Incorporating Interstate Trade In a Multi-region Timber Inventory Projection System

Lawrence Teeter, Maksym Polyakov and Xiaoping Zhou

Abstract: 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-a-vis all others as a producer of stumpage and as a consumer of stumpage products. The gravity model was incorporated in a multi-region version of DPSupply 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.

Key Words: supply, demand, modeling, FIA data, harvest

INTRODUCTION

The South is the major timber production region in the United States. In 1997, nearly 58% of US industrial roundwood and three-fourths of total US pulpwood production was produced in the region (USDA Forest Service 1999). A number of projections made in the 1970s and 1980s predicted an increasing share for the US South both in timber growth and removals (Haynes and Adams 1985).

The objective of this project was to develop an interregional trading model for stumpage products that recognizes the importance of demand centers (centers of forest products manufacturing activity) and inventory in forecasting future harvests and trade flows. The model adapted work done by Teeter and others (1989) who modeled interindustry trade and highlighted the interdependence of producing regions. In line with that work, a gravity model was constructed that considers the relative position of each region vis-à-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.

Multiregional input-output models

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.
Fixed trade coefficient models are based on the following principle: the total output of interindustry demands (including the industry itself) and demands by final users equal the industry’s output. While linear programming models require a large number of parameters to support the analytical mechanisms of interregional trade, fixed trade coefficient models utilize empirical trade relationships between industries and regions themselves. These models were developed by (Leontief 1963, Polenske 1970, and Bon 1984) and were designed as rough and ready working tools capable of making effective use of limited amounts of factual information. 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, or gravity coefficient model. Due to space limitations, only the gravity coefficient model will be described here.

According to the gravity coefficient model, the amount of good $i$ shipped from region $g$ to $h$ is:

$$X'_{gh} = \frac{X'_{gi} X'_{hi}}{X'_{io}} \hat{Q}_{gh} \quad \forall \quad i, g, h$$

where:

- $i, g, h$ – product, production and consumption regions
- $X'_{gh}$ – amount of product $i$ shipped from region $g$ to $h$
- $X'_{hi}$ – amount of product $i$ shipped to region $h$
- $X'_{io}$ – total amount of commodity $i$ produced in an economy;
- $\hat{Q}_{gh}$ – gravity coefficient, determined as:

$$\hat{Q}_{gh} = \frac{X'_{gi} X'_{hi}}{X'_{gi} X'_{hi}}$$

This method expresses the assumption that the shipments of commodity $i$ from region $g$ to region $h$ are proportional to the total production and total consumption of commodity $i$ in the two regions, respectively, and are inversely proportional to the total amount of commodity $i$ produced in all regions (Bon 1984).

Leontief and Strout (1963) developed four methods to derive gravity coefficients: the exact solution, a point estimate solution, a least squares solution and the simple solution. Details describing each of these methods can be found in Leontief (1963) or Teeter et al. (1989). Due to the availability of initial period data on interstate trade, this study implemented an exact solution to determining gravity coefficients.
DATA

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


- Timber Product Output (TPO) data on production, consumption and trade of major timber products for each of the US South states. The data were obtained from bulletins of the USDA Forest Service Southern Research Station, for example, (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.

METHODS

Modeling future trading activity in forest products

The availability of data on the production, consumption and trade of forest products between US Southern states allows us to use the exact solution method to determine base year gravity coefficients. However, direct application of the method would not allow us to model the trade dynamics resulting from changes in timber inventories of producing states.

The gravity coefficient method assumes that shipments of commodity $i$ from region $g$ to region $h$ are proportional to the total production and total consumption of commodity $i$ in the two regions, respectively, and are inversely proportional to the total amount of commodity $i$ produced in all regions. To adapt the basic model to accommodate the dynamics of inventory growth, it is reasonable to assume that the shipments of wood product $i$ from region $g$ to region $h$ are also proportional to the amount of wood available to harvest in region $g$. Now the amount of timber product traded will be:

$$ X_{gh}^i = \frac{X_{oi}^i I_{g}^i}{X_{oi}^i + \hat{Q}_{gh}^i} $$

and the ‘modified’ gravity coefficient will be:

$$ \hat{Q}_{gh}^i = \frac{X_{oi}^i}{X_{oi}^i I_{g}^i} X_{gh}^i $$

where:

- $g$ – supply region;
- $h$ – demand region;
- $I_{g}^i$ – amount of timber product $i$ available in supply region $g$. 

361
assuming that the ‘modified’ gravity coefficients remain stable, the goal is to determine regional
demands, and amounts of wood available for harvesting, harvest levels and trading levels in each
forest product for future periods through 2025.

Figure 1. Interregional DPSupply system

An interregional DPSupply model with stochastic prices

At the core of the Interregional DPSupply (IDPS) model are two main modules: a
dynamic programming (DP) model for determining optimal harvesting decisions, and a linear
programming (LP) harvesting model (see Figure 1). Both 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, Teeter and Zhou 1996, Zhou 1998) to incorporate the 13-state southern
region requires accounting for regional differences in growth, the anticipated products from
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 the FIA data from
the counties in each region, growth 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 using methods similar to those
used in earlier applications of the DPSupply model. Product distribution models to allocate the
projected volumes on each plot to each potential product class were constructed for each physiographic region following methods outlined by Teeter and Zhou (1999).

**Area Change**

Area change in the projection system has 3 integrated components:

1) acres gained by each of forest management type from non-timberland
2) acres lost by each forest management type to non-timber land
3) acres lost by one management type through transition 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. These plots were grouped by forest inventory unit. For each forest inventory unit, net loss and net 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. This method is similar to the method reported by Zhou and others (2003) that uses historical FIA data.

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 that a new (current) forest management type would be a particular type 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.

**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 cash flow.
The general recursive equation for the dynamic model can be expressed as:

\[ V_t = \max_k \left[ \pi \left( P_t, o_i, s_j, d_t, u_t, k_t \right) + \beta E_{P_{t+1}} \left( P_{t+1}, o_i, s_j, d_t, u_t, k_t \right) \right] \]

\[ \forall o_i, s_j \quad i = 1, 2; \quad j = 1, \ldots, 5 \]

Where:
- \( k_t \) --- cut decision at time \( t \);
- \( d_t \) --- dbh class at time \( t \);
- \( u_t \) --- volume per acre at time \( t \);
- \( P_t \) --- timber product price per cubic foot at time \( t \);
- \( o_i \) --- ownership -- non-industrial private or industry;
- \( s_j \) --- forest type – planted pine, natural pine, oak-pine, lowland or upland hardwood;
- \( \pi \) --- immediate net returns
- \( E \) --- a conditional expectations operator over random future prices \( P_{t+1} \)

Because prices change over time, the expectations for future prices influence forest owners’ decisions about when to harvest. For this reason, a stochastic pricing element, similar to the one developed in (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 unusually high because of the expectation that it will fall in the future.

The IDPS LP harvesting module was modified to accommodate individual states and/or FIA units separately and interface with 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 can be harvested at the lowest price. Stands that are not harvested are then ‘grown’ one year using the growth models, resulting in the next year’s initial inventory.
RESULTS

Inventories

We examined 3 different scenarios regarding future patterns of consumption (by firms) of wood products in the southern region using the IDPS model. These scenarios reflect trends similar to those examined by the 2000 RPA and the Southern Forest Resource Assessment including a) no change in the level of demand for forest products from its level in 2000, b) a 0.5% annual increase in demand for forest products and c) a 1% annual increase in demand. Only the 0.5% scenario is discussed below and will be referred to as the Base Case (it is considered the most likely scenario and is also close to the level of U.S. demand increase expected by Trømborg and others (2000).

Figure 2 illustrates inventory projections for the entire southern region. Total softwood inventory is projected to increase 26% between 2000 and 2025 with pulpwood inventories peaking in 2008 and ultimately declining about 7% from their 2000 levels. Softwood sawtimber is projected to increase throughout the projection period. Total hardwood inventories are projected to increase 23% with pulpwood inventories remaining stable after 2010 and sawtimber inventories increasing throughout the projection period.

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 (-34% and –22% respectively) for the Base Case. In North Carolina, hardwood pulpwood

Figure 2. Inventory projections for the 13-state southern region – Base Case.
inventories are also projected to decline (Figure 3). 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 increase 7% 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 7%-12%. Reductions in harvest levels during the projection period have allowed inventories to remain stable in some states.

Figure 3. Inventory projections - North Carolina – Base Case.

**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 4) 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 and 6).

Figure 4. Relative changes in hardwood pulpwood harvest level by state – 2000-2025.

Illustration of how these effects interact in the simulation model are best understood by example. Consider Figure 11 and Figure 18 (below). Alabama and Louisiana (Figure 18) 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 18 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 11 and Figure 19 can also be made. As hardwood pulpwood harvest levels are projected to increase in several states, (eg., Florida, Tennessee, East Texas, Oklahoma, North Carolina) the exports of the product from those states will increase to help meet demands in other states.

Figure 5. Dynamics of hardwood pulpwood state-level imports, 2000-2025, Base Scenario, MCF

Figure 6. Dynamics of hardwood pulpwood state-level exports, 2000-2025, Base Scenario, MCF

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 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. Figure 7 illustrates trading relationships embedded in the model for hardwood pulpwood. Georgia has export relationships with seven other regions (including Rest-of-the-World – oo) 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.
### Dynamics of Hardwood Pulpwood Trade

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Figure 7. Example trade matrices for three selected years for hardwood pulpwood, 2000, 2015 and 2025.
LITERATURE CITATION


