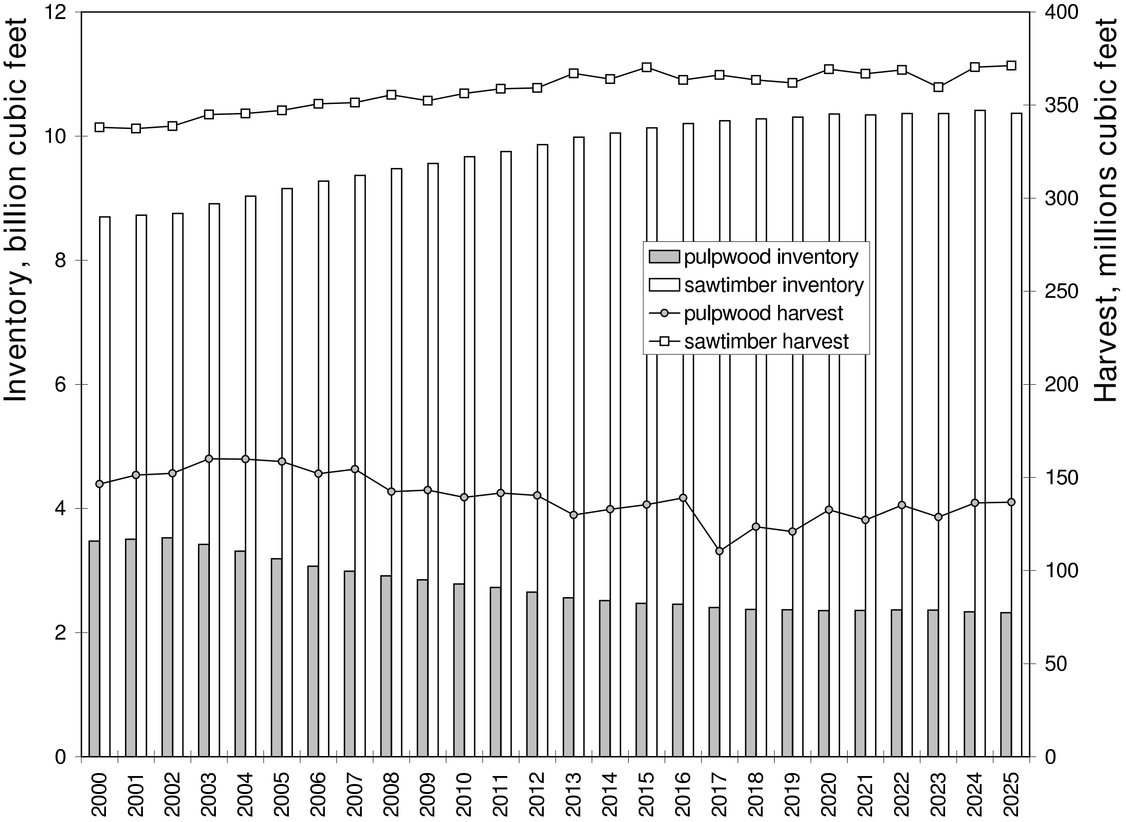

Figure 5.4: Softwood inventory and harvest projections for North Carolina, Base Case

Carolina, hardwood pulpwood inventories are also projected to decline (Figures 5.4 and 5.5). In general, most states show large softwood sawtimber increases and are projected to have declining softwood pulpwood inventories under all scenarios. Hardwood pulpwood inventories are projected to decline 5% for the region under the Base Case scenario, but a number of states including Alabama, Georgia, Louisiana, North Carolina, South Carolina, and Virginia show projected declines of 14%–23% (mostly due to trees migrating from the pulpwood to sawtimber size class over the period). Reductions in harvest levels during the projection period have allowed inventories to remain stable in some states.

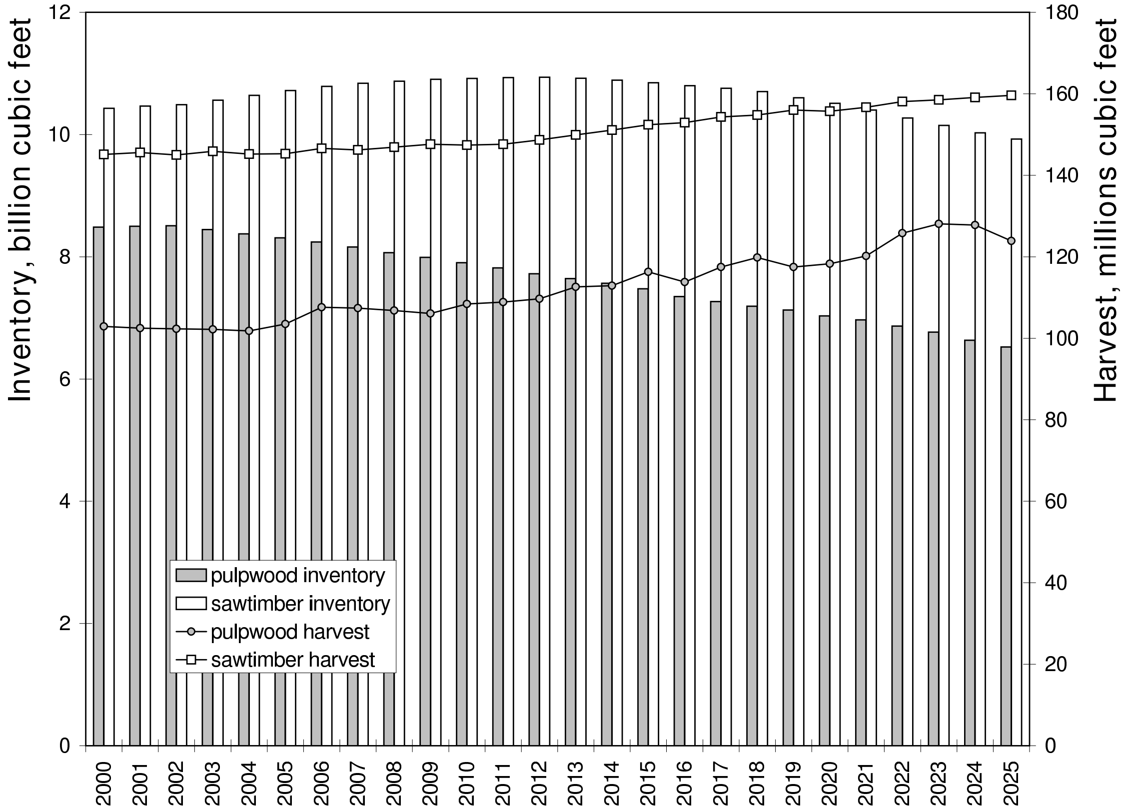

Figure 5.5: Hardwood inventory and harvest projections for North Carolina, Base Case

5.3.3 Interregional Trade

A key feature of the model developed for this study revolves around acknowledging the role of interregional trade in meeting regional demand for softwood and hardwood products. As was mentioned previously, harvest levels in some states dropped over the projection period (Figure 5.6) while overall harvest for the region increased over the projection period and met the demand levels for each state as they were represented by the scenarios. Trade among states allowed this to happen (see figures 5.8 and 5.9). Illustration of how these effects interact in the simulation model are best understood by example. Consider Figure 5.6 and Figure 5.8 (below). Alabama and Louisiana (Figure 5.6) are projected to reduce hardwood pulpwood harvest levels over the projection period, while accommodating a 0.5% increase in demand in the Base Case. In Figure 6 we see that this is accomplished by increasing imports of hardwood pulpwood in each state. No state that is projected to increase hardwood pulpwood harvest levels substantially is also projected to increase its imports of the product. A similar connection between Figure 5.7 and Figure 5.8 can also be made. As hardwood pulpwood harvest levels are projected to increase in several states, (e.g., Florida., Tennessee, East Texas, Oklahoma, North Carolina) the exports of the product from those states will increase to help meet demands in other states.

Trade matrices are recalculated for each year of the simulation to account for changes in the relative ability of states to produce timber over and above the regional (state level) demand. For example, a state that has 100,000 acres available for harvest above those necessary to meet regional demand would be relatively more likely to export to a state needing the product than another state that only has 50,000 acres available above its regional demand. Acres available means they meet the economic test of financial maturity. States with relatively more "surplus" available acres are more likely to be large exporters in a given period. States with a wider gap (deficit) between the amount of a product available for harvest and its regional demand will likely be a relatively larger importer of the product in any given year. Distance is also a factor in establishing trading relationships with other states and that is evidenced in the trading tables. Most states trade with neighboring states and possibly one or two others. Table 5.1 illustrates trading relationships embedded in the model for hardwood pulpwood. Georgia has export relationships with seven other regions

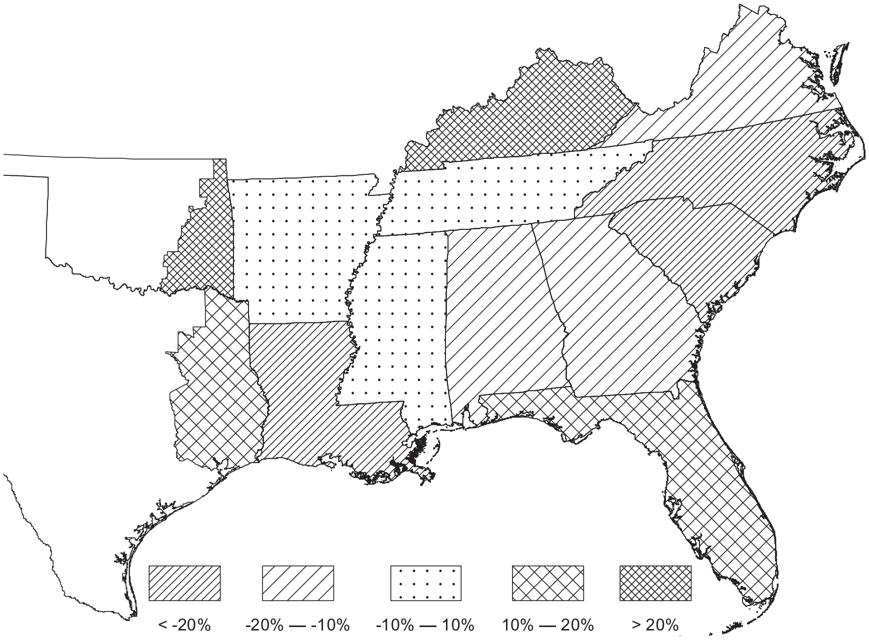

Figure 5.6: Relative changes in hardwood pulpwood inventory by state, 2000–2025

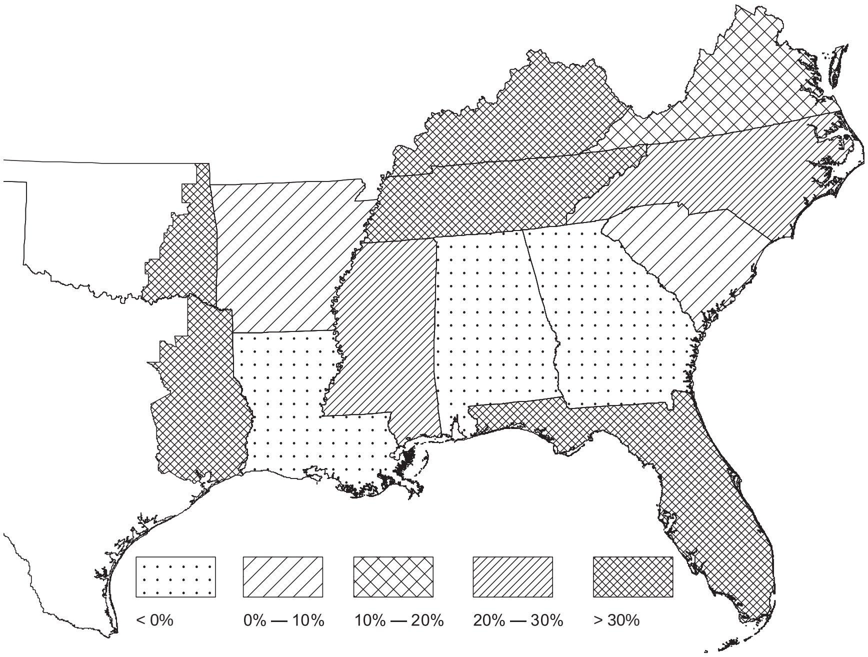

Figure 5.7: Relative changes in hardwood pulpwood harvest by state, 2000–2025

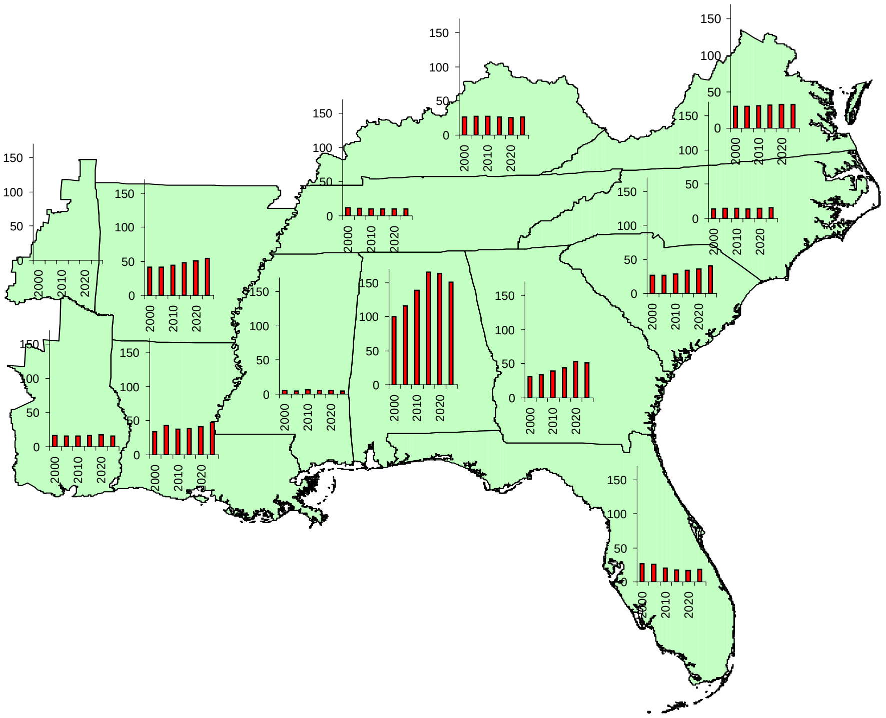

Figure 5.8: Dynamics of hardwood pulpwood state-level imports, 2000–2025, Base Scenario, MCF

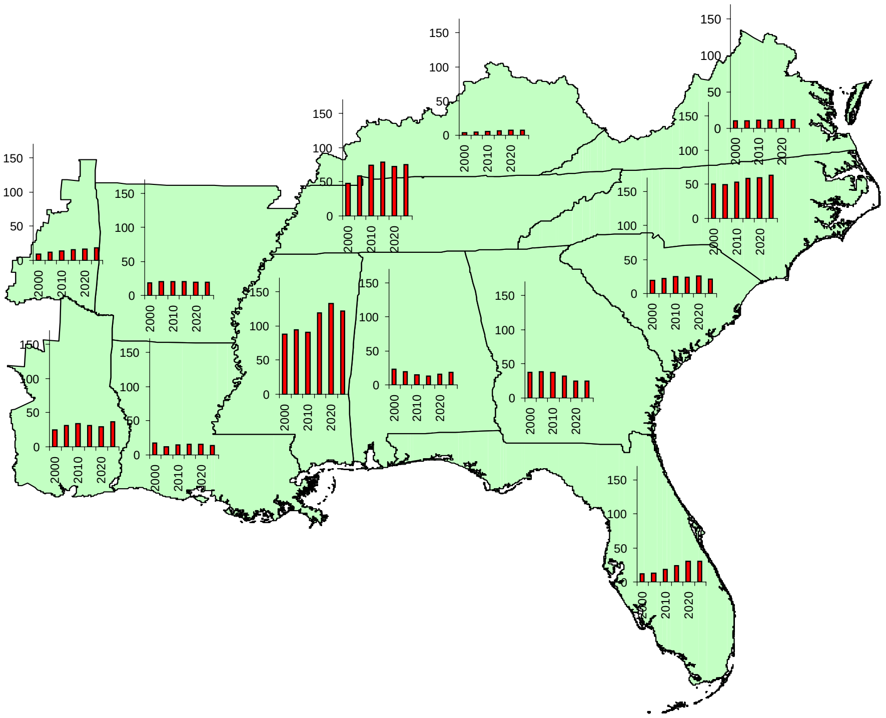

Figure 5.9: Dynamics of hardwood pulpwood state-level exports, 2000–2025, Base Scenario, MCF

(including Rest-of-the-World — ROTW) and imports from four. Tennessee imports hardwood pulpwood from seven states and exports to six. These trading relationships are important for understanding the dynamics of inventory growth and removals throughout the region and the ability of those relationships to help industries meet regional demands.

5.4 Conclusions

IDPS is an interregional multi-product timber inventory projection system, which models growth at the stand level, uses a net present value maximization framework to model optimal harvesting decisions, and a gravity model for interregional trade. It provides a framework for analyzing timber supply on regional and/or state levels.

The system was used to project timber inventories in thirteen Southern states through 2025. The projections show a 24% increase in softwood inventory and 9% increase in hardwood inventory given a base case scenario of 0.5% annual increase in consumption. However, the pulpwood component of total inventory is predicted to decline for both softwood and hardwood.

The IDPS model treats subregions (states) as interconnected markets. It recognizes the mutual influence of states as supply and demand regions. It could also be used to analyze regional demand or supply shocks such as new mill construction or mill closures, urbanization, or natural disasters.

Table 5.1: Example trade matrices for two selected years for hardwood pulpwood, 2000 and 2025, mcf

2000	To													
From	AL	AR	FL	GA	KY	LA	MS	NC	OK	SC	TN	TX	VA	ROTW	Total
AL	196.6		14.2	5.0			0.7	0.1			2.6				219.2
AR		60.4				5.4	0.6					12.0			78.4
FL	1.5		27.3	10.8											39.6
GA	13.1		12.4	117.9	2.8			1.1		0.5	4.7			2.8	155.3
KY	0.6				12.4					0.2	0.6			2.5	16.3
LA		8.5				70.1	4.1					4.7			87.4
MS	59.1	6.6	0.1			20.6	61.8	0.1			1.6				149.9
NC					4.3			53.1		25.4	0.3		15.5	4.3	102.9
OK		9.4							5.0			0.1			14.5
SC				14.9				4.5		62.9					82.3
TN	25.7			0.1	16.3			5.3			24.3		0.1	0.1	71.9
TX		16.7				7.6						21.3			45.6
VA								2.8		0.4	1.2		77.5	5.5	87.4
ROTW					3.4					0.2	1.2		14.8		19.6
Total	296.6	101.6	54.0	148.7	39.2	103.7	67.2	67.0	5.0	89.6	36.5	38.1	107.9	15.2	1170.3

2025	To													
From	AL	AR	FL	GA	KY	LA	MS	NC	OK	SC	TN	TX	VA	ROTW	Total
AL	185.9		10.3	5.9			0.5	0.1			1.7				204.4
AR		61.2				7.1	0.7					11.6			80.6
FL	3.2		43.1	27.4			0								73.7
GA	10.5		7.7	117	1.3		0	0.7		0.4	2.5			1.6	141.7
KY	1.6				18.2			0.1		0.5	1			4.4	25.8
LA		6.5				69.8	3.5					3.4			83.2
MS	86.0	6.8	0.1			27.1	71.3	0.1			1.6				193
NC				0.1	3.8			60.6		38.4	0.3		16.1	4.6	123.9
OK		17.6							5.6			0.2			23.4
SC				18.0				3.3		61.1					82.4
TN	49.0			0.2	18.0			7.6			31.5		0.1	0.1	106.5
TX		22.9				13.5						27.9			64.3
VA								3.5		0.7	1.4		89.4	6.6	101.6
ROTW					3.2			0.1		0.4	1.4		16.6		21.7
Total	336.2	115	61.2	168.6	44.5	117.5	76.0	76.1	5.6	101.5	41.4	43.1	122.2	17.3	1326.2

References

Abt, R.C., F.W. Cubbage, and G. Pacheco. 2000. Southern forest resource assessment using the subregional timber supply (SRTS) model. Forest Products Journal 50(4):25–33. 1, 12, 14, 17, 52

Adams, D.M. 1975. A model of pulpwood production and trade in Wisconsin and the Lake States. Forest Science 21(3):301–312. 3, 5, 6, 18

Adams, D.M., and R.W. Haynes. 1980. The 1980 softwood timber assessment market model: structure, projections, and policy simulations, volume 22 of *Forest Science Monographs*. 64 p. 12, 13, 50

Adams, D.M., and R.W. Haynes. 1996. The 1993 Timber Assessment Market Model: Structure, Projections, and Policy Simulations. USDA FS Pacific Northwest Research Station, Portland, OR, 58 p. 12, 13, 50

Anderson, J.E. 1979. A theoretical foundation for the gravity equation. American Economic Review 69(1):106–116. 7

Bailey, R.G. 1995. Description of the ecoregions of the United States. Misc. publ. 1391, USDA, Washington, DC. 108 p. 47

Bentley, J.W., T.G. Johnson, and C.W. Becker. 2002. Virginia's timber industry—an assessment of timber product output and use, 1999. USDA FS Southern Research Station, Asheville, NC. 49

Bergkvist, E. 2000. Forecasting interregional freight flows by gravity models. Jahrbuch für Regionalwissenschaft 20(2):133–148. 44

Bergstrand, J.H. 1985. The Gravity Equation in international trade: Some microeconomic foundations and empirical evidence. Review of Economics & Statistics 67(3):474–481. 7

Binkley, C.S. 1987. Economic models of timber supply. P. 109–136 *in* The global forest sector: an analytical perspective. Kallio, M., D.P. Dykstra, and C.S. Binkley (eds.). John Wiley & Sons, Chichester, UK. 52

Brännlund, R., P.O. Johansson, and K.G. Löfgren. 1985. An econometric analysis of aggregate sawtimber and pulpwood supply in Sweden. Forest Science 31(3):595–606. iv, 3, 4, 5, 17, 18, 20, 26

Breuss, F., and P. Egger. 1999. How reliable are estimations of East-West trade potentials based on cross-section gravity analyses? Empirica 26(2):81–94. 7

Carter, D.R. 1992. Effects of supply and demand determinants on pulpwood stumpage quantity and price in Texas. Forest Science 38(3):652–660. iv, 3, 5, 6, 18, 20, 26

Cubbage, F.W., T.G. Harris, jr, R.J. Alig, D.W. Hogg, and J.A. Burgess. 1991. Projecting State and Substate Timber Inventories: The Georgia Regional Timber Supply Model. Research Bulletin 398. The University of Georgia, Athens, GA, 32 p. 12

Daniels, B.J., and W.F. Hyde. 1986. Estimation of supply and demand for North Carolina's timber. Forest Ecology & Management 14(1):59–67. 3, 18

Davidson, R., and J. MacKinnon. 1981. Several tests for model specification in presence of alternative hypotheses. Econometrica 49(3):781–793. 40

Egger, P. 2000. A note on the proper econometric specification of the Gravity Equation. Economics Letters 66(1):25–31. 7, 32

Egger, P., and M. Pfaffermayr. 2003. The proper panel econometric specification of the gravity equation: A three-way model with bilateral interaction effects. Empirical Economics 28(3):571–580. 8, 32, 33, 34

Egger, P., and M. Pfaffermayr. 2004. Distance, trade and FDI: a Hausman–Taylor SUR approach. Journal of Applied Econometrics 19(2):227–246. 8

Greene, W.H. 2000. Econometric Analysis. Prentice-Hall, NJ, 1004 p. 23, 33

Gregory, G.R. 1960. A statistical investigation of factors affecting hardwood flooring. Forest Science 6(2):123–134. 3

Gujarati, D.N. 1988. Basic Econometrics. Second edition. McGraw-Hill, New York, 706 p. 22

Hausman, J.A., and W.E. Taylor. 1981. Panel data and unobservable individual effects. Econometrica 49(6):1377–1398. 8

Haynes, R.W., and D.M. Adams. 1985. Simulations of the effects of alternative assumptions on demand-supply determinants of the timber situation in the United States. USDA Forest Service, For. Res. Econ. Res., Washinton, DC, 113 p. 1, 3, 18

Haynes, R.W., D.M. Adams, R. Alig, et al. 2003. An analysis of the timber situation in the United States: 1952 to 2050 Gen. Tech. Rep. PNW-GTR-560. USDA, Forest Service, Pacific Northwest Research Station, Portland, OR, 254 p. 1

HETEMÄKI, L., AND J. KUULUVAINEN. 1992. Incorporating data and theory in roundwood supply and demand estimation. American Journal of Agricultural Economics 74(4):1010–18. 3, 17

HOLLEY, D.L., R.W. HAYNES, AND H.F. KAISER. 1975. An interregional timber model for simulating change in the softwood forest economy. Technical Report 54, School of Forest Resources, NC State University, Raleigh, NC. 70 p. 13, 50

HOWARD, J.L. 1999. U.S. Timber Production, Trade, Consumption, and Price Statistics 1965–1997. Gen. Tech. Rep. FPL–GTR–116. USDA Forest Service, Madison, WI, 76 p. 1

HOWARD, J.L. 2001. U.S. Timber Production, Trade, Consumption, and Price Statistics 1965–1999. Gen. Tech. Rep. FPL–RP–595. USDA Forest Service, Madison, WI, 90 p. 17

HUA, C. 1990. A flexible and consistent system for modeling interregional trade flows. Environment and Planning A 22(4):439–457. 8, 35

ISARD, W. 1960. Methods of Regional Analysis, chapter 11: Gravity, Potential, and Spatial Interaction Models, p. 493–598. Massachusetts Institute of Technology, Cambridge, Massachusetts. 6

JOHNSON, T.G., AND D.R. BROWN. 2002. North Carolina's timber industry—an assessment of timber product output and use, 1999. USDA FS Southern Research Station, Asheville, NC. 49

JOHNSON, T.G., AND C.D. STEPPLETON. 2001. Southern Pulpwood Production, 1999. Resource Bulletin SRS–57. USDA FS Southern Research Station, Asheville, NC, 34 p. 49, 57

JOHNSON, T.G., AND C.D. STEPPLETON. 2003. Southern Pulpwood Production, 2001. Resource Bulletin SRS–84. USDA FS Southern Research Station, Asheville, NC, 40 p. 17, 36, 37

JOHNSON, T.G., AND J.L. WELLS. 1999. Georgia's timber industry—an assessment of timber product output and use, 1997. USDA FS Southern Research Station, Asheville, NC, 36 p. 58

KANG, M. 2003. United States wood products and regional trade: A gravity model approach. Ph.D. dissertation, Auburn University, Auburn, AL. 103 p. 7

KANGAS, K., AND A. NISKANEN. 2003. Trade in forest products between European Union and the Central and Eastern European access candidates. Forest Policy and Economics 5(3):297–304. 7

LARSON, R.W., AND M.H. GOFORTH. 1970. TRAS: a computer program for the projection of timber volume. Agriculture handbook ; no. 377. USDA Forest Service, Washington, DC, 24 p. 13

LEONTIEF, W., AND A. STROUT. 1963. Multiregional input-output analysis. P. 119–150 *in* Structural Interdependence and Economic Development. Barna, T. (ed.). St. Martin's Press, New York. 9, 35, 36, 50, 51, 52

LEUSCHNER, W.A. 1973. An econometric analysis of the Wisconsin aspen pulpwood market. Forest Science 19(1):41–46. 3, 4, 5, 18, 19, 21

MÁTYÁS, L. 1997. Proper econometric specification of the gravity model. World Economy 20(3):363–368. 7, 32, 33

MÁTYÁS, L. 1998. The gravity model: Some econometric considerations. World Economy 21(3):397–401. 7, 32

MCKILLOP, W.M. 1967. Supply and demand for forest products—an econometric study. Hilgardia 38(1):1–132. 3

MERZ, T.E. 1984. An econometric analyis of the market for pulpwood harvested in Michigan's Upper Peninsula. Forest Science 30(1):107–113. 6

MILLER, D.M. 1984. Reducing transformation bias in curve fitting. American Statistician 38(2):124–126. 39, 40

MOSES, L.N. 1955. The stability of interregional trading patterns and input-output analysis. American Economic Review 45(5):803–826. 9, 10, 35, 51

NAGUBADI, V., I.A. MUNN, AND A. TAHAI. 2001. Integration of hardwood stumpage markets in the Southcentral United States. Journal of Forest Economics 7(1):69–98. 5, 18

NEWMAN, D., AND D. WEAR. 1993. Production economics of private forestry: a comparison of industrial and nonindustrial forest owners. Am J Agric Econ 75(3):674–684. 53

NEWMAN, D.H. 1987. An econometric analysis of the Southern softwood stumpage market: 1950–1980. Forest Science 33(4):932–945. iv, 3, 4, 5, 18, 20, 23, 26

NEWMAN, D.H. 1990. Shifting Southern softwood stumpage supply: implications for welfare estimation from technical change. Forest Science 36(3):705–718. 3

NORRIS FOUNDATION. 1977–2001. Timber Mart-South. The Daniel B. Warnell School of Forest Resources, University of Georgia, Athens. 22, 49, 53

Oguledo, V.I., and C.R. MacPhee. 1994. Gravity models: a reformulation and an application to discriminatory trade arrangements. Applied Economics 26(2):107–120. 31

Polenske, K.R. 1970. An empirical test of interregional input-output models: Estimation of 1963 Japanese production. American Economic Review 60(2):76–82. 9, 10, 35, 51

Polenske, K.R. 1980. The U.S. multiregional input-output accounts and model. D. C. Heath and Company, Lexington, 360 p. 50

Pöyhönen, P. 1963. A tentative model for the volume of trade between countries. Weltwirtschaftliches Archiv 90(1):93–99. 6

SAS Institute, Inc. 1999. SAS/ETS User's Guide, Version 8. SAS Institute Inc., Carry, NC, 1546 p. 38

Serlenga, L., and Y. Shin. 2004. Gravity models of intra-EU trade: Application of the Hausman-Taylor estimation in panels with heterogeneous time-specific common factors. Working paper, School of Economics, University of Edinburgh. 35 p. 8

Teeter, L. 1994. Methods for predicting change in timber inventories and product markets over time: A dynamic programming approach for modeling change in timber inventories. Final rep. to the USDA For. Serv. Coop. Agree. USFS–29–749, Auburn University. 27 p. v, 12, 15, 47

Teeter, L., G.S. Alward, and W.A. Flick. 1989. Interregional impacts of forest-based economic activity. Forest Science 35(2):515–531. 46, 51

Teeter, L., G. Somers, and J. Sullivan. 1993. Optimal harvest decisions: A stochastic dynamic programming approach. Agricultural Systems 42(1–2):73–84. 54

Teeter, L., and X. Zhou. 1999. Projecting timber inventory at the product level. Forest Science 45(2):226–231. 15, 48

Tinbergen, J. 1962. Shaping the world economy; suggestions for an international economic policy. Twentieth Century Fund, New York, 330 p. 6, 31

Trømborg, E., J. Buongiorno, and B. Solberg. 2000. The global timber market: implications of changes in economic growth, timber supply, and technological trends. Forest Policy and Economics 1(1):53–69. 17, 58

Wear, D.N., and J.G. Greis (eds.). 2002. Southern forest resource assessment. General technical report SRS–53. Southern Research Station, Asheville, NC, 635 p. 1, 58

WEAR, D.N., AND P.J. PARKS. 1994. The economics of timber supply: an analytical synthesis of modeling approaches. Natural Resources Modeling 8(3):199–223. 46

WHITE, H. 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica 48(4):817–838. 23

WU, C.S. 1994. Assessing the economic effect of streamside management zones on the forestry sector. Ph.D. dissertation, Auburn University, Auburn, AL. 165 p. 57

ZHOU, X. 1998. Methods for improving timber inventory projections in Alabama. Ph.D. dissertation, Auburn University, Auburn, AL. 114 p. v, 12, 15, 47, 48

ZHOU, X., J.R. MILLS, AND L.D. TEETER. 2003. Modeling forest type transitions in the South-Central region: results from three methods. Southern Journal of Applied Forestry 27(3):190–197. 56

ZHOU, X., AND L. TEETER. 1996. DPSupply: a new approach to timber inventory projection in the Southeast. P. 293–298 *in* Proceedings of the 25th annual Southern Forest Economics Workshop; 5 April 17–19; New Orleans, LA. Caulfield, J.P., and S.H. Bullard (eds.). Mississippi State University, Department of Forestry, Mississippi State, MS. v, 47