# A TIMBER SUPPLY MODEL AND ANALYSIS

# FOR

# SOUTHWEST VIRGINIA

by

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(ABSTRACT)

A model was developed to estimate the economic stock supply of primary wood products. Two hardwood products were recognized: logs and bolts. The supply model was used to evaluate the impacts of shifting primary product demands and increasing supply costs on delivered prices and quantities in southwest Virginia.

Homogeneous supply response cells, identified from Forest Service forest survey data, were used to generate log and bolt supplies. Response cells define blocks of forest land with similar biologic, physiographic, and landowner characteristics. Yield equations estimate the volume of logs and bolts available. Harvesting and hauling costs depend on a response cell's physiographic characteristics. Stumpage owners set reservation price as a function of expected stumpage prices, future timber yields, and an alternative rate of return. Recovery cost per cunit in a response cell equals the sum of harvesting and hauling costs and reservation price. The quantities of logs and bolts supplied are determined by comparing harvest revenues to recovery costs. If revenues are greater than or equal to costs in a particular response cell, then timber is harvested

The demands for logs and bolts are derived from the demand for manufactured products. Log and bolt demand equations in the model were statistically estimated.

For each time period, the model determines the delivered log and bolt prices which equate the quantities of logs and bolt supplied to the quantities demanded. The solution technique is iterative. The quantities demanded and supplied of logs and bolts are determined for the given delivered prices. If quantities supplied do not equal the quantities demanded, then delivered prices are adjusted, and the quantities are recalculated.

Primary product supplies in southwest Virginia are price elastic because of extensive hardwood resources and relatively constant recovery costs. Expansions in primary product demands expected over the next 15 years should have little direct impact on delivered prices. Delivered prices, however, will be sensitive to production costs. These costs will rise if factor input prices, such as fuel prices, wage rates, or machinery costs, increase.

# Acknowledgements

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# Chapter I

# INTRODUCTION

## *Problem Statement*

Recently, public and private groups concerned about economic conditions in southwest Virginia, expressed an interest in expanding the forest products industry. The region has traditionally relied upon the coal industry as an economic base. The importance of coal in the region, however, is diminishing. Recent developments in production technologies and sluggish market conditions have reduced mining labor requirements and coal production levels.

Several factors are considered in the industrial location decision. These include labor conditions, access to markets, transportation, and raw material availability (Karaska and Bramball 1969; and Wheat 1973). Knapp et al. (1986) have compiled and analyzed statistics on the first three factors. Their findings indicate that labor is available at rea-

sonable wages, and also dispel preconceived notions of poor labor relations. They identify market access and transportation as the region's weakest points, though improvements are foreseen as highways are completed in the area. The report gives cursory consideration to raw material availability, stating that:

> "...natural resources are only useful to the economy if they meet the "market test" - that is, the price of the commodity must be high enough to cover the costs of production and transportation."

No studies have considered the economics of procuring, harvesting, and hauling timber resources in southwest Virginia. The *Mountains of Hardwood* report contains information on the physical hardwood inventory and on the ability of this inventory to supply new wood processing facilities (V.D.F. 1984). The report, however, does not consider the economic supply of roundwood.[1]

An analysis of primary wood products supply, emphasizing the economic availability of roundwood, would provide decision makers with resource data useful for planning the expansion. The supply analysis would determine the economic stock supply of roundwood. Haley and Cooney (1982) defined economic stock supply as:

> "...that portion of the resource for which product sales revenues equal or exceed all the costs incurred in bringing the products to market."

In other words, stock roundwood supply is the volume of logs that could be delivered, given recovery costs and log prices. Stock supply is limited by the existing physical timber inventory and occurs in the time period during which all factors of production are fixed. This supply may be delivered to the mill by contracting on a cut and haul basis or by loggers operating independently and paid a delivered log price.

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[1] The report provides a basic growth-drain analysis of timber supply; see the Literature Review section for a description of growth-drain studies.

The supply analysis would be useful to several types of decision makers. Manufacturers of wood products considering expansion in southwest Virginia will be interested in resource availability and the price effects of increased roundwood demand. Public agencies may use the analysis to evaluate public policy issues, such as allowable cut levels on national forests. An private landowners may use price information in forestry investment analyses. In general, the analysis would alleviate some of the uncertainty concerning the quantities, types, and prices of primary wood products available within the region. Decision makers would be provided with information to evaluate the type and extent of potential forest industry expansion.

## *Objectives*

The overall objective of this study was to perform a timber supply analysis for southwest Virginia. Specifically, the study:

1. Developed a model to estimate the regional economic stock supply of primary hardwood products.
2. Applied the model from Objective 1 to estimate periodic supply (price-quantity) schedules for primary hardwood products for the next 15 years.
3. Demonstrated the model's ability to evaluate the price and quantity effects of different levels of forest industry expansion.

## *Description of the Study Area*

The study area included the Virginia counties of Buchanan, Dickenson, Lee, Russell, Scott, Smyth, Tazewell, Washington, and Wise (Figure 1). These counties, except Smyth and Washington, form the major coal region of the state.

The study area's forests, geography, and market conditions are relatively homogeneous. The area contained 1,765,903 acres of commercial forest land, 87 percent of which is privately owned. Ownerships are: 220,072 acres of public lands (federal, state, county, and municipal), 396,546 acres owned by forest industry and miscellaneous corporations, and 1,149,285 acres owned by farmers and miscellaneous private individuals (U.S.D.A. 1985).

The area is mountainous, and often has steep terrain. Several forest types are present, but the oak-hickory type is dominant.

The primary wood products market is relatively small. Approximately 32 sawmills were operating in the study area as of 1985 (TVA 1984 and Frame and White 1986). In addition, there were ten miscellaneous wood products plants, three dimension stock mills, one veneer log and two pulpwood concentration yards. A pulp and paper mill is located in Kingsport, Tennessee, just south of the study area, and a waferboard plant is located in Dungannon, Virginia.

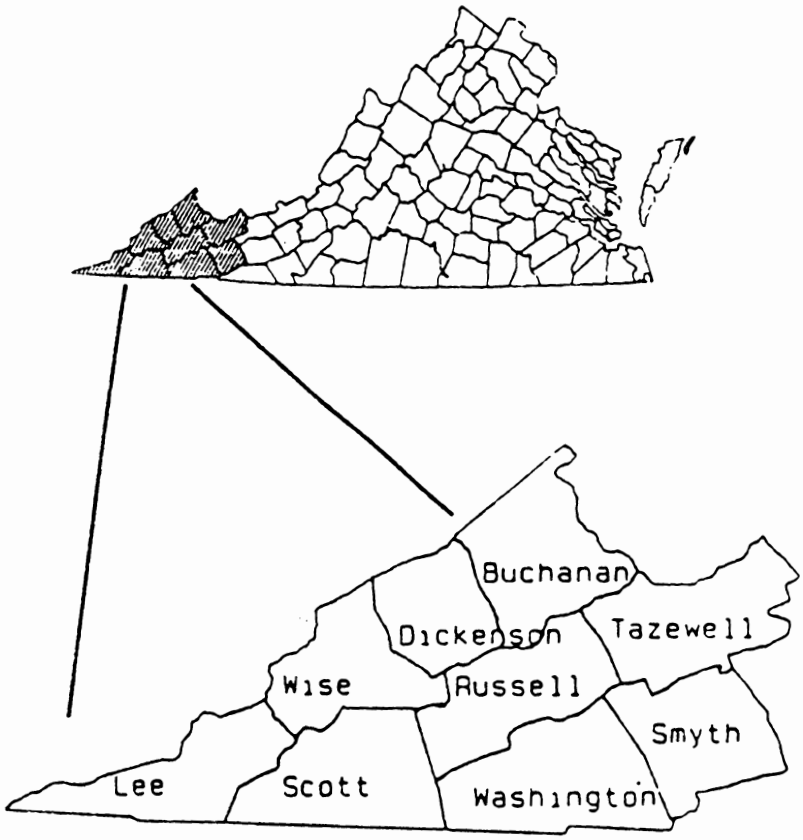


Figure 1. Counties in the study are of southwest Virginia.

# *A Literature Review*

Literature on timber supply analysis is extensive. Greber (1983) categorized four types of timber supply studies: 1) basic growth-drain, 2) economically constrained, 3) econometric, and 4) process analysis. The first three types of studies are reviewed briefly. Studies involving process analysis are emphasized.

## Basic Growth-drain Studies

Basic growth-drain studies are descriptive analyses giving little recognition to the economic determinants of timber supply. They involve growth and yield equations or quantitative descriptions of the physical timber supply. Timber drain or removals are established allowable cuts or extrapolations of past harvest trends. Examples include the U.S. Forest Service "Gap"[2] (1946, 1958, 1965, and 1973), and work by Davis et al. (1957), Guthrie and Armstrong (1961), Nelson (1963), Gedney (1963) and Zivnuska et al. (1965).

## Economically Constrained Studies

Studies of economically constrained timber supply incorporate economic harvest criteria into biological growth-drain models. These studies take into account some of the

[2] So called because these studies calculated the difference or gap between long range projections of timber requirements and timber supplies in the United States.

economic determinants of supply and demand equilibria. Some studies also address the time jointness of timber production exemplified by Duerr's (1960) description of timber supply responses: stock, short-run, and long-run. Mivelle-Deschenes (1975) and Hassler (1978) incorporated Duerr's theories, but assumed fixed future price levels. Leuschner (1972 and 1972a) combined econometric supply and demand equations with a growth-drain model to determine annual market equilibria for aspen in Wisconsin.

## Econometric Studies

Econometric studies use statistical regression techniques to estimate timber supply. These studies typically rely upon historical data of behavioral factors which influence the supply response. Few econometric studies deal exclusively with the stumpage or log markets. Works by McKillop (1967), Robinson (1973 and 1974), and Mills and Manthy (1974) involved multiple market level models and give superficial treatment to lower markets. These models are useful to identify important supply and demand determinants.

## Process Analysis Studies

Process analysis analyzes production capabilities using an optimization or simulation description of the relationships between inputs and outputs (Manne and Markowitz 1966). Process analysis involves a description of the physical input constraints, and the production possibilities given these constraints. The prices of inputs and outputs can

be incorporated to determine production levels which maximize profits, minimize costs, represent market equilibria, or demonstrate economic theories of firms or industries.

A process analysis approach was chosen to model timber supply because (Anderson 1970, Adams and Griffin 1972, Adams 1973, and Hyde 1980) it:

1. provides thorough descriptions of the production process;
2. is rich in information about process interrelationships, capacity constraints, and technological developments;
3. permits consideration of changes in institutional conditions;
4. focuses on technical relationships, allowing generation of observations outside the range of historic variations.

Process analysis has been widely applied to study regional timber supply. These studies emphasized the economically available supply of timber. This supply refers to the economic reality that, at a given log price, only certain timber stands will be economical to harvest (see Morgan 1965; Stone 1968; Paille et al. 1972; and Haley and Cooney 1982).

Economic harvest feasibility requires that delivered log prices cover stumpage or reservation price, recovery or conversion costs, and profit margins (Duerr 1960 and Gregory 1972). Logging contractors will not harvest and haul logs if logging and stumpage costs and an acceptable profit margin are not covered. Forest landowners place value on the stumpage they own. This value, combined with the logger's differential between log prices and production costs, will determine stumpage price.

## Homogeneous Supply Response Cells

Timber supply process analysis centers on the harvest activity. Regionally, it is difficult to keep track of the growth, management, and harvest of individual stands. Though not unique to process analysis, homogeneous supply response cells facilitate regional supply analysis.

Marty (1969) and Mills (1976) suggested aggregating stands by similar physical, biologic, and economic characteristics. These aggregations are called homogeneous supply response cells, hereafter response cells. Response cells represent blocks of forest land that could be similarly managed and manipulated. A supply schedule can be constructed by identifying the minimum log price at which each cell would be economical to harvest.

The following section highlights timber process analysis supply studies. Ultimately this study uses process analysis to make projections of the economic stock supply of primary wood products in southwest Virginia.

## Timber Supply Studies

Vaux (1954 and 1973) is credited with the earliest process analysis type of timber supply analysis. In the 1973 study, a long-run timber supply curve was derived. Vaux identified 20 response cells based on forest type and site class information from forest survey data. Average per acre costs for given management practices were determined for each type-site cell, and the cells were arranged in ascending order of costs. Total po-

tential annual yields were estimated for each cell. A long-run timber supply schedule was created by pairing the long-run average costs with the cumulative yields from all cells with lower costs. Vaux was primarily interested in the long-run economic supply of timber, assuming fixed management practices, maximum forest growth potential, and different long-run demand projections.

Several studies adopted and refined the Vaux approach. GASPLY was a computer program developed to estimate long-run timber supply in Georgia and the southeast (Montgomery et al. 1975 and 1976; and Robinson et al. 1978 and 1981). The model involved response cells classified by geographic region, forest type, ownership, site class, and physiographic characteristics. Timber supply was assumed to be a function of the amount and productive quality of land available for growing timber, the management strategies used, and the per acre yields and management costs.

Long-run supply in GASPLY was estimated by first choosing the management strategy which maximized net present worth (NPW) for a given stumpage price. All response cells with NPW greater than or equal to zero contributed to annual harvest. The supply curve was assembled by considering the volume yields from profitable response cells and the per unit volume management costs associated with these cells. Later versions of GASPLY incorporated adjustments for land use changes, management practice restrictions, and multiple timber products.

Hyde (1979 and 1980) modelled long-run timber supply in the Douglas-fir region using process analysis. Response cells were defined by site quality and ownership. Timber production was assumed to be a function of silvicultural intensity, rotation length, and stumpage price.

Hyde estimated the least costly way of producing different annual harvest volumes. The optimal silvicultural intensity and rotation age were determined, given biological quality, accessibility characteristics, and stumpage price. These optimal strategies implied an optimal annual harvest volume. The loci of stumpage prices and optimal harvest volumes represented the long-run supply schedule for individual response cells. Aggregate regional supply was the sum, over all response cells, of the optimal harvests at each price.

The studies by Vaux and Hyde, and the GASPLY models shared several features. They focused on the static, long-run timber supply, often based on some desirable ending forest condition. As a result they disregarded existing timber inventories in favor of potential, future yields. Vaux and Hyde also set stumpage prices exogenously, while later versions of GASPLY incorporated econometric estimates of timber demand. These studies did not explicitly consider the stock supply response of timber supply.

Berndt et al. (1979) developed a cost-output relationship for an area in British Columbia, using an econometric analysis of logging costs. They estimated logging costs as a function of volume per acre, percentage of volume defect, average haul distance to mill, and average slope. The equation was then applied to five slope classes (response cells) to obtain recovery costs per unit volume. An "incremental cost" curve was plotted by pairing recovery costs with cumulative volumes. This "incremental cost" curve was identified as "essentially a stock notion with no time dimension." This curve indicated the cost per unit volume which various quantities of fixed resource stock could be recovered, i.e., a stock supply curve.

Linear programming (LP) is commonly used to analyze timber supply at the forest, regional, and national levels. Timber harvest scheduling is an application of LP at the forest level. Computer programs such as Timber RAM (Navon 1971), MAX-MILLION (Ware and Clutter 1971), and FORPLAN (Johnson 1982) use LP to schedule harvesting of individual stands, given maximizing or minimizing objective functions, and a set of resource and production constraints.

Holley et al. (1975) and Haynes et al. (1978) used LP to model spatial equilibrium in the United States softwood economy. The first model used a transportation problem formulation of LP to minimize the costs of moving softwood stumpage from the woods to processing facilities to final consumers. The model incorporated time and product jointness concepts and recognized initial timber inventories. Prices were set exogenously. The second model incorporated regional product demand equations using separable programming and calculated equilibrium roundwood and secondary wood product allocations among regions by maximizing social welfare.

Greber and Wisdom (1985) developed a single period, joint timber supply model based on process analysis (also see Greber 1983). They defined production possibility frontiers with the constraint set and maximized net social welfare in the objective function using an LP format. The model defined stepped supply functions (Henry and Raunikar 1963) by estimating recovery costs for several hundred response cells. The model also incorporated perfectly elastic, perfectly inelastic, and downward sloping demand functions to determine multiple market equilibria.

Lyon and Sedjo (1983) developed a regional, long-run timber supply model using optimal control theory. The model can be conceptualized as an integration of a short-

term harvest scheduling approach and a long-run steady state supply approach; the latter approach is equivalent to that used by Vaux (1973) and Hyde (1980). The model projected the optimal time path of periodic harvests through a transition period (old growth depletion), to arrive at a period of steady, or stable harvest levels. Intertemporal links were a critical aspect of the model structure. Also, the generic formulation of the model allowed it to be applied to any region. Several factors, however, were not considered or were lacking in detail in Lyon and Sedjo. Timber volumes were aggregated for both the supply and demand equations. Management intensity was measured by the level of regeneration input only. And no consideration was given to the behavioral characteristics of different owner types.

## *Theoretical and Conceptual Considerations*

Process analysis model development must consider: 1) the nature of timber production, 2) the stock supply response, and 3) the basic assumptions of regional supply analysis. This section addresses the impact of these considerations on model development.

### Nature of Timber Production

The timber product is also the timber-growing machine. The decision to harvest or supply timber products is a decision of liquidating the timber capital. Recognition of this decision process is important in a supply analysis, since timber supply ultimately

relies upon which stands are harvested and when. Models projecting annual timber supply can account for the harvest decision by incorporating the stock supply response, as described below.

Timber growing maybe a joint production process where a single tree or an acre of forest land yields several different products. Two types of joint production may be distinguished. In one the products are produced in technically fixed proportions; for example, a particular sawmill may produce one ton of chips with every 1500 board feet of lumber. Product proportions may also be technically variable. Such products have the characteristic that, although some productive factor is jointly used, the proportion in which the products can be produced may vary. A given acre of forest can yield varying proportions of logs and bolts.

Product differences depend on physical attributes and different market values. Larger diameter trees are typically more valuable than smaller trees, because they can be converted to lumber or veneer. Tree quality, in terms of straightness, defect from scars or knots, and species, also affects market value.

Differences in product mix can be incorporated into a supply analysis by including market factors which influence the mix at the stand level. These factors include delivered prices, harvesting and hauling costs, and the physical stumpage characteristics. These factors influence which stands are profitable to harvest, and the proportions of each timber product produced. Product mix aggregated for all harvested stands determines total supplies. These supplies interact with total demands to determine product prices, which in turn, are determinants of product mix.

A third aspect of timber production is the diversity of timber ownership. The harvest decision of timber owners is related to how these owners perceive the benefits derived from timber production. The perception and evaluation of timber benefits in the public sector are apt to differ from those in the private sector. Interpretations also differ within these groups.

Even more diverse than timber ownership are the forests themselves. Such factors as species, site quality, logging conditions, and proximity to market influence the stand's supply function. Aggregated over a region, these heterogeneities greatly impact the manner in which timber supply can be modeled.

## Stock Supply Response

Economic timber supply is tied directly to the stock supply response. Three components of the stock supply response are: (Duerr 1960, Gregory 1972, and Greber 1983): 1) the cost of availability, 2) the opportunity cost of holding timber, and 3) product mix.

The cost of availability is the cost of log production, including felling and bucking, skidding, loading, and hauling costs. Only some stands will have harvest revenues greater than or equal to harvest costs. More stands become economically available when log prices increase, or log production costs decrease, disregarding stumpage costs.

Within the set of stands that are economically available for harvest, only certain stands will actually be harvested. Landowners with nonprofit objectives may not harvest. Financial objectives are reflected in the opportunity cost of holding timber for fu-

ture harvest. If this opportunity cost is greater than the excess of revenue added by postponement, over harvest costs, then there is apt to be no harvest. In other words, it would be more profitable to postpone harvest.

Finally, the stock supply response involves product mix determination. As implied above, product mix arises from the interrelationships between production costs, the quantities of each product yielded, and product demands and prices.

## Regional Supply Analysis

Two assumptions were made regarding regional timber supply. First, products were homogeneous within a product group, regardless of the supply source. Data availability precluded the distinction of products by quality differences. Attention to such detail in a regional model would entail considerable complexity. Second, timber suppliers acted as a perfectly competitive group. This assumption was reasonable, particularly for the study area where logging contractors were numerous and involved relatively small operations.

Given these assumptions, regional timber supply was estimated by summing horizontally the output from individual producers in the region. This result implied that all sources of supply respond similarly to a given set of timber product prices. This implication was contrary to previous statements concerning the diversity of landowner objectives and forest land production capabilities. This problem was alleviated by using response cells, as previous described. Each cell represents blocks of forest land which respond similarly to management practices and operate under similar economic con-

straints. The response cells expressed landowner and forest diversities, and their impact on timber supply.

# Chapter II

# MODEL DEVELOPMENT

## *Introduction*

A process analysis simulation model was developed, in a FORTRAN program, to estimate the stock supply of logs and bolts. Outputs for the 15-year simulation period included annual prices (in 1982 dollars) and quantities (in cunits)[3] of logs and bolts marketed. The model was used to analyze the impact on delivered prices and quantities of changes in regional mill capacity, product demands, and logging and transportation costs.

Hardwood log and bolt supplies are analyzed. Available inventory data were used to identify these resources in the forest. Logs are defined as trees straight and sound,

[3] One cunit equals 100 cubic feet. Conversion factors used were: 2.4 cunits per thousand board feet (MBF), Doyle log scale, and 0.8 cunits per cord of hardwood.

at least eight feet long, and 12 inches or more in diameter inside bark. Logs can be converted to lumber or veneer. Bolts are trees not meeting these standards or portions of trees not suitable for logs but still merchantable. Bolts can be used as mine props or chipped for use in paper or waferboard production.

A simulation approach was taken for several reasons. The approach allowed the analyst to play "what if" games by simply changing or adding lines of computer code. Fewer decision variables were necessary and multiple period analyses were less complex than optimization techniques, such as linear programming, required. Finally, theoretical considerations of timber supply analysis were easily incorporated and modified as research and actual conditions dictated.

## *Model Description*

The model developed in this chapter involves two market levels, one for logs and bolts, and one for stumpage (see Figure 2). For each market level, the model determines the quantities of products demanded and supplied at alternative prices. The two market levels are linked by market prices; prices in the log and bolt market affect demand in the stumpage market; and prices in the stumpage market affect the supply of logs and bolts. This section describes the model components, the relationship within and between components, and how market prices are derived.

The demands for logs and bolts (Box 1) are derived from the demand for manufactured products (e.g., lumber and paper). Log and bolt demand equations in the model

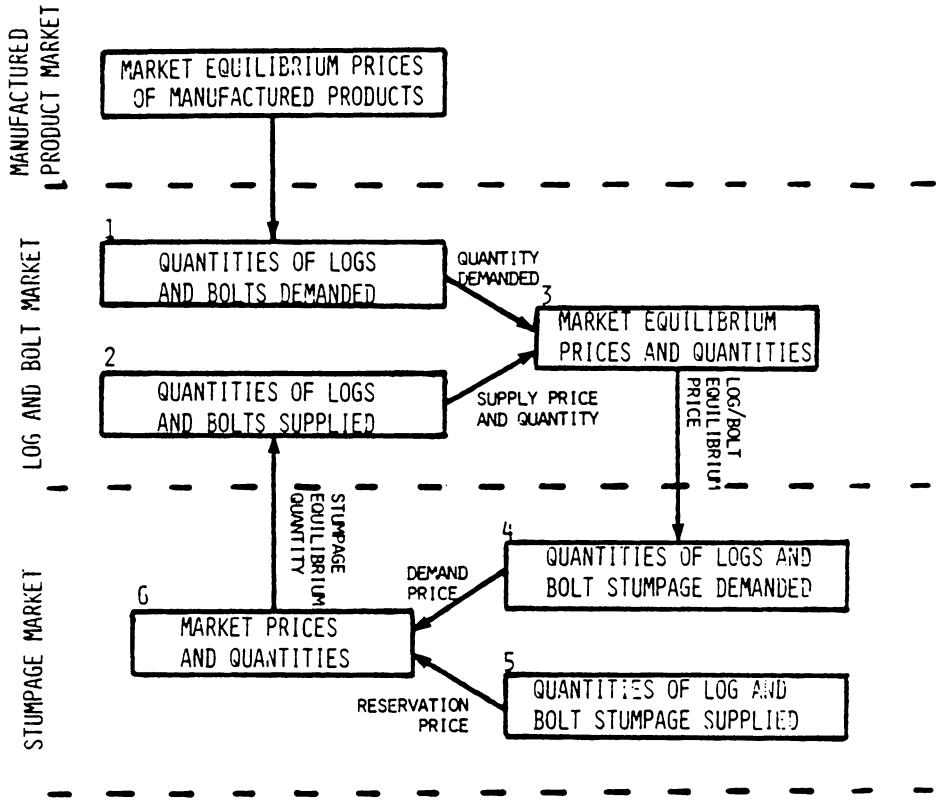


**Figure 2. A conceptual flowchart of the timber supply model.**

were statistically estimated. The quantity of logs demanded is a function of delivered log price, housing starts lagged one year, and sawmill input costs. The quantity of bolts demanded is a function of paper prices. Annual estimates of lagged housing starts, sawmill costs, and paper prices are required; these estimates are treated as exogenous variables.

The supply of logs and bolts (Box 2) depends on the available timber inventory and the costs of procuring, harvesting, and hauling this inventory. The model identifies blocks of forest land by biologic, physiographic, and landownership characteristics; these blocks are called response cells. Timber inventories are estimated with yield equations. Reservation price is the minimum price loggers must pay for stumpage, and equals the stumpage owner's reservation price; this concept is developed below. Harvesting costs are related to the physical terrain features identified by a response cell. Hauling costs depend on the distance logs and bolts are transported between the harvest site and the mill. Recovery cost equals the sum of procurement, harvesting, and hauling costs for a specific response cell.

The quantities of logs and bolts supplied in any time period is determined by comparing harvest revenues to recovery costs. The model calculates recovery cost and harvest revenue (market prices for each product weighted by their respective volumes per acre) for each response cell. If revenues are greater than or equal to costs in a particular response cell, then timber is harvested. The total quantities of logs and bolts supplied are determined by aggregating the volume of logs and bolts in the harvested response cells. Note that the quantities supplied will change with market prices because harvest revenue will change.

For each time period, the model determines the delivered log and bolt prices (Box 3) which equate the quantities of logs and bolts supplied to the quantities demanded. The solution technique is iterative. The quantities of logs and bolts demanded and supplied are determined for the given delivered prices. If the quantities supplied do not equal the quantities demanded, then delivered prices are adjusted, and the quantities are recalculated.

The steps involved in the solution technique are:

1. Set initial delivered log and bolt prices.
2. Estimate the quantities of logs and bolts demanded, given delivered prices and values for the exogenous variables.
3. Determine the quantities of logs and bolts supplied by comparing harvest revenues to recovery costs in all response cells.
4. If the quantity supplied of one product is greater than the quantity of that product demanded; decrease the product's delivered price; return to step 2.
5. If the quantity supplied of one product is less than the quantity of that product demanded; increase the product's delivered price; return to step 2.
6. If the quantities of logs and bolts supplied equal the quantities demanded, equilibrium delivered prices have been found.

In steps 4 and 5, prices are adjusted for the product with the largest relative difference between the quantities supplied and demanded.

The demand for log and bolt stumpage (Box 4) is derived from log and bolt delivered prices (calculated in step 6 above) and harvesting and hauling costs. The demand price

the logger will pay to buy stumpage from a particular stand is delivered price minus harvesting and hauling costs. If the difference is negative, then the logger will not bid for the stumpage. The model does not explicitly consider the demand for log and bolt stumpage; this consideration is discussed below.

The model assumes that all landowners behave as profit maximizers. The quantities of log and bolt stumpage supplied (Box 5) depends on the stumpage owner's reservation price. Reservation price is defined as the minimum price at which a stumpage owner would be willing to sell timber. Stumpage owners reserve timber from sale at prices below this minimum. Reservation price equals the opportunity cost of holding timber one more time period. It is a function of expected stumpage prices, future timber yields, and an alternative rate of return. Expected stumpage prices are assumed to be a function of past regional log and bolt stumpage prices. The model assumes that stumpage owners will sell timber at prices equal to or exceeding their reservation price.

Market equilibrium log and bolt stumpage prices cannot be determined by equating the quantities of stumpage demanded and supplied (Box 6) (Gregory 1972). Each timber sale has a unique stumpage price. If the demand price is greater than or equal to the stumpage owner's reservation price, then the timber is sold. Enough timber sales will be "bought" so that the quantities of log and bolt stumpage supplied and demanded (Box 6) will just equal the market equilibrium quantities of logs and bolts (Box 3). The model does not explicitly consider stumpage demand because equilibrium in the log and bolt market implies equilibrium in the stumpage market.

Regional stumpage prices are calculated from delivered log and bolt prices. Historical price data indicate that regional average stumpage prices can be calculated as a

percentage of delivered log and bolt prices. The model determines regional log and bolt stumpage prices after equilibrium delivered prices for logs and bolts have been found. It is assumed that regional stumpage prices are constane percentages of delivered prices.

The model components are linked by delivered log and bolt prices and by reservation prices. Reservation prices, calculated for each response cell (Box 5), are used to derive the supply of logs and bolts (arrow between Boxes 5 and 6). The delivered log and bolt prices, tested at each iteration of the solution technique, influence the quantities of logs and bolt stumpage demanded and supplied (arrows between Boxes 3 and 4). Price and quantity equilibria in the log and bolt market assure quantity equilibrium in the stumpage market.

The model iterates for each time period until equilibrium log and bolt delivered prices have been determined. The first iteration operates as follows:

1. Set the time period equal to one ($t = 1$).
2. Initialize delivered log and bolt prices at last period's prices.
3. For each response cell:
    a. Estimate the volume of logs and bolts.
    b. Estimate reservation prices given regional stumpage prices from the last two years.
    c. Add harvesting and hauling costs to reservation price.
    d. Calculate harvest revenue.
    e. If harvest revenue is greater than or equal to harvest cost, then accumulate log and bolt volumes. If not, then look at the next response cell.
4. Compare the quantities of logs and bolts supplied and demanded.

a. If the quantities are not equal, then adjust delivered log or bolt price; go to step 3.

b. If the quantities are equal, then equilibrium prices have been found.

   1) Given equilibrium log and bolt prices, calculate regional log and bolt stumpage prices

   2) Increment time ($t = t + 1$) and return to step 2 if simulation is to continue.

Model outputs include delivered log and bolt prices for each year and the quantities of logs and bolts marketed.

A flowchart of the model's algorithm is presented in Appendix I. Appendix V contains a listing of the FORTRAN program code. The following sections describe the development of, and the data for, the model elements and a technique for achieving market equilibrium.

## *Homogeneous Supply Response Cells*

Physiographic and timber inventory data were from the 1985 Virginia Forest Survey (U.S.D.A. 1985). Response cells were defined by the following variables:

1. ownership,
2. accessibility,
3. operability,
4. site class,

5. stand age, and
6. stocking density.

These variables were used to identify 365 response cells. Response cells recognized the diversities of landownership and forest conditions that affect timber supply. Response cells, therefore, formed the backbone of the model because they allowed differences in production costs and potentials to be identified.

The data set also included the number of acres and the cubic foot volume of two hardwood size classes in each response cell.[4] Five ownerships were recognized: public (federal, state, county, and municipal), forest industry, farmer, miscellaneous private corporation, and miscellaneous private individual. Forest Service accessibility and operability codes are defined in Table 1. Site class, stand age, and stocking density were used with volume data to derive yield equations.

## *Stumpage Market*

Stumpage supply in the stock supply period was related to the existing timber inventory and the harvest decision (Duerr 1960). The physical inventory sets an upper limit on the volume of stumpage available. The harvest decision determines the proportion and value of the inventory made available at any point in time.

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[4] The size classes are trees five to 11 inches, diameter at breast height (d.b.h.) and trees greater than 11 inches d.b.h.

Table 1. Definition of Forest Survey accessibility and operability codes.

| ACCESSIBILITY CODE | DEFINITION |
|---|---|
| 1 | Area is highly accessible using existing roads. |
| 2 | Roads could be easily built into the area. |
| 3 | Roads would be difficult to build into the area. |
| 4 | Roads would be difficult or impractical to build into the area due to slope, water, or other physical obstacles. |

| OPERABILITY CODE | DEFINITION |
|---|---|
| 1 | No problem. |
| 2* | Limited to seasonal use due to water conditions in wet weather. |
| 3 | Moderate slope (20-39%), irregular terrain, or other ground conditions limiting the type of equipment that could be operated within the stand. |
| 5 | Severe slopes (40-49%), broken terrain, or other adverse ground conditions drastically limiting equipment use. |
| 7 | Slopes of 50% or more. |

* Operability codes 1 and 2 are grouped together due to the small area in code 2 and assuming these areas are avoided during wet conditions.

Assuming profit maximizing behavior, the harvest decision is based on the landowner's opportunity cost of harvesting now versus waiting one time period. Opportunity cost is a function of future timber yields, stumpage price expectations, and an alternative rate of return (ARR). Timber is harvested when present period revenues equal or exceed the present value of expected future revenues. Landowners interested in optimizing returns from their forests are apt to offer more timber for sale if they anticipate a permanent stumpage price decrease. Landowners expecting stumpage price increases and higher harvest revenues withhold timber from sale. Timber buyers can bid lower prices and procure the same or greater quantities of stumpage, than when landowners are expecting price increases. If landowners withhold timber, stumpage bid prices may be forced upward to obtain the same quantities. The minimum price necessary to persuade the stumpage owner to sell a particular volume or area of timber is the minimum cost that loggers must pay to buy that stumpage. The following sections describe the equations used in this study to simulate the harvest decision.

Three models were used to determine the log and bolt stumpage prices which will persuade stumpage owners to sell timber. These models included Duerr's financial maturity model (1960), price expectations, and yield equations. Regional stumpage prices were linked to primary product prices by market margins.

## Financial Maturity Model

Duerr's model was used to capture stumpage supply response behavior. The model states that if current annual value growth percent is less than or equal to the stumpage owner's ARR, then timber should be harvested. Current annual value growth is the

percentage change in timber harvest revenue between time periods. In other words, current annual value growth is the change in harvest revenue between time periods divided by harvest revenue in time period t. The ARR represents the return on investment that could be earned by cutting and investing harvest revenues in time period t.

Duerr's decision rule can be restated; if current harvest revenues equal or exceed discounted future revenues, then timber should be harvested. Given this statement, a two product model was used in this study:[5]

$$SPL_i^t \times YL_i^t + SPB_i^t \times YB_i^t = \frac{(PE_L^{t+1} \times YL_i^{t+1} + PE_B^{t+1} \times YB_i^{t+1})}{(1 + ARR)} \qquad [2.1]$$

The left-hand side of expression 2.1 equals total harvest revenue in period t, and the right-hand side equals the present value of harvest revenue in period t+1. An equality sign is used because the stumpage owner's minimum log and bolt stumpage prices ($SPL_i^t$ and $SPB_i^t$) is determined.

Expression 2.1 is rearranged to solve for bolt stumpage price. The steps involved are:

1. Let $SPL_i^t$ = R × $SPB_i^t$, where R equals the ratio of the last observable regional log and bolt stumpage prices ($SPL^{t-1}/SPB^{t-1}$).
2. Substitute the equation for $SPL_i^t$ into the left-hand side of expression 2.1 and factor out $SPB_i^t$. The left-hand side is $SPB_i^t \times (YL_i^t \times R + YB_i^t)$.
3. Divide the right-hand side of expression 2.1 by ($YL_i^t$ × R + $YB_i^t$). The final equation for $SPB_i^t$ equals:

[5] Model variables are defined in Appendix I, Table 13.

$$SPB_i^t = \frac{PE_L^{t+1} \times YL_i^{t+1} + PE_B^{t+1} \times YB_i^{t+1}}{(1 + ARR) \times (\mathrm{R} \times YL_i^t + YB_i^t)} \qquad [2.2a]$$

Log stumpage price can be calculated by multiplying $SPB_i^t$ by R:

$$SPL_i^t = \mathrm{R} \times SPB_i^t \qquad [2.2b]$$

These log and bolt stumpage prices are the prices loggers must pay to procure stumpage from a specific response cell. Reservation price per cunit is determined by weighting each price by the proportion of logs and bolts in each response:

$$RP_i = SPL_i^t \times KL_i + SPB_i^t \times KB_i \qquad [2.3]$$

Reservation price is the lowest price the stumpage owner would be willing to sell, or the minimum price loggers pay to buy stumpage (Gregory 1972). Reservation price was added to the harvesting and hauling costs of each response cell to determine recovery cost. The resulting total recovery cost is the minimum cost a logger must pay to deliver logs and bolts from a specific response cell to the mill.

Several variables were required to calculate log and bolt stumpage prices. They include expected stumpage prices, alternative rate of return, and timber yields in the current and next time periods. The following sections describe how these variables were derived.

## Expected Stumpage Prices

Conversations with procurement foresters in southwest Virginia suggest that landowners form price expectations through knowledge of past timber sales. Landowners are apt to know the number of acres cut, the general stand conditions, and the total sales revenue on neighboring timber

sales. Given this information landowners may expect a certain stumpage price for their timber. The harvest decision may be expressed as a function of price expectations based on past prices, since past prices or sales may be the best or only information known to landowners. A simple price expectations formulation is desirable to reflect the naive manner in which landowners are apt to set expected prices.

The price expectation model formulated for this study was:

$$PE^t = SP^{t-1} + \beta(SP^{t-1} - SP^{t-2}) \qquad [2.4]$$

The model was adapted from models developed by Goodwin (1948), Greber (1983), and Nerlove (1958 and 1979). These models are classified as extrapolative expectation models, and reflect the belief that expectations of future prices are a function of past prices.

An auxiliary equation was needed because price expectations are not directly observable. Greber (1983) and Nerlove (1958) used stock adjustment equations, hypothesizing that the acreage of trees or annual crops planted was a function of price expectations. Planting as a regeneration practice is uncommon in southwest Virginia. The auxiliary equation chosen for this study assumed that the volume of stumpage harvested annually was a function of stumpage price expectations. The auxiliary equation proposed for this study was:

$$HV^t = b_0 + b_1 PE^t + b_2 Z^t + u^t \qquad [2.5]$$

Expression 2.4 is substituted into 2.5, expressing harvest volume in time period t as a function of past observable prices.

$$\begin{aligned} HV^t &= b_0 + b_1(SP^{t-1} + \beta[SP^{t-1} - SP^{t-2})] + b_2 Z^t + u^t \\ &= b_0 + b_1 SP^{t-1} + b_1\beta(SP^{t-1} - SP^{t-2}) + b_2 Z^t + u^t \end{aligned} \qquad [2.5a]$$

$\beta$ was determined by dividing the regression coefficient $b_1\beta$ by $b_1$.

The initial procedure combined the total harvest volumes for logs and bolts and used a weighted average stumpage price; weights equaled the proportion of product to total volume harvested. Regression analysis results indicated a poor fit and an insignificant model with combined data. These results suggested that price expectation equations should be developed for each product. Examination of the two stumpage markets substantiated this possibility. Stumpage prices for logs tended to have relatively wider fluctuations than bolt prices. The two markets may have different structures; the log market is apt to be competitive, while the bolt market is oligopsonistic.

Two price expectation and auxiliary equations were formulated.[6] Regression analysis on the log auxiliary equation yielded acceptable results (see Table 2). The model was overall significant, multiple collinearity was minimal, but the test for first degree autocorrelation was inconclusive. The estimate of $\beta$ equaled .61; this value coincided with the value range (-1 to 1) cited by Goodwin (1948). Regression analysis on the bolt auxiliary equation also yielded acceptable results (see Table 2). An F-test revealed overall model significance, multiple collinearity was minimal, and the null hypothesis of no positive or negative first degree autocorrelation could not be rejected. The estimate of $\beta$ for the bolt price expectations equaled .34. These estimates of $\beta$ were assumed to hold for all landowner types throughout the study area, and for the entire simulation period.

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[6] Supplementary variables ($Z^t$), were insignificant in initial regression analyses. Therefore, none of these variables appear in the final auxiliary equations.

Table 2. Auxiliary and price expectation equations for logs and bolts.*

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Logs:

Auxiliary Equation:

$$HV^t = -12991.69 + 2388.1 \times SPL^{t-1} + 1459.3 \times (SPL^{t-1} - SPL^{t-2})$$

(15119.67) (517.09) (658.77)

F-value = 10.716 Adj. $R^2$ = .5992 DW = .845 n = 14

Price Expectation Equation:

$$PE_L^t = SPL^{t-1} + .61 \times (SPL^{t-1} - SPL^{t-2})$$

Where $HV^t$ = total volume of logs harvested in time period t, in cunits.

$SPL$ = observed regional average log stumpage price per cunit in time periods t-1 and t-2.

$PE_L^t$ = average expected log stumpage price per cunit for time period t, as formed in time period t-1.

Bolts:

Auxiliary Equation:

$$HV^t = 111130 - 13748.57 \times SPB^{t-1} - 4718.39 \times (SPB^{t-1} - SPB^{t-2})$$

(7762) (1415.58) (1933.83)

F-value = 47.458 Adj. $R^2$ = .8773 DW = 2.015 n = 14

Price Expectation Equation:

$$PE_B^t = SPB^{t-1} + .34 \times (SPB^{t-1} - SPB^{t-2})$$

$R^2 = ?$

Where $HV^t$ = total volume of bolts harvested in time period t, in cunits.

SPB = observed regional average bolt stumpage price per cunit in time periods t-1 and t-2.

$PE_B^t$ = average expected bolt stumpage price per cunit for time period t, as formed in time period t-1.

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* Standard errors shown below each coefficient estimate. Price expectation data is presented in Appendix II.

## Alternative Rate of Return

Choice of an alternative rate of return was a subjective matter. Hassler (1978) found that real discount rates of 3 percent for corporate and public lands and 4 percent for non-industrial private forest lands were acceptable for eastern Virginia. Greber (1983) used a real discount rate of 4.75 percent, representing a weighted average for the three landowner types. Other studies suggested rates of 5 and 6 percent. A real discount rate of 4 percent was used in this study for all landowners. Results were not overly sensitive to changes in the discount rate because discounting occurred for only one year.

## Timber Yields

A literature search of hardwood growth and yield models did not uncover models completely compatible with the Forest Survey data. McClure and Knight (1984) provided a series of yield tables, but these tables were not used for two reasons: inadequate coverage of forest types and site classes in the study area; and difficulty in adapting the tables to the computer algorithm. Therefore, yield equations were developed from the Forest Survey data. Volume per acre was estimated as a function of stand age, site index, and growing stock stocking percent.

Cautions accompany the use of these data. First, the reliability of reported timber inventories decreases as state level statistics are disaggregated into smaller units. Standard errors of volume estimates for each county and the study area are larger than those for volume estimates over the entire state. Second, even-aged stands are assumed. Historical forest treatments and occurrences likely invalidate the even-age assumption.

These historical facts, however, cannot be properly accounted for without data on age class distribution within each response cell. Third, age classes between 0 and 40 years are poorly represented, relative to age classes over 40; sample mean age is higher than 40 years. This condition affects prediction ability when a regression equation, estimated using all observations, is applied to younger age classes. Confidence and prediction intervals drawn around the regression line was wider near younger age classes, since these classes are further from the sample mean age.

Merchantable cubic foot volume per acre for bolts and logs were included in the survey data. Merchantability standards were defined by that portion of all live trees five inches, diameter at breast height (d.b.h.) and larger, between a one foot stump and a minimum four inch top diameter outside bark. These standards coincide with locally observed standards.

The Forest Service used five site classes to measure stand productivity. Response cell site classes were converted to site indices (base age 50) using an approach by Giaugue (1977) and a Forest Service inventory guide (U.S.D.A. 1975).

Stocking density is defined as the ratio of trees per acre at some age to trees per acre of a normally stocked stand of the same age. Density is assumed to remain constant over the stock inventory period; this assumption is based on several premises. The shade tolerant nature of many hardwood species is apt to keep stocking density relatively stable over the 15 year simulation period. The high possibility of uneven-aged stands also strengthened the constant density assumption, because ingrowth is apt to equal mortality.

Two yield equations were estimated, one for total volume per acre, another for log volume (see Table 3). The functional form for total volume reflects the biological nature of stand volume growth (see Clutter et al. 1983). The log volume equation represents the best fit.

Bolt volume per acre equaled the difference between total and log volumes when log volume was less than the total. In older stands, the log volume equation yielded estimates larger than total volume. In these cases, log volume was set equal to total volume and bolt volume to zero.[7] More observations were used to estimate the total volume equation than log volume. The difference in number of observations gave the total volume equation greater statistical reliability; the total volume equation provided a better measure of log volume.

## Public Stumpage Supply Response

Public stumpage supply in the stock supply period was influenced by the annual allowable cut and the appraised stumpage value.[8] Annual allowable cut levels in the Jefferson National Forest Clinch Ranger District, for 1985 to 1995, were published in the final draft of the Forest Management Plan (U.S.D.A. 1985a). These levels were used in the supply model to limit volume availability from public lands in the study area (see Appendix III).

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[7] In reality some bolt volume may exist, but this possibility could not be accounted for in the model.

[8] All public land in the study was assumed to be National Forest; 15% of this land was not controlled by the Forest Service.

Table 3. Yield equations for estimating total, log, and bolt volumes per acre.*

Total volume per acre in cunits:

$$\ln(Y_i) = 2.435 - 62.942/A + .631 \times SI/A + 1.194 \times \ln(GSS)$$

(.553) (8.276) (.149) (.125)

F-value = 215.52 Adj. $R^2$ = .6471

Log volume per acre in cunits:

$$\ln(YL_i) = -4.447 + .053 \times A + .051 \times SI + 1.014 \times \ln(GSS)$$

(.811) (.003) (.007) (.183)

F-value = 130.467 Adj. $R^2$ = .5253

Bolt volume per acre in cunits:

$$YB_i = Y_i - YL_i$$

Where

A = stand age

SI = site index (base age = 50 years)

GSS = growing stock stocking in percent

$Y_i$ = total volume in response cell i

$YL_i$ = log volume in response cell i

$YB_i$ = bolt volume in response cell i

ln = natural log

* Standard errors shown below each coefficient estimate. Data for the regression analyses are available from the author.

Although the Forest Service uses a timber appraisal procedure to determine public stumpage values, this procedure was not incorporated in the model. A reservation price, as described above, was determined for response cells identified as public. The appraisal procedure was omitted for several reasons. First, accurate appraisals were not possible because secondary product prices and manufacturing costs, important to the procedure, were not model inputs. Second, appraised stumpage values could fall below an acceptable minimum value, or below zero, in response cells with high harvesting and hauling costs. These erroneous values would distort total recovery costs for the response cell and bias supply estimates.

## Regional Stumpage Prices

In perfectly competitive markets, log and bolt stumpage prices for a response cell will equal regional delivered prices minus harvesting and hauling costs. Forming "normal" stumpage demand and supply curves is a problem because individual stands will have unique log and bolt stumpage price. The price a logger is willing to pay for stumpage from a particular stand depends on delivered prices and the harvesting and hauling costs for that stand. The stumpage owner values timber based on expected future prices and volumes and his alternative rate of return. This difference effectively prevents the usual variety of stumpage supply and demand curves from being constructed (Gregory 1972), and determination of stumpage prices via supply and demand intersection. Therefore, no one log or bolt stumpage price prevails within a region.

Market equilibria in the primary product markets identify regional log and bolt prices, and which response cells are feasible to harvest at these prices. Prices paid for

stumpage in each of the harvested cells are greater than or equal to reservation prices, depending on the difference between delivered prices and logging costs. The stumpage owner accrues an economic rent if stumpage prices paid exceed reservation prices. It is assumed that producers pay stumpage owners the full economic rent arising from timber harvesting.

Regional log and bolt stumpage prices in a given time period were calculated as a function of regional primary product prices. The average ratio of stumpage to delivered prices over the past 15 years was used; this procedure assumed that marketing margins between market levels were a constant percentage. Further it was assumed that the ratio for logs (.40) and bolts (.11) would remain constant over the simulation period.[9] The assumption of constant percentage market margins was consistent with other forest products derived demand studies (Haynes 1977).

[9] These ratios were determined from stumpage and delivered prices from the Virginia Forest Products Tax data (Source: E. Frame, V.D.F.).

## *Primary Product Market*

The economic stock supply of primary wood products is a schedule of the costs of producing alternative quantities of these products. The sum of procurement, harvesting, and hauling costs equals the recovery cost of delivering primary products from a response cell. Recovery costs for logs and bolts from response cell i are:

$$RL_i = SPL_i^t + HL_i + TL_i \qquad [2.6]$$

$$\mathrm{RB}_i = SPB_i^t + HB_i + TB_i \qquad [2.7]$$

Ultimately the quantity of each primary product supplied is a function of recovery costs, the volume of each product available, and the market clearing price of the products. Response cell stumpage prices are derived in the previous section. Harvesting and hauling cost estimations and primary product demand equations are presented in this section.

It is assumed that loggers are the major purchasers of stumpage. In reality, however, the better quality timber and larger tracts may be purchased directly by consuming mills. These mills then contract loggers to cut and haul the stumpage. Mills are apt to pay higher stumpage and roundwood prices under the contract system since they retain greater control of supply. The model may underestimate delivered prices because it does not consider the contracting possibility. In southwest Virginia, however, the majority of timber sales are bought by loggers who operate independent of mills. Estimated delivered prices should not greatly affected.

## Harvesting and Hauling Costs

Harvest and hauling costs are the costs of availability and are important in determining the stock supply response. Estimating the economically available roundwood supply hinges on accurate descriptions of harvesting and hauling costs in each response cell.

Harvest cost estimates were based on work by Gardner (1982), Greber (1983), LeBoux (1985), and Withycombe (1982), and verified by actual logging contract costs (see Table 4). The logging operation was divided into four components: road building; felling and bucking; skidding; and loading. Costs per cunit were estimated for logs and bolts under the following assumptions:

1. The average logging chance occurred on 35% slopes, the average slope for the study area identified by operability code 3 (see Table 1).
2. The typical logging operation involved a five man crew, a knuckleboom loader, rubber-tired skidder, bulldozer, and a double axle, tandem trailer truck.
3. All hardwoods were hand felled and ground skidded, whole tree length to the landing.
4. One mile of road accessed 200 acres. Per acre roading costs were converted to costs per cunit by dividing by volume per acre. Roading costs were accounted for when a response cell has accessibility code 2, 3, or 4 (see Table 5).
5. Profit margin was 7% of all costs.
6. Harvesting and hauling costs were constant throughout the simulation period.

Table 4. Summary of harvesting and hauling costs for an average site in southwest Virginia.

| ACTIVITY | PRODUCT | |
|---|---|---|
| | LOGS ($/CUNIT) | BOLTS ($/CUNIT) |
| Felling and Bucking | 9.25 | 13.88 |
| Skidding | 6.57 | 9.56 |
| Loading | 3.47 | 5.21 |
| Hauling* | 17.19 | variable |

* Hauling costs for logs was based on an average 75 mile, one-way haul, $1.65/mile, and 7.2 cunits (3 MBF) per load. Hauling costs for bolts are shown in Table 6.

Table 5. Road building costs in relation to response cell accessibility code.

| ACCESSIBILITY CODE | COST PER MILE ($) | COST PER ACRE ($)* |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 3,000 | 15 |
| 3 | 6,000 | 30 |
| 4 | 15,000 | 75 |

* Assuming 200 acres are accessible per mile of road.

Felling and bucking, and skidding costs were adjusted to reflect differences in logging difficulties. Adjustments were made by weighting the costs in Table 4 by the following factors:

| Operability Code | Weight |
|---|---|
| 1 and 2 | .90 |
| 3 | 1.00 |
| 5 | 1.05 |
| 7 | 1.15 |

Weights were determined by examining the median and range of actual logging contract costs and assuming costs increase proportionally with slope steepness. Weights for operability codes 5 and 7 are low. More accurate felling and skidding costs would be achieved by setting the weight for code 5 at 15 to 20 percent. Skidding costs for code 7 should be based on cable logging systems.[10]

Estimates of the actual hauling distances for each response cell were impossible to obtain because the cells were not geographically identified. An average hauling distance of 75 miles, one-way, was used for logs because facilities using logs were distributed evenly throughout the study area.[11] Delivery points for bolts were few and concentrated in the southern portion of the study area; a single average hauling distance for bolts was inappropriate.

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[10] Sensitivity analysis with higher weights on codes 5 and 7 did not change model results. Results were most sensitive to the weight for code 3.

[11] This value was based on discussion with area procurement foresters and loggers. A shorter distance may be appropriate (see Shaffer 1984). A shorter hauling distance would reduce log delivered prices.

Each response cell was subdivided to approximate five hauling distances for bolts; this procedure increased the number of response cells five-fold, to 1825. Mileages were estimated by measuring and adjusting the straight line distance from each county's centroid to the nearest principal bolt delivery point; these points were pulpwood concentration yards in Norton and Jonesville, Virginia; the Louisiana-Pacific waferboard plant in Dungannon, Virginia; and Mead pulp and paper mill in Kingsport, Tennessee. Distance adjustments based on relative road curvature and terrain features within the county. The ratio of commercial forest land area in a county to the regional total commercial forest land area was used to approximate the percentage of a response cell's area within a particular hauling distance (see Table 6).

Harvesting and hauling costs were assumed constant in each response cell and time period. Constant logging costs implied that derived demand for logging factor inputs interacts with a perfectly elastic or unlimited supply of logging firms in the short-run. These firms enter and exit the market in response to pecuniary signals.

Production capacity of all potential logging firms, however, is apt to be restricted in the short-run. Logging costs per unit volume increase with regional roundwood output because higher output levels involve less efficient logging operations. Submarginal logging firms become profitable with increasing primary product prices. At some regional output level, however, the potential number of logging firms is exhausted and no additional volume can be produced at any price; primary product supplies become perfectly inelastic. Prices would be determined solely by demand shifts, at maximum regional logging capacity.

Table 6. Hauling distances, percentage of commercial forest land area within the hauling distance, and estimated hauling costs for bolts.

| DISTANCE[1] (MILE) | PERCENT OF COMMERCIAL FOREST LAND WITHIN THE HAULING DISTANCE | HAULING COSTS[2] ($/CUNIT) |
|---|---|---|
| 20 | 41 | 4.58 |
| 26 | 8 | 5.96 |
| 30 | 12 | 6.87 |
| 42 | 16 | 9.62 |
| 59 | 22 | 13.52 |

1. One-way hauling distance

2. Costs based on $1.65/mile, 7.2 cunits per load.

The model did not account for regional logging capacity. Log and bolt volumes were restricted only by regional inventories in a given time period; prices increased with volume because of rising response cell recovery costs. Interpretations of model results were made in light of these omissions, particularly when simulating severe system shocks. If regional primary product demands shift between time periods, market equilibrium quantities may exceed logging capacity with no effect on market prices. Resultant prices may appear low at logging capacity, compared to prices arising from an inelastic supply at that capacity.

Harvesting and hauling costs were also held constant over the simulation period. This condition assumed that technological changes improved production efficiency and reduced costs per unit output. The rate of cost reduction was implicitly assumed to keep pace with real price increases of factor inputs. Therefore, total recovery costs for all levels of output remained constant from period to period, implying constant average and marginal recovery costs.

## Primary Product Demands

Demand equations for logs and bolts were estimated using ordinary least squares (OLS) and two-stage least squares (TSLS). A literature review indicated that few studies have explicitly considered primary product demand. Empirical work by Adams (1973) and Leuschner (1972) dealt primarily with pulpwood demand, while Adams and Blackwell (1973) and Daniels and Hyde (1986) considered sawlogs. Several studies considered both primary products (see Greber 1983; Hotvedt 1975; Hudspeth 1979;

McKillop 1967; and Robinson 1974). These studies were used to specify initial demand equations.

Criteria were established for selecting models and retaining variables. Coefficient estimates were retained if they had theoretically correct signs, though they could be statistically insignificant. Models were acceptable if they were statistically significant according to an F-test and $R^2$ values were above .50. These criteria are justified by the desire to capture market influences and behavior in southwest Virginia and to have a theoretically precise model formulation, rather than develop a strictly predictive model.

**Log Demand** - Log demand was specified to reflect derived demand theory. Surveys of primary forest industries in southwest Virginia indicate that rough hardwood lumber is the major product, accounting for approximately 80 percent of total mill output (F. Lamb; Personal Communication). Pallets and hardwood flooring are approximately 19 percent of output, and miscellaneous hardwood products account for the remainder of total output.

Initial estimates of log demand included pallet and lumber price indices, and an index of furniture and fixture production. These variables were dropped because they were consistently estimated with incorrect signs. Lagged housing starts was included because it reflects overall economic conditions and aggregate demand for hardwood fixtures, flooring, and furniture; this variable was expected to have a positive coefficient. Cost of production inputs, fuel and wages in sawmills, were also included, and were expected to have a negative effect on log demand.

The final equation is shown in Table 7. Diagnostics from the OLS analysis indicated that multicollinearity was not a problem in the final equation, but the test for positive or negative autocorrelation was inconclusive at the .01 level of significance. The final equation was reestimated using TSLS to account for simultaneous equations bias; OLS and TSLS produced similar coefficient estimates, indicating equation stability.

**Bolt Demand** - Bolt demand was assumed to be inelastic in the short-term because of high capital investments relative to raw material costs for mills using bolts, and because of the high fixed costs of operating such mills. Two studies, Greber (1983) and Hudspeth (1979), found pulpwood demand to be price insensitive in eastern Virginia and for the state, respectively. This condition was expected to hold for southwest Virginia.

Bolt demand was also specified to reflect derived demand theory. Although the study area has two major bolt users, Mead (paper) and Louisiana-Pacific (waferboard), available data excluded influences of the latter user; L-P did not begin procurement until late 1985. Therefore, bolt demand was specified only as a function of paper price (IPP) and industrial production indices (IIP).

Preliminary regression analyses used OLS. When both variables were regressed on bolt volume, an incorrect sign resulted on $IIP^t$; $IIP^t$ was subsequently dropped from the equation. Paper price index alone had the expected positive effect and yielded a good fit (see Table 8). The null hypothesis of no positive or negative serial autocorrelation was rejected. Therefore, the SAS procedure AUTOREG was used to reestimate bolt demand and correct for autocorrelation.

Table 7. Regional log demand equation.*

Ordinary Least Squares Results:

$$QL_D^t = 53025.59 - 84.91 \times PL^t + 2.03 \times HS^{t-1} - 26791.40 \times WTCI^t$$

(18934.12) (91.26) (2.70) (6046.98)

F-value = 15.274 Adj. $R^2$ = .7671 DW = 1.361 n = 14

Two-stage Least Squares Results:

$$QL_D^t = 57491.17 - 107.86 \times PL^t + 2.15 \times HS^{t-1} - 27884.98 \times WTCI^t$$

(19785.05) (95.87) (2.71) (6215.88)

F-value = 15.313 Adj. $R^2$ = .7676 n = 14

$$QL_S^t = -758297.42 + 1327.34 \times PL^t + 573102.11 \times PCI^t$$

(238126.83) (352.81) (185066.24)

F-value = 9.76 Adj $R^2$ = .5740 n = 14

Where $QL_D^t$ = log volume, in MBF, demanded from the region in time period t.

$QL_S^t$ = log volume, in MBF, supplied in the region in time period t.

$PCI^t$ = relative producer cost index; a weighted average of fuel (15%), hourly wages of non-agricultural employees (25%), and agricultural machinery (60%) producer price indices, divided by the all commodity producer price index.

$PL^t$ = delivered log price per MBF in time period t.

$HS^{t-1}$ = total number of public and private housing starts, in thousands, lagged one time period.

$WTCI^t$ = weighted cost index, derived from fuel and related products price index (60%) and wages paid in sawmills (40%).

* Standard errors shown below each coefficient estimate. Data for log demand estimation are shown in Appendix II.

Table 8. Regional bolt demand equation.[1]

Ordinary Least Squares Results:

$$QB_D^t = -20698.84 + 75787.58 \times IPP^t$$
$$(6859.06) \quad (8708.56)$$

F-value = 75.74 Adj. $R^2$ = .8422 DW = .618 n = 15

Autoregression Procedure Results:[2]

$$QB_D^t = -15313.39 + 69657.98 \times IPP^t$$
$$(11300.71) \quad (14076.81)$$

Where $QB_D^t$ = bolt volume, in cords, demanded from the region in time period t.

$IPP^t$ = paper price index, except newsprint, in time period t.

1. Standard errors shown below each coefficient estimate. Data for bolt demand estimation is shown in Appendix II.

2. Estimates determined using Yule-Walker technique.

# *Developing a Solution Technique*

The solution technique estimates the equilibrium level of commodities within the study area for given demand and supply schedules. For regional roundwood supply analysis, supply schedules are defined by the primary product recovery costs of individual response cells, and demand schedules by regional log and bolt demand equations. The conceptual framework for reaching a market equilibrium solution with the technique assumes that microeconomic models can be applied to individual response cells.

## Conceptual Framework

Several assumptions underlie the solution technique. Total volume in a response cell is produced as either logs and bolts in fixed proportions, or as all bolts. Total volume per acre in a response cell is fixed in a given time period. Each response cell is considered a single production facility, and the harvest decision involves an all or nothing output level, except for the response cell representing the marginal logging chance. Finally, the producer or logger working a particular response cell, and the stumpage owner represented by the cell, behave as perfectly competitive, profit maximizers.

Each response cell has two product harvest mix choices: harvest both logs and bolts in fixed proportions, or harvest all volume as bolts. The option chosen depends on which one generates the largest net harvest revenue. Recovery costs and harvest revenue equations are expressed as functions of $KL_i$, $KB_i$, and $Y_i$, given the delivered prices and recovery costs for each product.

A "logs only" harvest option was not considered. Incorporating this option into the model is conceptually easy, but difficult to program. An all or nothing harvest in each response cell simplifies the data accounting procedures. If a response cell is harvested and all volume is removed, then it is excluded from future harvest considerations. If a "logs only" option is included, then only a portion of the volume in a response cell is harvested. The cell's identity and residual volume must be tracked differently than all other response cells. This tracking complicates programming logic.

The recovery cost ($RC2_i$) equation for harvesting both products from response cell i is:

$$RC2_i = (KL_i \times RL_i + KB_i \times \mathrm{RB}_i) \times Y_i \qquad [2.8a]$$

Cost allocation is based on a weighted average of the recovery cost for the two products; the weights equal $KL_i$ and $KB_i$. The marginal cost ($MC_i$) of harvesting an additional cunit of volume from response cell i is constant, and equal to ($KL_i \times RL_i + KB_i \times \mathrm{RB}_i$). Constant input prices or recovery costs within a response cell are consistent with the assumption that perfectly competitive producers are price takers.

Recovery costs for harvesting all bolts is:

$$RC1_i = [RP_i + (KL_i \times HL_i) + (KB_i \times HB_i) + TB_i] \times Y_i \qquad [2.8b]$$

Cost allocations differ from expression 2.8a only in the way transportation costs are determined. Producers pay log stumpage price and harvesting costs for that portion of total volume considered log quality, but since all volume is produced and delivered as bolts, only bolt hauling cost is applicable. $MC_i$ equals $[RP_i + (KL_i \times HL_i) + (KB_i \times HB_i) + TB_i]$.

Harvest revenue ($HR1_i$ and $HR2_i$) from response cell i, for harvesting one or two products, can be expressed in a similar manner:

$$HR2_i = (KL_i \times PL^t + KB_i \times PB^t) \times Y_i \qquad [2.9a]$$

$$HR1_i = PB^t \times Y_i \qquad [2.9b]$$

Marginal revenue for two products equals the weighted average of the two product prices, and for a single product it is simply bolt delivered price. Delivered prices ($PL^t$ and $PB^t$) within a response cell and for a single time period are fixed. Over the region, however, delivered product prices are related to the aggregate product volumes produced.

A response cell is harvested if net revenue is greater than or equal to zero, or $MR_i \geq MC_i$; this rule is consistent with profit maximizing behavior. One or both products are harvested depending on which strategy yields the highest net revenue. Total products supplied for given regional delivered prices are determined by accumulating the product volumes for all cells harvested according to the $MR_i \geq MC_i$ rule. Market equilibrium solutions are obtainable given the response cell product volumes and recovery costs, and regional product demands derived in previous sections.

A final solution exists when the following restrictions hold:

1. The total volume available for harvesting in a response cell, $Y_i$, is greater than or equal to zero, for all i = 1,...,1825.
2. If a response cell is harvested, $Q_i \neq 0$, then $MR_i - MC_i \geq 0$. Otherwise, $Q_i = 0$ and $MR_i - MC_i < 0$.

3. For response cells where $MR_i - MC_i > 0$, all available volume is harvested, while cells with $MR_i - MC_i = 0$ may have only a portion of available volume harvested.
4. The aggregate volume supplied, the sum of $Q_i$ for all cells where $MR_i - MC_i \geq 0$ ($QB_S^t$ and $QL_S^t$), cannot differ from regional demands ($QB_D^t$ and $QL_D^t$) by some tolerance.

## The Solution Technique

The solution technique iteratively searches for the delivered product prices which equate, within a tolerance limit, regional product demands and aggregate product supplies. Steps of the algorithm for one time period are:

1. Determine recovery costs and harvest revenues for each response cell. Regional delivered log and bolt prices ($PL^t$ and $PB^t$) for the first iteration may be set equal to market prices from the previous year.
2. Compare the net revenues for each product strategy, select the maximum, and set $MR_i$ and $MC_i$ equal to the selected strategy values.
   a. If $MR_i < MC_i$ then the cell is not harvested; look at the next response cell.
   b. If $MR_i \geq MC_i$ then the cell's product volume(s) is (are) accumulated; look at the next response cell.
3. After all response cells are examined, estimate the quantity of each product demanded at the set prices, $PL^t$ and $PB^t$.
4. Compare the quantities of each product demanded and supplied.
   a. If $QB_D^t > QB_S^t$ or $QL_D^t > QL_S^t$, increase $PB^t$ or $PL^t$; go to Step 1.
   b. If $QB_D^t < QB_S^t$ or $QL_D^t < QL_S^t$, decrease $PB^t$ or $PL^t$; go to Step 1.

c. If $QB_b^t = QB_s^t$ and $QL_b^t = QL_s^t$, within tolerance, then market equilibrium is achieved for time period t.

Price adjustments at Step 4 are initiated for the product with the largest relative difference between quantity demanded and quantity supplied. For example, if $QL_s^t$ is 25 percent greater than $QL_b^t$ at a particular price, and the difference is 20 percent for bolts, then log price is decreased. Bolt prices are reduced when the relative difference between bolt quantity supplied and demanded is greater than the relative difference for logs. This procedure reduces the number of iterations necessary to reach equilibrium.

The process of iteratively adjusting delivered prices to determine equilibria in each time period essentially traces sets of supply curves for each product. Since the products are jointly produced in some response cells, a change in one product's delivered price may cause a supply shift in the other product. If bolt price increases (decreases) while log price is fixed, then the quantity of logs supplied will increase (decrease) also, when the relationship between the two products is complementary. Therefore, the iterative process may involve several price changes for both products until the quantities demanded and supplied are within the tolerance limit.

# Chapter III

# MODEL APPLICATION

## *Overview*

This chapter explains model variables, their validity, and the model's sensitivity to changes in variable values. A baseline market scenario is presented. Scenarios are developed and analyzed based on those variables most influential to model results, and on anticipated market conditions.

Variables are model elements which help to complete the formulation of relationships among model components (Lee et al. 1981). They are usually constant values, changing for different cases of the same problem. Exogenous variables derive their values outside the system and cannot be controlled by decision makers. The analyst can alter any variable value and thereby simulate different market scenarios.

# *Model Variables*

Variables chosen for the sensitivity analysis were those exhibiting historical trends and those set by the model builder based on empirical observations and expert opinion. Variables occurred in both stumpage and primary product market models. Stumpage market variables influenced volume availability in any time period via landowner propensity to harvest and merchantable stand age. Roundwood production was influenced by harvesting and hauling costs (see Expressions 2.6 and 2.7), and by assumptions on how these costs changed over time. Finally, product demand equations, in Tables 7 and 8, required projections of exogenous variables.

## Volume Availability

**Propensity to harvest** - In any time period only a portion of the total acreage and volume in a response cell is apt to be harvested. Response cells represent blocks of similar forest land, identified by a single landowner type. A response cell's acreage may actually be owned by several individuals, corporations, or agencies. The numerous owners represented by one response cell are unlikely to react identically to stumpage prices in any particular time period. Some landowners either do not offer their stumpage for sale, or are not approached to sell it. Landowners with nontimber management objectives may refuse to sell stumpage at any time.

Acreage factors were used to reflect the possibility that different landowners make different harvest decisions in any time period. Factors, based on landowner type, were

multiplied by each response cell's acreage, to determine the number of acres that could be harvested in any time period. For example, if a response cell was identified as forest industry land (with an acreage factor equal to 0.10), and had 2000 acres, then only 200 acres would be harvested in any time period.

Acreage factors were based on the historical harvest levels of recognized landowner types. Factors used in the baseline simulation were: 0.12, 0.10, 0.084, and 0.096 for public, forest industry, farmers, and miscellaneous private individuals and corporations, respectively. These figures are the ratios of commercial forest land acreage harvested by the landowner type to the total commercial forest land acreage in each owner type; ratios were derived from the 1985 forest survey data for the study area. These figures do not sum to 1.00 since only a portion of the acreage held by each landowner type is harvested annually.

**Merchantable Stand Age** - The yield equations used in the model provided volume estimates at young stand ages. Examination of published hardwood yield tables for individual and mixed hardwood stands, and discussion with procurement foresters suggested that stands with an average age below 30 were unmerchantable. This age was used in the baseline simulation to restrict harvest in young, unmerchantable stands.

## Harvesting and Hauling Costs

Harvesting cost estimates originate from several sources: logging costs reported in Forest Service studies; cost equations used in harvest simulators; estimates from other

academic studies; and actual logging contract costs. Estimates derived from negotiated contracts and/or actual harvest operations in the study area would be ideal, but such information is difficult to obtain. Procurement foresters are hesitant to reveal contract rates and small logging operators typically do not keep detailed records of costs and production.

Though harvesting cost estimates may not reflect reality perfectly, their use should not adversely impact conclusions drawn from model results. If harvesting costs are over- or underestimated, absolute market prices will be biased. Relative market prices and production trends should remain valid, as long as the relative cost adjustments for each response cell are accurate. Adjustments made for logging operability conditions and product types mitigate estimation problems and provide credence to model interpretation. The accuracy of these adjustments is acceptable, since their bases are logging contracts and actual costs reported in other studies.

Accurate hauling cost estimates are hindered because of the inability to identify response cells geographically; dividing response cells into five hauling distances partially corrects this problem. Greater resolution of distances might achieve more realistic hauling patterns, but improvement may be minimal if additional cell divisions are subsets of exiting divisions.

Harvesting and hauling costs were held constant over time in the baseline simulation. Trend data on input prices (wages, fuel prices, and machinery costs), indicated that weighted prices[12] have risen at a rate of approximately 6.9 percent since 1971, and 2.2

[12] Weighted price was calculated as 60 percent agricultural machinery and equipment price index, 15 percent fuel and related products price index, and 25 percent hourly wages for non-agricultural employees (Data Source: U.S.D.C. 1971-1985).

percent in the last five years. The former rate includes a period of considerable inflation. The later rate is assumed to be more indicative of trends expected over the next 15 years. Therefore, real price increases between one and three percent were tested.

## Demand Equation Variables

Variables used to estimate regional primary product demands were exogenous. Their occurrence in the demand equations was validated by derived demand theory and statistical testing. These variables were projected over the simulation period. Use of these projections assumed that past regional primary product market conditions continued into the future.

**Log Demand** - Housing starts and sawmill factor input prices were required for log demand estimates. The Forest Service provided medium level projections of housing starts (U.S.D.A. 1987); high and low levels were set at plus or minus 10 percent of medium projections, respectively. Medium level projections were used in the baseline simulation.

High sawmill factor input prices may partially explain the regional tendency of mill closures over the past 15 years. (R. McElwee and M. White; Personal Communications). This tendency may itself partly explain decreases in log volume marketed and delivered log prices. In other words, mill closures may have caused inward log demand shifts. Rising factor prices and mill closures are likely to continue. Past trends in factor prices are observable and their effect as demand shifters are validated statistically in Table 7.

The number of sawmills was not explicitly considered in the model, but rising factor prices were. Sawmill input prices, based on fuel price index and wages in sawmills, have historically increased at an annualized rate of eight percent over the last 15 years, and 1.2 percent in the last five. As with harvesting and hauling costs, the former rate included an inflationary period, while the later rate was assumed indicative of future trends. Input prices were compounded at 1.5 percent in the baseline simulation and at rates between one and three percent in sensitivity analyses; higher rates were expected to cause greater inward demand shifts.

Projecting past housing starts and factor input price trends has two implicit assumptions: 1) the types of facilities buying logs remain the same, and 2) log demand continues to shift inward. The first assumption reveals the log demand function's inability to capture regional changes in the secondary product market. If new secondary products are independent of the housing market, then the derived demand relationship for logs will change and the estimated function will be invalid.

The second assumption is based on the premise that lower log demand results partly from fewer sawmills in the study area. Mill closures may stabilize at some point in time, as either efficient levels of production are achieved in existing mills, or new facilities start up. Such conditions could alleviate, and perhaps reverse falling log demand, but these conditions as demand shifters are not explicitly recognized. The log demand function may capture this stabilization by incorporating constant factor input prices, prices increasing at a rate less than past trends, or short-term price decreases.

**Bolt Demand** - The Forest Service projected paper price increases at less than one percent annually (U.S.D.A. 1982). Producer price indices for paper, excluding newsprint, indicated paper prices increased at an annualized rate of 6.6 percent since 1971, and 1.5 percent in the last five years. The former rate included an inflationary period, the latter rate was assumed indicative of future trends.

If paper prices are compounded at 6.6 percent over the 15 year simulation period, annual bolt demand would equal 152,878 cunits; over two and a half times the highest observed market volume of bolts. Such a result is unlikely without considerable expansion of existing regional paper production capacity.

The 1985 paper price index was compounded at one percent in the baseline simulation. Maximum bolt demand was set at 56,000 cunits; this level equalled the highest observed bolt volume marketed in the region in the last 10 years. This maximum reflected the likelihood that the study area is only a portion of Mead's procurement area. Loggers and procurement foresters in the region indicated that they frequently faced mill quotas on bolt volume. The maximum was assumed to be the highest quota expected. Paper prices were not included in the sensitivity analysis because of this maximum; compounding paper prices at a higher or lower rate than one percent caused the maximum to be reached at an earlier or later time period.

# *Baseline Simulation*

## Market Scenario

A market scenario was established, simulated, and interpreted as a baseline for all simulations. Characteristics of the scenario extended price trends and variable values observed in the past five years. The baseline conditions are summarized in Table 9 and results in Table 10.

## Simulation Results

Simulation results behaved as expected. Delivered log prices and quantities decreased slightly over time; this trend was due to inward shifts in log demand over time. Delivered bolt prices and quantities rose with outward shifting bolt demand; maximum bolt demand was reached in year 14. The two products also appeared to behave as complements.

The behavior of the log market reflected the interaction of an inelastic to slightly elastic demand and highly elastic supply. Price elasticity of log demand ranged from .81 to 1.33 over the simulation period.[13] Log supply was highly elastic; price elasticity of supply exceeded 10 in simulation periods one, eight, and 15. Inward demand shifts occurred over time as rising sawmill input prices offset relatively stable housing starts. An

[13] Calculated by differentiating the log demand function with respect to price and evaluating elasticity at the market equilibrium price and quantity.

Table 9. Description of the market scenario used in the baseline simulation.

BASELINE SCENARIO

Acreage Factors: 12% - Public land
10% - Forest Industry
8.4% - Farmer
9.6% - Miscellaneous Private Individuals and Corporations

Merchantable Stand Age: 30 years

Harvesting and Hauling Costs: No real price increase

Housing Starts: Medium level projections

Sawmill Input Prices: The 1985 price index is compounded at 1.5% annually.

Paper Price Index: The 1985 paper price index is compounded at 1.0% annually. Maximum demand set at 56,000 cunits

Table 10. Results of the baseline market scenario simulation.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 57.13 | 41903 | 38.16 | 47890 |
| 2 | 56.92 | 41376 | 38.40 | 46955 |
| 3 | 56.69 | 41440 | 38.71 | 47951 |
| 4 | 56.69 | 39708 | 38.78 | 48520 |
| 5 | 56.69 | 38063 | 38.94 | 49116 |
| 6 | 56.44 | 35740 | 39.21 | 48931 |
| 7 | 56.36 | 35946 | 39.54 | 49671 |
| 8 | 56.30 | 33937 | 39.82 | 50895 |
| 9 | 56.28 | 32852 | 40.04 | 51205 |
| 10 | 56.26 | 31610 | 40.27 | 51454 |
| 11 | 56.25 | 30974 | 40.51 | 53167 |
| 12 | 56.24 | 29184 | 40.67 | 52457 |
| 13 | 56.24 | 26900 | 41.08 | 53189 |
| 14 | 56.23 | 26740 | 41.49 | 53431 |
| 15 | 56.22 | 27018 | 41.87 | 53231 |

abundant and growing log inventory combined with stable harvesting and hauling costs yielded a relatively flat log supply. The interaction of shifting steep demand curves and flat supply curves resulted in falling delivered prices and quantities.

The log price and quantity trends appeared consistent with recent market patterns. Since 1980 delivered log prices and quantities have fallen. Variable values used in the baseline simulation were intended to capture this trend. The low real rate of sawmill input price increase mimicked stabilization of mill closures and concentration. Constant recovery costs reflected the recent tendency of little change in these costs.

Bolt delivered price and quantity behavior was also as expected; prices and quantities increased with demand. Demand and supply in the bolt market resembled the log demand; perfectly inelastic bolt demand by assumption, and highly elastic supply by empirical observation. The behavior characterized a market with outward shifting demand, low production levels relative to overall economic supply, and an elastic supply in the range of production.

Price and quantity projections in the bolt market were also consistent with past trends. Though market quantities have increased, observed prices have been relatively stable, rising approximately 14 percent since 1975. Similarly, projected bolt quantities rose over the simulation period, while prices increased only 9.7 percent. Relative price stability in the presence of increasing quantities suggested the existence of: 1) highly elastic bolt supply, and/or 2) monopsonistic pricing powers. The former possibility was proven empirically with the supply model. Though the price elasticity of bolt supply remained fairly elastic, it also decreased over time; price elasticity in year 15 was less

than that in year one. The second possibility was speculative; theoretical and empirical effects of pricing powers are discussed in the following section.

## *Model Sensitivity*

Model sensitivity was examined by individual variable perturbations; a single variable was changed while all others were kept at their baseline values. Sensitivity results were evaluated for theoretically correct and realistic behavior, and for anomalies arising from basic assumptions. Absolute and relative price and quantity values and trends aided evaluation and interpretation.

### Sensitivity Results

The model was less sensitive to linear variable changes compared to exponential changes. Linear variable changes involved one time additions or substractions from baseline values. Exponential changes resulted when 1985 prices were compounded at some annual rate. Linear changes in housing starts, merchantable stand age, and acreage factors had relatively little effect on prices and quantities. Changes in the growth rates of sawmill input prices and harvesting and hauling costs had substantial effects on both prices and quantities. Sensitivity results are summarized in Table 11.

Variable perturbations influenced either product demand or supply. Housing starts and sawmill input price increases affected log demand, while merchantable stand age,

Table 11. Summary of sensitivity analysis results.

| Variable Perturbation | Model Sensitivity[1] |
|---|---|
| Propensity to Harvest: | |
| Halved | All prices slightly higher; quantities unchanged. |
| Doubled | All prices slightly lower; quantities unchanged. |
| Merchantable Stand Age: | |
| 35 years | All prices and quantities unchanged. |
| 40 years | Log prices slightly higher; bolt prices slightly lower; quantities unchanged. |
| Harvesting and Hauling Cost Increases: | |
| 1.0 percent | Log prices averaged $3.80 per cunit higher; bolt prices $2.80 higher; log quantities slightly lower; bolt quantities unchanged. |
| 3.0 percent | Log prices averaged $11.60 per cunit higher; bolt prices $9.50 higher; log quantities were lower; bolt quantities unchanged. |
| Log Demand: | |
| Housing Starts: | |
| High | Log prices and quantities slightly higher; bolt prices and quantities unchanged. |
| Low | All prices and quantities unchanged. |
| Sawmill Input Price Increases: | |
| 1.0 percent | Log prices and quantities slightly higher; bolt prices slightly lower and quantities unchanged. |
| 3.0 percent | Log prices over $2.00 per cunit lower by year 15, and quantities drastically lower; bolt prices higher and quantities unchanged. |

[1] Model sensitivity statements are made in relation to baseline scenario results.

acreage factors, and harvesting and hauling cost increases influenced the supply of both products. No perturbations explicitly affected bolt demand.

The nature of the demand and supply curves also affected market price and quantity determination. Product demand curves were very steep or vertical; the log demand had a slope of -0.01 in price-quantity space and bolt demand was perfectly inelastic. Empirical estimates of the log and bolt supply curves indicated that they were relatively flat.[14] Consequently, market quantities were determined mainly by demand and prices by supply shifts. Variables affecting demand had a greater influence on market quantities, while those affecting supply influenced prices.

Sawmill input price increases had the greatest impact of the demand shifters. Input prices compounded at a three percent real rate caused delivered log quantity to be 20,000 cunits below baseline levels by year 15, and prices $2.00 lower; this rate was twice the baseline value. Higher input prices caused larger inward demand shifts than in the baseline scenario. Surprisingly, housing starts had little impact on delivered log prices or quantities. The bolt market was relatively unaffected by either of these perturbations.

Harvesting and hauling cost increases had the greatest impact of variables influencing supply; these increases shifted primary product supplies inward. Compounding harvesting and hauling costs at a conservative rate of one percent caused log prices to average $3.80 and bolt prices $2.80 higher than baseline, while quantities were affected very little. When costs were compounded at three percent delivered prices averaged $11.60

[14] These estimates were only made for the baseline scenario and at time periods one, eight, and 15.

and $9.50 higher than baseline, for logs and bolts respectively. These results also implied that delivered prices would be sensitive to basic harvesting and hauling cost estimates.

Changes in merchantable stand age and acreage factors had essentially no impact on prices or quantities. Log prices increased and bolt prices decreased less than one percent from baseline values when merchantable age was 40. Quantities of either product were unaffected with higher merchantable ages. Results of halving or doubling acreage factors were similar to negative or positive supply responses, respectively. Log and bolt prices were higher than baseline when factors were halved, mimicking a negative supply response; less volume available at the same price. Doubled acreage factors caused lower prices, similar to results expected of a positive supply response.

## Conclusion of Sensitivity Analysis

The model performed as expected for the given assumptions and variable perturbations. No anomalies were observed in sensitivity analyses conducted with the final model formulation. The variable perturbations examined provided an indication of the magnitude of change that could be expected. They also served to identify incorrect model formulations in the early stages of development.

Several variables were maintained at baseline values, while others were included in analyses of alternative market scenarios. Sensitivity results suggested that merchantable stand age, acreage factors, and housing starts be kept at baseline values for all alternative scenarios examined. The influential nature of harvesting and hauling costs and sawmill input price increases warranted their inclusion in other market scenarios.

## *Analyses of Alternative Market Scenarios*

Analyses of alternative market scenarios provide decision makers with two types of information. First, these analyses address the economic availability of timber resources over the next 15 years. Wood products firms considering expansion in southwest Virginia may want to know if resources are available to support their operations in the long-run. Second, these same firms may be interested in price information showing what impact their procurement activities may have on delivered prices. Other landowners may use the price information when conducting forestry investment analyses.

Several market scenarios are described in Table 12. These scenarios evaluate the impact of increases in the demand for one or both products on prices and quantities. The effects of price increases in harvesting and hauling costs are also examined. Scenarios including changing sawmill input prices are excluded because changes in this parameter produce results similar to other scenarios. Comparisons of scenario results indicate: 1) if resources are economically available for expansions in both product markets, and 2) how the relationship between logs and bolts develops over time with increased demand in both markets.[15]

### Scenario Group I

Four levels of expanded log demand were simulated: 7,200, 14,400, 21,600, and 28,800

[15] Results are presented as price trend graphs. Appendix IV contains price and quantity results for all scenarios.

Table 12. A summary description of the alternative market scenarios analyzed.

Baseline Scenario: See Table 10

Scenario Group I: Expanded Log Demand

A. Demand expanded 7,200 cunits in year 1, and then leveled.

B. Demand expanded 14,400 cunits in year 1, and then leveled.

C. Demand expanded 21,600 cunits in year 1, and then leveled.

D. Demand expanded 28,800 cunits in year 1, and then leveled.

Scenario Group II: Expanded Bolt Demand

A. Demand was expanded by 22,400 cunits in year one, by 30,400 cunits in year two, by 41,260 cunits in year three, and by 56,000 cunits in year four and all years thereafter.

B. Demand expanded as in Scenario A, plus an additional expansion of 28,000 cunits in years 10 to 15.

C. Demand expanded as in Scenario A, plus an additional expansion of 84,000 cunits in years 10 to 15.

Scenario Group III: Expanded Log and Bolt Demands

A. A combination of Scenarios ID and IIA.

B. Same expansions as Scenario A, and harvesting and hauling costs compounded at 0.5% annually.

C. Same expansions as Scenario A, and harvesting and hauling costs compounded at 1.0% annually.

cunits.[16] Each expansion was added to predicted log demand starting in year one and all years thereafter. Increased demand changed the intercept term of the estimated log demand function, but not the function's slope term. These levels represented multiples of the sawmill size (three MMBF) considered most efficient for the Appalachian hardwood region (W. Luppold; Personal Communication). They also represented 18, 36, 55, and 73 percent of the regional log volume marketed in 1985, respectively.

**Results** - Delivered log prices were above baseline and bolt prices equal to or below for all expansion levels (see Figures 3 and 4). The relationship between log and bolt prices indicated the two products were complementary; this behavior was expected since bolts, by definition, cannot be used as logs. Logs and bolts were produced jointly. The quantity of logs supplied and log price increased with expanded log demand. Bolt supply shifted outward when the quantity of logs supplied rose, causing bolt prices to fall. Rising log demand did not impinge upon the economic supply of bolts, but complemented that supply so that the same bolt volume was deliverable at lower prices.

Price effects were different between the 7,200, 14,400, and higher levels. The lower levels had delivered log prices higher than baseline, but like the baseline prices, they declined over time. This behavior indicated continuation of complementarity between logs and bolts. Inward shifts of the underlying log demand caused declining log prices, since lower levels of expansion represented a relatively small part of predicted regional demand.

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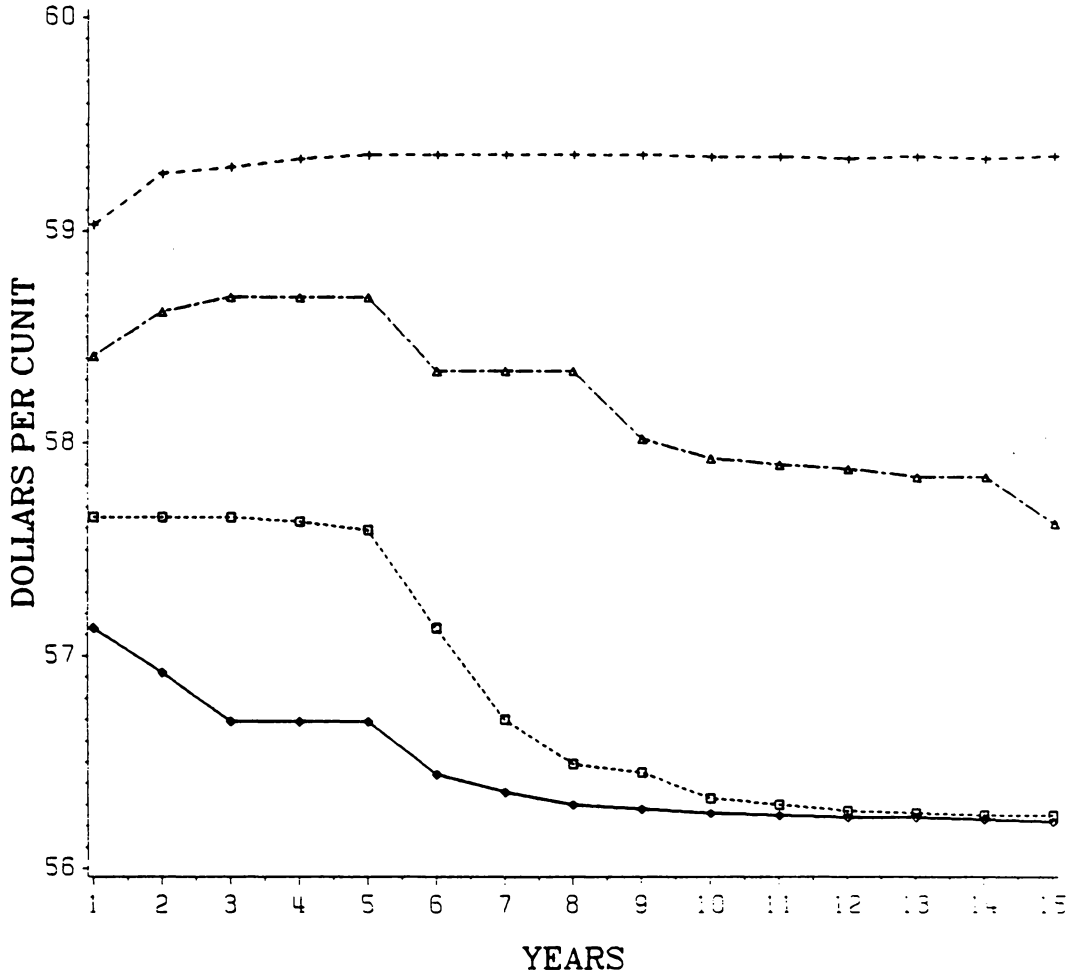
[16] These values equalled three, six, nine, and 12 million board feet (MMBF), respectively.




Key:

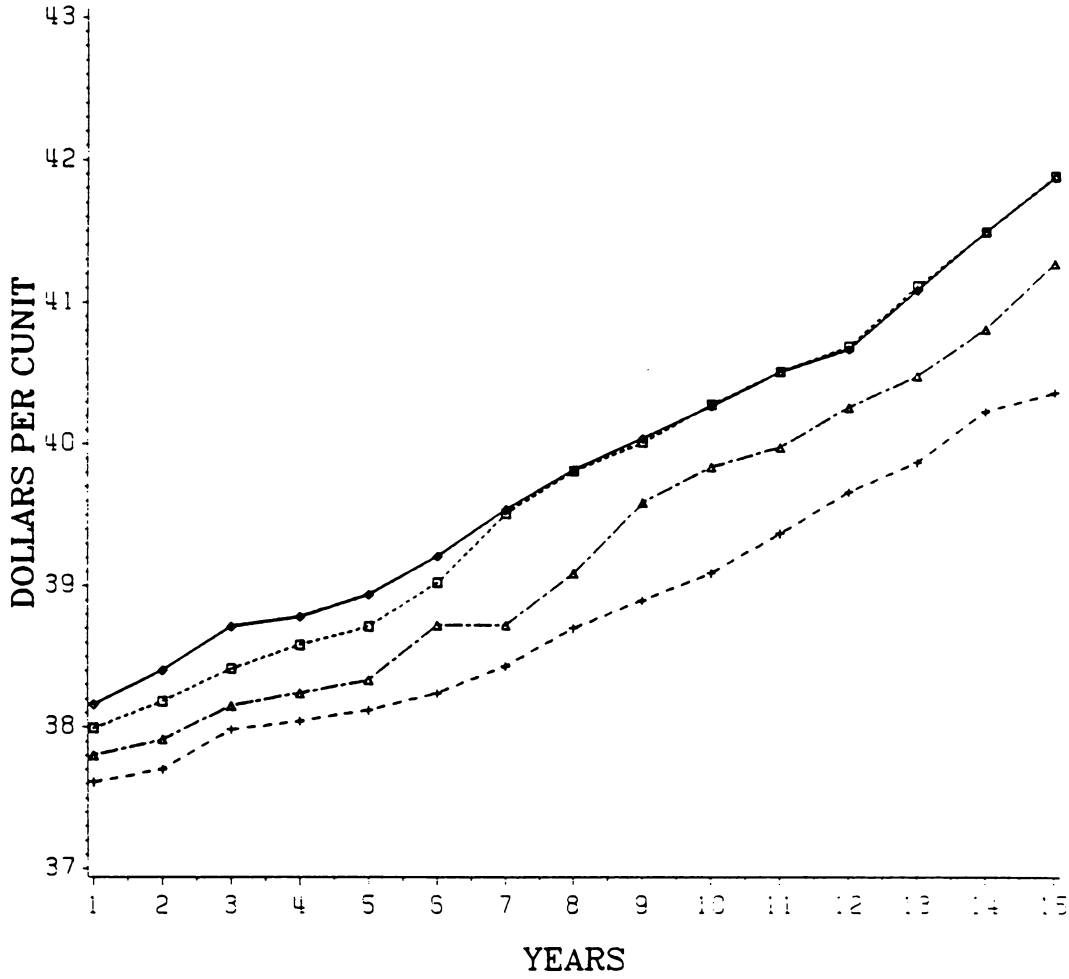
◇---◇ Baseline Scenario

□---□ Scenario A

△---△ Scenario B

+---+ Scenario D

**Figure 3. Log price trends for Scenario Group I.**




Key:

◇---◇ Baseline Scenario

□---□ Scenario A

△---△ Scenario B

+---+ Scenario D

**Figure 4. Bolt price trends for Scenario Group I.**

Delivered log prices stabilized at approximately $59.30 per cunit for the two highest levels.[17] Expansion levels 21,600 and 28,800 exhibited similar price effects, so only the curve for the 28,800 level is shown in Figures 3 and 4. The inward shifts of log demand had less impact at these higher expansion levels.

Log stabilization is partly explained by the price elasticity of log supply. Log supply may be perfectly elastic at some price and over some ranges of output. This perfectly elastic segment of log supply likely arises from harvesting and hauling cost calculations. Numerous response cells have similar accessibility and operability characteristics, differing only by landowner type and stand conditions. Consequently, log harvesting and hauling costs are similar for these response cells. These cells possibly contain enough volume to supply the higher quantities demanded without increasing price, at least during the simulated time period.

Delivered bolt prices, as indicated, were equal to or below baseline, but continued to increase under each expansion level. Bolt price increase reflected the outward shifts of bolt demand over the simulation period.

## Scenario Group II

Three scenarios of expanded bolt demand were analyzed by adding the expansions to annual estimates of bolt quantities demanded. Scenario A simulated Louisana-Pacific

[17] Analyses with 36,000 and 43,200 cunit expansions produced results similar to the 21,600 and 28,800 levels.

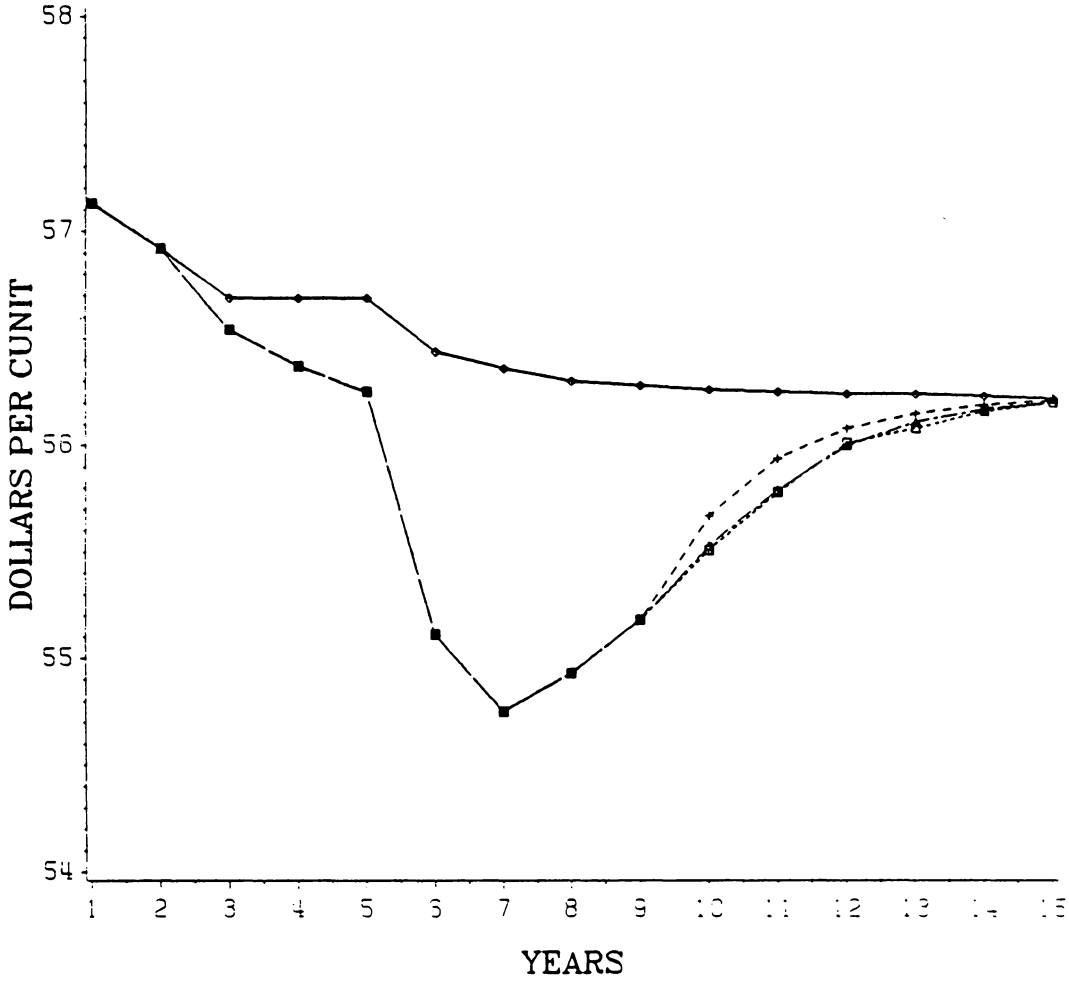
(L-P) operations by adding 22,400 cunits to year one's predicted demand; 30,400 cunits to year two's; 41,260 cunits to year three's; and 56,000 cunits to year four's and all years thereafter. In other words, L-P procurement was phased in over the first four years, starting at 40 percent of rated mill capacity (70,000 cords or 56,000 cunits). Annual demand generated by the L-P mill was assumed price insensitive for reasons similar to the inelasticity assumption for paper mills. Scenario B included the L-P expansion, plus an additional 28,000 cunit increase in year 10; years 10 to 15 had 84,000 cunits added to annual demand estimates. This scenario simulated a 50 percent expansion of L-P operations in year 10. Finally, Scenario C simulated Scenario A and the establishment of a new mill in year 10, adding 84,000 cunits to predicted demand; total additions to annual demand was 140,000 cunits in years 10 to 15.

**Results** - All three scenarios generated higher bolt and lower log prices than the baseline (see Figures 5 and 6). Log price trends were similar for all scenarios, decreasing until year seven, increasing through year 13, then stabilizing.

Bolt price effects were identical until year 10. Prices rose 6.5 percent higher than baseline for Scenario A, 6.9 percent for Scenario B, and 8.5 percent for Scenario C. All scenarios exhibited rising bolt prices over the simulation period.

The relationship between logs and bolts appeared to change from complementary to competitive between years seven and eight.[18] Initially, the products appeared complementary; log prices fell as bolt prices rose. Reversal of this behavior in year eight implied

[18] Cross price elasticities were not be calculated because the model was not modified to allow such calculations. Therefore the relationship change could not be empirically measured.




Key:

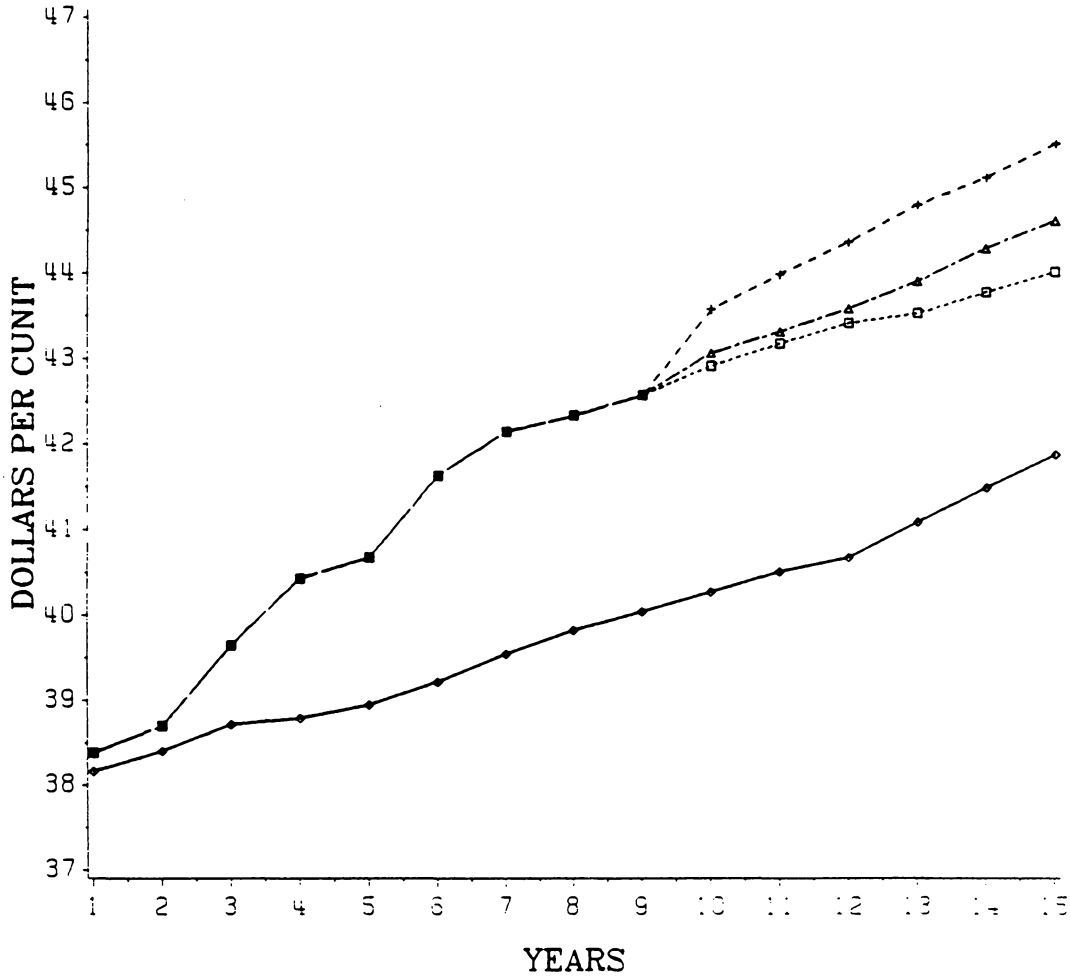
◇---◇ Baseline Scenario

□---□ Scenario A

△---△ Scenario B

+---+ Scenario C

**Figure 5. Log price trends for Scenario Group II.**




Key:

◇---◇ Baseline Scenario

□---□ Scenario A

△---△ Scenario B

+---+ Scenario C

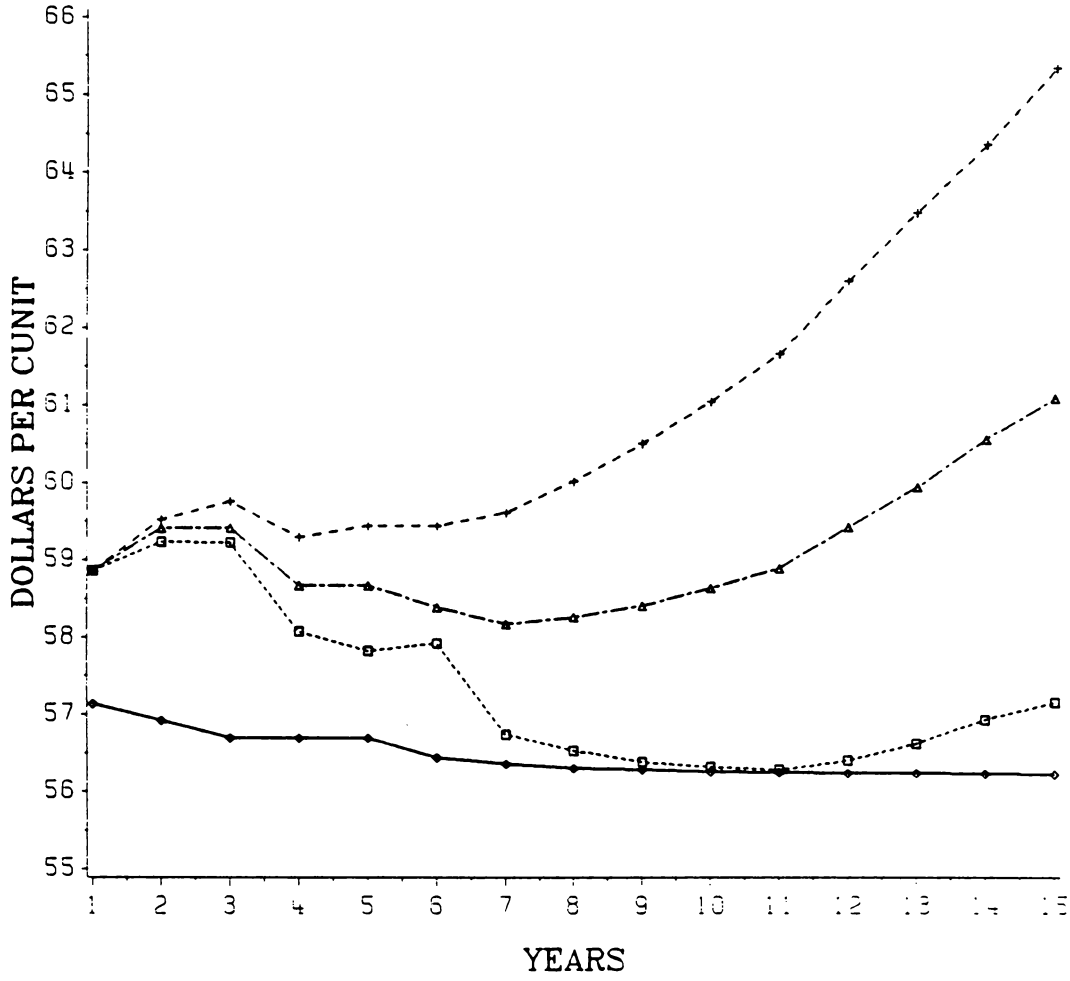
**Figure 6. Bolt price trends for Scenario Group II.**

that increased bolt demand eventually created a competitive or substitute relationship between the two products. Log prices rose faster with higher levels of bolt demand expansions, indicating greater competitive pressures. Competition seemed to diminish, however, as log prices appeared to stabilize in years 14 and 15. Price stability seemed to imply that increased bolt demand pushed log production into a perfectly elastic portion of the log supply schedule; this behavior is discussed in the following section.

## Scenario Group III

Simultaneous expansions in both product markets, along with price increases in harvesting and hauling costs were considered. Scenario A examined a combination of Scenarios ID and IIA. This combination was simulated two additional times (Scenarios B and C) with harvesting and hauling costs compounded at 0.5 and 1.0 percent. These scenarios tested the timber resources ability to accommodate a doubling of total regional wood demand.

**Results** - The change from a complementary to a substitute relationship between logs and bolts was strongly evident (see Figures 7 and 8). Increased log demand, and subsequently higher log prices, initially complemented bolt supply and kept bolt prices below baseline. Log prices gradually declined as bolt prices continued rising. The relationship appeared to switch in year 10, when log prices bottomed out and began to rise along with bolt prices. The relationship switch was barely evident in Scenario B at years 7 and 8, and in C at years 6 and 7.




Key:

◇---◇ Baseline Scenario

□---□ Scenario A

△---△ Scenario B

+---+ Scenario C

**Figure 7. Log price trends for Scenario Group III.**

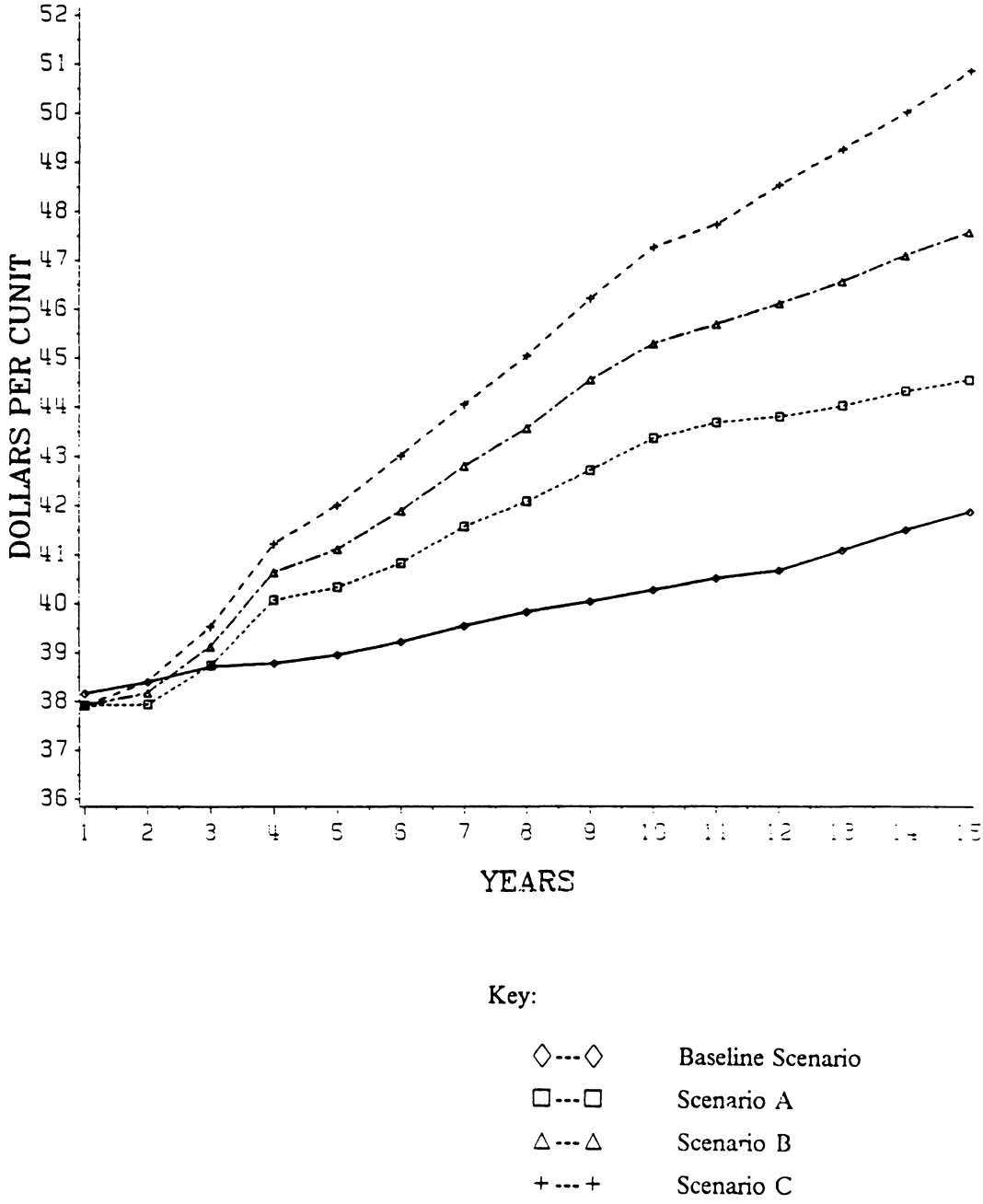



**Figure 8. Bolt price trends for Scenario Group III.**

Price trends exhibited by Scenario A were overshadowed by the exponential impact of price increases. The strong influence of compounding harvest and hauling costs at some rate was demonstrated in the sensitivity analysis. Increases in production costs, combined with expanded product demands, results in log and bolt prices up to 14 percent higher than those when only demands were expanded.

## *Discussion of Scenario Results*

Scenario results in Figures 3 through 8 imply that economically available primary product supplies in southwest Virginia are price elastic. High own price elasticities endure for several levels of regional demand expansions. Expansion levels examined range from 18 to 73 percent of the five-year average log volume marketed, and 112 to 282 percent of average bolt volume. Shifting demand for logs, bolts, or both products have little relative or absolute impact on delivered prices because of high elasticities. Prices are determined primarily by supply shifts, while market quantities are determined by demand shifts.

Two factors contribute to price elastic log and bolt supplies: abundant physical timber resources, and low levels of consumption relative to this resource. Response cell data indicate that large blocks of forest land and accompanying timber inventories have similar logging conditions as defined by operability and accessibility codes. Consequently, harvesting and hauling costs are similar for these lands. Cost similarities result in relatively flat, if not perfectly elastic, segments in the supply schedules. Price stabilization results when quantities demanded coincide with the perfectly elastic segments,

over a series of time periods; delivered prices do not change regardless of the direction demand shifts.

Log and bolt supplies remain relatively elastic over time because annual consumption is a small percentage of total available economic supplies. Annual roundwood removals are assumed to proceed from stands with low harvesting and hauling costs to those with higher costs. These removals affect only the lowest portion of the supply schedules, leaving remaining inventories to grow and expand economic supply. Existing regional demands and simulated expansions do not and would not tap the timber resources faster than these resources expand. The supply schedules therefore shift in shape and direction over time. The lowest portion of the log supply schedule is eliminated each year, while the middle and upper portions shift to the right. Log supply elasticity increases over the simulation period because of the shifting middle and upper portions of the schedule. Bolt supply behaves similar to log supply in the lower portion of its schedule, but the middle and upper portions appear to shift inward as bolt size timber grows into log size. Bolt supply remains relatively price elastic, but this elasticity decreases over the simulation period.

These explicit observations are complicated by underlying assumptions and relationships. Seven of the ten scenarios simulated assume harvesting and hauling costs remain constant over time. Changes in these costs have a considerable impact on primary product supplies, as demonstrated by sensitivity analysis and in Scenarios B and C in Group III. Delivered prices rise when harvesting and hauling costs increase over time because supplies shift upward.

Actual short-term price effects caused by increased quantities demanded are not captured by the model because of the unlimited logging capacity assumption. In reality, a sudden increase in the quantity of logs or bolts demanded may result in a larger single period price increase than the model predicts. This increase occurs as less cost efficient logging operations start up to meet increased demand. Higher prices eventually attract new logging firms, causing supplies to shift outward. Delivered prices will fall to a level equal to or higher than before the expansion, assuming a constant or increasing cost industry, respectively. Consequently, long-term price trends exhibited by the model may not diverge from reality by an excessive amount. If the logging industry is characterized by decreasing costs, the model's long-term prices may overestimate actual prices.

The relationship between log and bolt supply also affects delivered price trends. The two products are complementary for all or a portion of the simulation period in the scenarios examined. As the quantity demanded of one product increases and the price and quantity supplied of that product rise, the other product's supply shifts outward and it's price falls. In other words, the products are jointly supplied. This behavior is evident when log or bolt demands expand separately. In Scenario Groups I and II, the increased quantity demanded of logs or bolts causes the other product's price to drop below baseline levels.

The complementary relationship switches to a competitive one in later time periods and at high expansion levels. Expansion of bolt demand, in Scenario Group II, eventually causes a competitive relationship to develop. The higher quantities of bolts demanded cause the quantities of bolts supplied to rise. Higher bolt prices pull timber resources out of log production, shifting log supply inward, and causing log prices to rise.

Competition diminishes in Scenario Group II, however, when log prices stabilize near baseline levels. Simulation runs, extending the time horizon from 15 to 25 years, indicate that bolt prices eventually stabilize also. For Scenario IIC, stable prices are short-lived, as competition again causes both prices to rise. Price stability may arise because expanded bolt demand forces log and bolt production into perfectly elastic portions of their supply schedules.

Contrast the behavior of Scenario Group II with that of Scenario IIIA where both product demands expand. The competitive relationship does not arise until years 11 or 12, but the relationship endures because production requirements are higher. Simulations with extended time horizons indicate log and bolt prices continue to rise through year 25 under Scenario IIIA. Higher log and bolt production requirements eliminate the perfectly elastic portions of both supplies, as response cells comprising these portions are harvested.

The existence of only two large bolt buyers, with perhaps a small competitive fringe, suggests that the larger firms may possess pricing powers. Theoretically, the model results are consistent with the monopsonistic pricing strategy (see Figure 9). A monopsonistic buyer recognizes that the more input (bolts) purchased, the higher the input price will be. Therefore, the marginal factor cost (MFC) is the rate of price change for each additional unit of input purchased or supplied; MFC is the slope of the input supply curve (Scherer 1980). The monopsonist sets the quantity of input purchased where the value of marginal product (VMP) equals MFC, and price where a vertical line through this point intersects input supply. VMP equals the marginal product of an additional unit of input times the end product's market price; VMP is equivalent to the monopsonist's derived demand for the input. Bolt prices produced by the model are

consistent with this theoretical strategy, assuming perfectly inelastic bolt demand; VMP is vertical. The bolt demand curve intersects the MFC curve and bolt supply at the same quantity, implying that VMP equal to supply is the same as demand equal to supply.

The presence of the theoretical behavior was not empirically tested. If L-P and Mead have pricing powers not described by the theoretical strategy, then delivered bolt prices predicted by the model are apt to be high. The degree of discrepancy between actual and predicted prices is indeterminant without further research.

Several factors should be considered before conclusions are made concerning pricing powers. First, the effects on delivered prices should be observed after L-P has operated several years. Preliminary indications are that competition between the two buyers, L-P and Mead, is raising bolt prices; this observation is made by area procurement foresters. Second, if bolt supply remains relatively elastic, then increased bolt demand will have little impact on delivered prices, and pricing powers may be negligible.

## *Implications and Conclusions*

Scenario results have several implications for regional forest industry and economic development. Basically, raw material availability and prices are favorable for expanded primary product demands. The level and type of expansion will influence the degree of price effect, but, in general, the price impact will be slight.

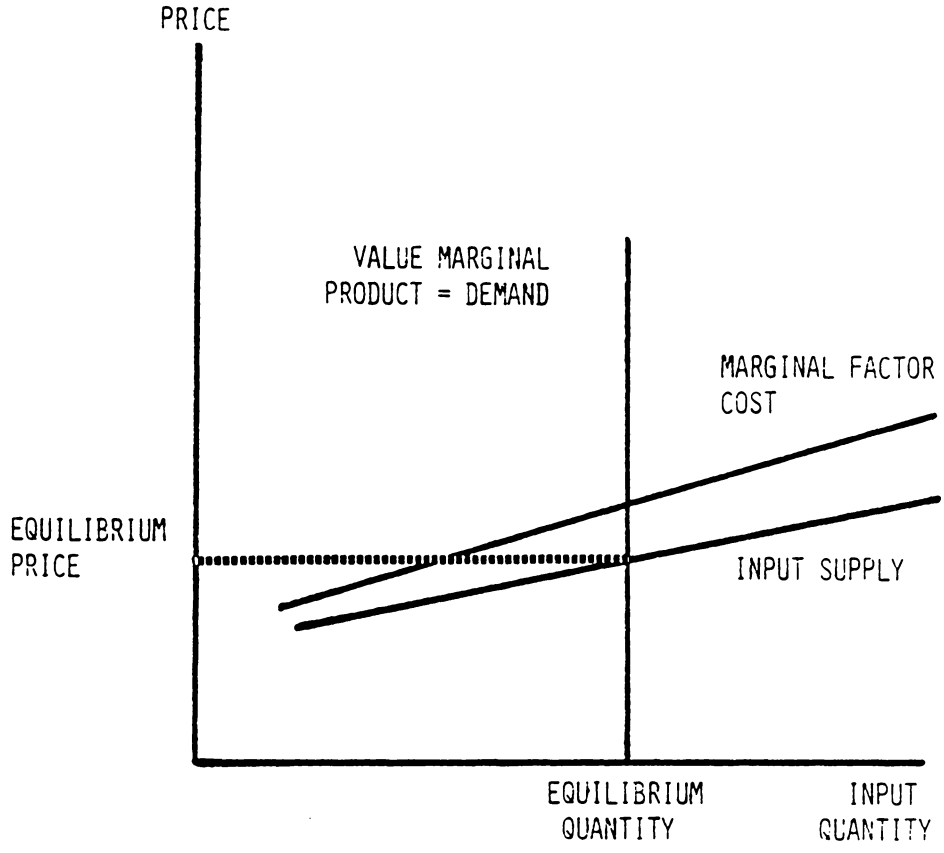



**Figure 9. Graphical presentation of monopsonistic pricing strategy.**

The initial impact of increased bolt demand is apt to be a drop in delivered log prices, if the products are produced jointly. Lower delivered log prices may stimulate the establishment of new sawmills or restart existing inactive facilities, assuming secondary product market demands are stable or increasing. Expansion of both product demands will cause a competitive supply relationship over time. However, the impact on log prices is expected to be relatively less than the bolt price effect because maturing timber resources will keep log supply highly price elastic, and shifting outward.

Delivered bolt prices will be higher for all levels of bolt demand expansion. Relative price increases over the next 15 years are apt to be small. Bolt price increases are expected with expanded demand, assuming purchasers have no pricing powers. Prices are likely to increase in the long-term, regardless of pricing powers, as bolt inventories grow into larger size classes. In the long-term, more than 25 years, a larger percentage of the bolt volume requirements could be supplied by low grade, log size timber. Such a conversion assumes that facilities requiring bolt furnish can accommodate or adapt to larger material.

# Chapter IV

# SUMMARY AND CONCLUSION

## *Summary of Model Development and Use*

A model was developed to determine the economically available supply of logs and bolts in southwest Virginia. Model outputs included primary product market prices and quantities of logs and bolts. The model was used to evaluate the impact on delivered prices and economic supplies of expanded regional demands for logs and/or bolts.

A process analysis approach was used to generate supply relations. Homogeneous supply response cells were identified from 1985 Forest Survey data. These response cells characterized blocks of forest land by ownership type, accessibility and operability conditions, stand age, site index, and stocking density. These characteristics were used to estimate reservation price, harvesting and hauling costs, and the volume of logs and

bolts per acre. The price and cost estimates combined with volume yielded supply schedules.

Log and bolt demand equations were estimated. Log demand was a function of delivered log price, lagged housing starts, and a sawmill input price index. Bolt demand was price insensitive, and was a function of paper price index. Annual estimates of the quantities demanded were made using projections of housing starts, input prices, and paper prices.

A solution technique was developed to determine the market equilibrium quantities and prices. Perfect competition was assumed. The technique was based on maximizing net revenue; response cells were harvested when marginal harvest revenue was greater than or equal to marginal harvest costs. The marginal rule was examined for each response cell, given a set of regional delivered log prices and response cell recovery costs. Volumes of both products from cells meeting the marginal rule were accumulated and compared to the quantities demanded. Delivered prices were adjusted up or down depending on whether quantities supplied were less than or greater than quantities demanded, within some tolerance. Market equilibria were achieved when quantities supplied of both products equalled quantities demanded within tolerance, for given delivered prices.

The effect on prices and quantities was examined for changes in exogenous variables, harvesting and hauling costs, and expansions in quantities demanded. Delivered prices were most sensitive to supply shifts, while market quantities were sensitive to demand shifts. These behaviors resulted from the interactions of highly price elastic log and bolt supply schedules and highly inelastic demands.

## *Conclusions*

Primary product supplies in southwest Virginia are price elastic because of extensive hardwood resources and relatively constant recovery costs. Expansions in primary product demands expected over the next 15 years should have little direct impact on delivered prices. Delivered prices, however, will be sensitive to production costs. These costs will rise if factor input prices,such as fuel prices, wage rates, or machinery costs, increase.

Concurrent expansions in both product markets will at first generate complementary supplies, but eventually the relationship will become competitive. The degree of competition, and hence the price-quantity effects, is indeterminant. It is likely, however, that the price effect of competition on logs will be less than that on bolts. In the next 10 to 25 years, log supply elasticity continues to increase, assuming constant harvesting and hauling costs and increasing log inventories. Conversely, bolt supply appears to shift inward and elasticity decreases as bolt size timber grows into larger size classes.

Interpretation of model results must be made with several assumptions and conditions in mind. Logs and bolts are conglomerates of several product grades and types. "Logs" include all grades of sawlogs and veneer logs. "Bolts" include pulpwood, posts, and mine props, encompassing both hard and soft hardwoods. A finer distinction of products could be recognized in the model given data necessary for demand and production cost estimations.

Harvesting and hauling costs within a given time period are insensitive to logging capacity limitations. These limitations could be incorporated into the model in one of two ways. Log and bolt supplies could be made perfectly inelastic at volumes estimated to be logging capacity; this approach represents a first approximation. The second approach would require additional research into the regional logging market. Essentially, a supply and demand function for logging firms would be incorporated as a third, independent market; the model would seek equilibria in three markets instead of two. The demand for primary products would be related to the logging market by derived demand theory. The interaction of the derived demand for logging firms and the supply of these firms would affect logging costs in the response cells. Both approaches require an estimate of regional logging capacity and a method of adjusting capacity over time. Delivered primary product prices produced by the model in the absence of these modifications are apt to be low.

All landowners are assumed to set reservation prices in the same way, and behave as profit maximizers. Individual landowner behavior is one of the most difficult components of timber supply to model. Response cell information allows the supply model to recognize several landowner types. More sophisticated landowner behavior models may be adapted. These behavior models would reflect different stumpage supply responses made by different landowner types.

The supply model produces acceptable estimates of future market prices and quantities under different market scenarios. Though the model is applied to southwest Virginia, it could be used in any forested region where forest survey data are available. Several components would have to be changed to apply the model to another region. New yield, price expectation, and demand equations would have to be developed. Har-

vesting and hauling costs would depend on the regional logging systems and hauling distances. Different primary products might also be identified.

The component nature of the model makes it easy to adapt the model to other regions or incorporate new research findings. New components might include advanced techniques for predicting landowner behavior, new estimates of harvesting and hauling costs, and updated demand equations. As more precise model components are adapted, more accurate projections of primary product prices and quantities can be expected.

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# *APPENDIX I*

Table 13. Definitions of variables used in the dissertation text.

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ARR = alternative rate of return

$b_0, b_1, b_2$ = regression coefficients used in the price expectation equation

$\beta$ = beta, coefficient of adaptation, reflects how rapidly observed price differences are adjusted in making price expectations

$HB_i$ = bolt harvesting costs per cunit in response cell i

$HL_i$ = log harvesting costs per cunit in response cell i

$HR1_i$ = total harvest revenue for harvesting all volume in response cell i as bolts

$HR2_i$ = total harvest revenue for harvesting the volume in response cell i as logs and bolts

$HS^{t-1}$ = lagged housing starts

$HV^t$ = total volume of logs and bolts harvested in the study area in time period t

i = response cell, i = 1,...,1825

$IIP^t$ = paper price index, except newsprint, in time period t (1982 = 1.000)

$KB_i$ = ratio of bolt volume per acre to total volume per acre in response cell i

$KL_i$ = ratio of log volume per acre to total volume per acre in response cell i

$MC_i$ = weighted marginal recovery cost per cunit in response cell i

$MR_i$ = weighted marginal harvest revenue per cunit in response cell i

$PB^t$ = market equilibrium, delivered bolt price in time period t

$PE^t$ = weighted average expected stumpage price per cunit for time period t, and all time periods thereafter, as formed at the end of time period t-1

$PE_B^{t+1}$ = average expected bolt stumpage price per cunit in time period t + 1

$PE_L^{t+1}$ = average expected log stumpage price per cunit in time period t + 1

$Q_i$ = total volume harvested from response cell i

$QB_D^t$ = total bolt volume demanded from the region in time period t

$QB_S^t$ = total bolt volume supplied from the region in time period t

$QL_D^t$ = total log volume demanded from the region in time period t

$QL_S^t$ = total log volume supplied from the region in time period t

R = ratio of regional average log stumpage price to regional average bolt stumpage price, as observed in time period t-1

Table 13. Definition of variables (continued).

---

$RB_i$ = bolt recovery cost per cunit in response cell i

$RC1_i$ = recovery cost for harvesting the volume in response cell i as bolts.

$RC2_i$ = recovery cost for harvesting the volume in response cell i as logs and bolts.

$RL_i$ = log recovery cost per cunit in response cell i

$RP_i$ = reservation price for response cell i.

$SP^{t-1}$ = weighted average, regional stumpage price per cunit in time period t-1

$SPB^t$ = regional average bolt stumpage price per cunit in time period t

$SPB_i^t$ = bolt stumpage price per cunit, calculated from the financial maturity model for response cell i, in time period t

$SPL^t$ = regional average log stumpage price per cunit in time period t

$SPL_i^t$ = log stumpage price per cunit, calculated from the financial maturity model for response cell i, in time period t

t = time period, t = 1,...,15

$TB_i$ = bolt hauling cost per cunit for response cell i

$TL_i$ = log hauling cost per cunit for response cell i

$u^t$ = random error term in auxiliary equation for time period t

$WTCI^t$ = weighted average sawmill input price index, derived from fuel and related products price index (60%) and wages paid in sawmills (40%)

$Y_i$ = total volume per acre in response cell i

$YB_i$ = bolt volume per acre in response cell i

$YL_i$ = log volume per acre in response cell i

$Z^t$ = other variables which might impact price expectations in time period t

---

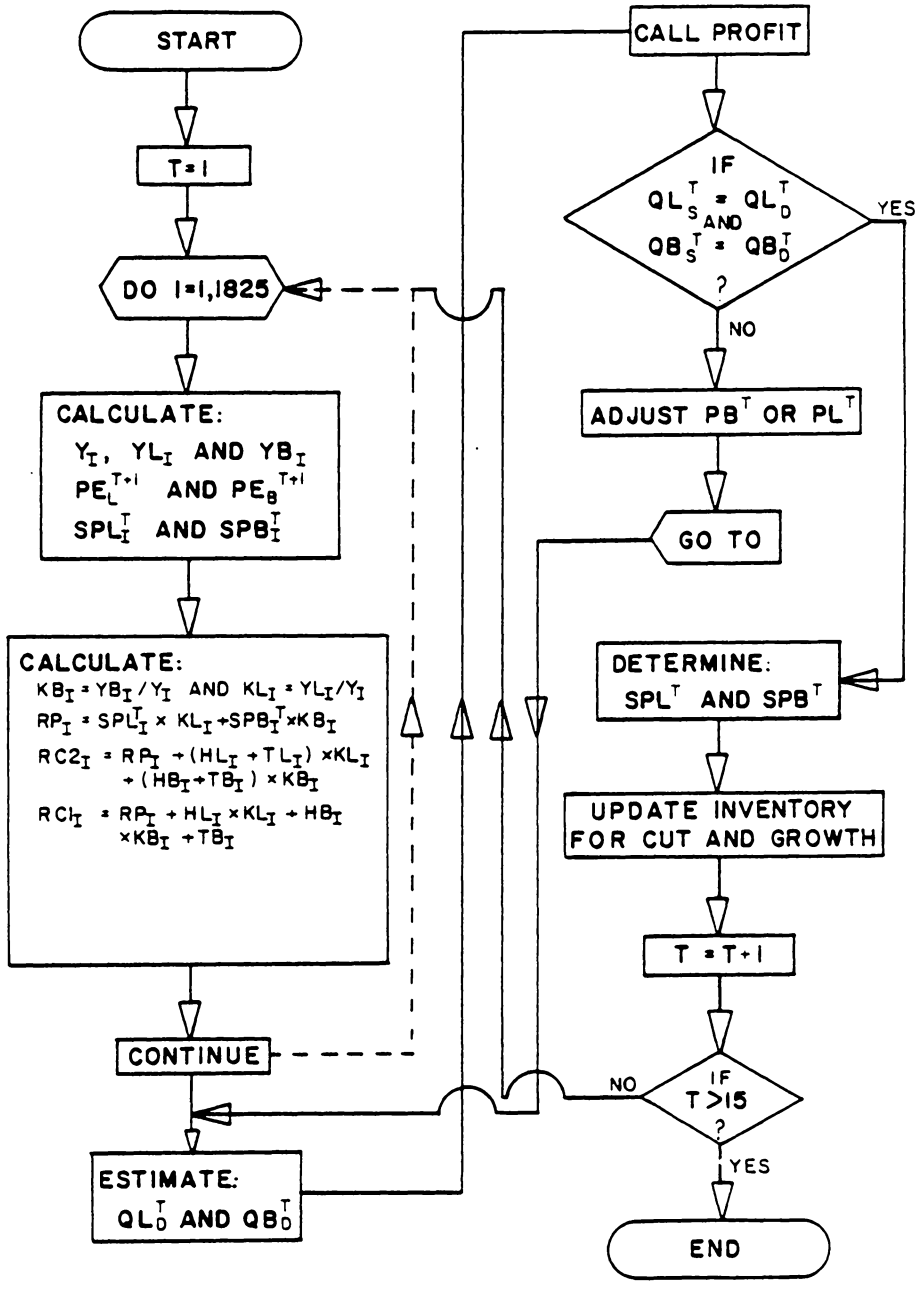


Figure 10. A flowchart of the timber supply model and subroutine.

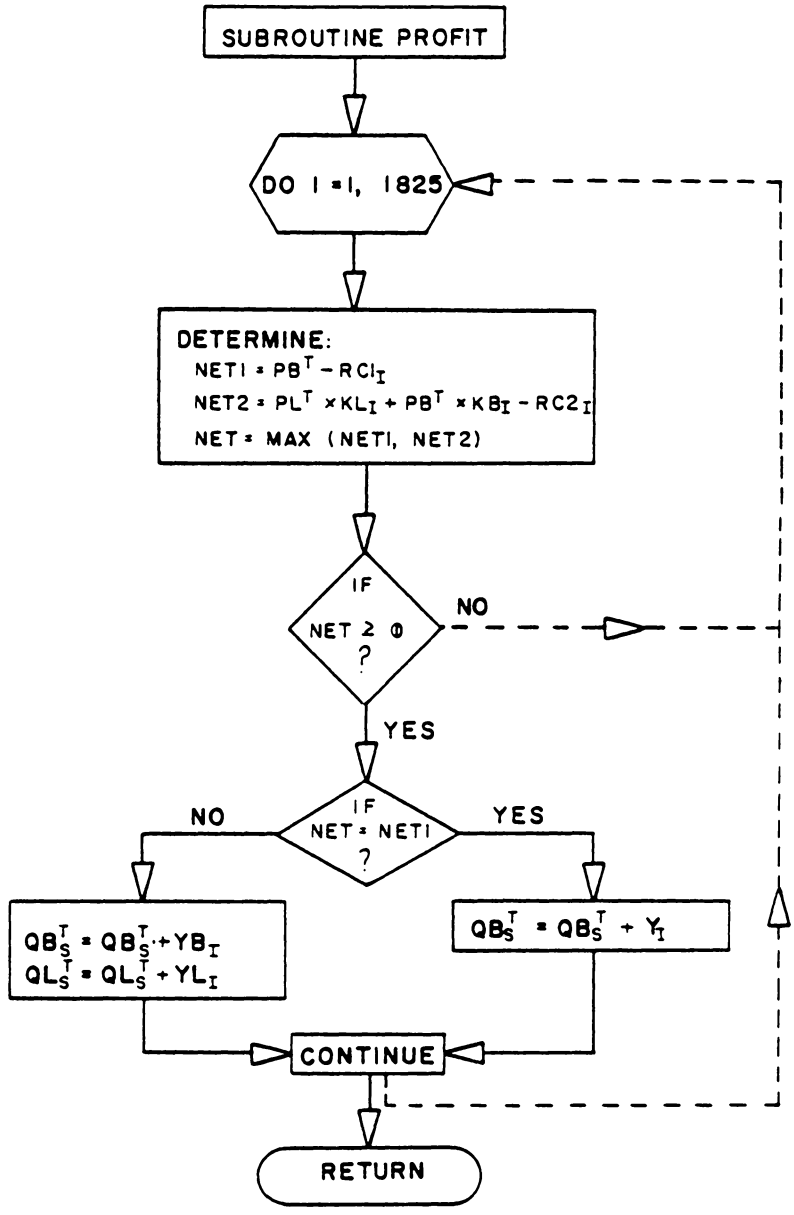


Figure 10 continued

# *APPENDIX II*

Table 14. Data used to estimate log demand and log price expectation equation.

| YEAR | LOG VOLUME (MBF)[1] | DELIVERED PRICE ($/MBF)[2] | HOUSING STARTS[3] (1000S) | WEIGHTED COSTS[4] |
|---|---|---|---|---|
| 1971 | 31,100 | 156.33 | 2084.5 | .320 |
| 1972 | 38,100 | 163.51 | 2378.5 | .336 |
| 1973 | 34,000 | 193.41 | 2057.5 | .371 |
| 1974 | 27,200 | 196.18 | 1352.5 | .436 |
| 1975 | 23,400 | 179.74 | 1171.4 | .487 |
| 1976 | 24,700 | 174.28 | 1547.6 | .534 |
| 1977 | 24,500 | 180.41 | 1989.8 | .585 |
| 1978 | 22,100 | 175.39 | 2023.3 | .638 |
| 1979 | 24,800 | 180.35 | 1749.1 | .726 |
| 1980 | 19,800 | 174.53 | 1312.6 | .860 |
| 1981 | 19,100 | 162.94 | 1100.3 | .966 |
| 1982 | 17,100 | 149.98 | 1072.0 | 1.000 |
| 1983 | 19,600 | 148.86 | 1712.4 | 1.013 |
| 1984 | 12,100 | 147.37 | 1755.8 | 1.027 |
| 1985 | 14,000 | 141.85 | 1739.2 | 1.025 |

1. Source: Elvin Frame, V.D.F.; Virginia Forest Products Tax Data.

2. Delivered log prices were estimated from the following equation:

$$DLP = 578.55 + .385*LSP - 4.48*PCI$$

where

DLP = delivered log price per MBF
LSP = log stumpage price per MBF
PCI = relative producer cost index; a weighted average of fuel (15%), hourly wages of non-agricultural employees (25%), and agricultural machinery (60%) producer price indices, divided by the all commodity producer price index (1982 = 1.000).

Data Source:
For regression equation - monthly issues of Timber Mart South. Values used from January 1983 to September 1986.
Stumpage prices - E. Frame, V.D.F.; Virginia Forest Products Tax Data
Price Indices - Survey of Current Business and Business Statistics

3. Source: U.S. Department of Labor, Bureau of Labor Statistic, Producer Prices and Price Indexes.

4. Weighted cost index was calculated from hourly wage index (60%) and fuel price index (40%). Data Source: U.S. Department of Labor, Bureau of Labor Statistics, Producer Prices and Price Indexes.

Table 15. Data used to estimate bolt demand and bolt price expectation equation.

| YEAR | BOLT VOLUME (CORDS)[1] | DELIVERED BOLT PRICE ($/CD)[2] | PAPER PRICE INDEX[3] |
|---|---|---|---|
| 1971 | 18,100 | 29.27 | .412 |
| 1972 | 16,318 | 28.94 | .417 |
| 1973 | 17,594 | 26.06 | .435 |
| 1974 | 20,909 | 24.97 | .531 |
| 1975 | 22,991 | 26.39 | .608 |
| 1976 | 26,800 | 27.14 | .636 |
| 1977 | 18,919 | 27.58 | .673 |
| 1978 | 23,237 | 27.42 | .716 |
| 1979 | 26,238 | 27.10 | .801 |
| 1980 | 41,945 | 27.26 | .896 |
| 1981 | 55,972 | 28.07 | .996 |
| 1982 | 61,563 | 29.23 | 1.000 |
| 1983 | 68,779 | 29.37 | .995 |
| 1984 | 63,519 | 29.47 | 1.082 |
| 1985 | 60,911 | 30.02 | 1.074 |

1. Source: U.S.D.A. 1972, 1973a, 1974, 1975a, 1976, 1977, 1978, 1979, 1981, 1982a, 1982b, 1984, 1986

2. Delivered bolt prices were estimated from the following equation:

$$DBP = -9.70 - .19*BSP + .39*PCI$$

where
DBP = delivered bolt price per cord
BSP = bolt stumpage price per cord
PCI = relative producer cost index; a weighted average of fuel (15%), hourly wages of non-agricultural employees (25%), and agricultural machinery (60%) producer price indices, divided by the all commodity producer price index (1982 = 1.000).

Data Source:
Prices for regression equation from monthly issues of Timber Mart South. Values used from January 1983 to September 1986.
Stumpage prices - E. Frame, VDF; Virginia Forest Products Tax Data
Price Indices - Survey of Current Business and Business Statistics

3. Source: Paper, except newsprint (1982 = 100), U.S. Department of Labor, Bureau of Labor Statistics, Producer Price and Price Indexes.

# *APPENDIX III*

Table 16. Annual allowable cut levels for the Clinch Ranger District, Jefferson National Forest.[1]

| YEAR | TOTAL VOLUME (1000 CBFT) |
|---|---|
| 1986 | 1,600 |
| 1987 | 1,700 |
| 1988 | 1,700 |
| 1989 | 1,750 |
| 1990 | 1,750 |
| 1991 | 1,800 |
| 1992 | 1,800 |
| 1993 | 1,800 |
| 1994 | 1,800 |
| 1994 | 1,800 |
| 1995 | 1,800 |

1. Source: U.S.D.A. (1985a), Final Forest Management Plan for the Jefferson National Forest.

# *Appendix IV*

Table 17. Simulation results for Scenario IA.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 57.65 | 51044 | 37.99 | 48053 |
| 2 | 57.65 | 49432 | 38.18 | 47510 |
| 3 | 57.65 | 47845 | 38.41 | 47269 |
| 4 | 57.63 | 47784 | 38.58 | 50474 |
| 5 | 57.59 | 45640 | 38.71 | 50904 |
| 6 | 57.13 | 41873 | 39.02 | 49483 |
| 7 | 56.70 | 43902 | 39.51 | 49427 |
| 8 | 56.49 | 41019 | 39.81 | 50744 |
| 9 | 56.45 | 41862 | 40.02 | 50891 |
| 10 | 56.33 | 39942 | 40.28 | 52672 |
| 11 | 56.30 | 38143 | 40.51 | 54320 |
| 12 | 56.27 | 36366 | 40.69 | 53301 |
| 13 | 56.26 | 34088 | 41.11 | 53583 |
| 14 | 56.25 | 34115 | 41.49 | 53220 |
| 15 | 56.25 | 33173 | 41.88 | 53520 |

Table 18. Simulation results for Scenario IB.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 58.41 | 54120 | 37.80 | 48198 |
| 2 | 58.62 | 52297 | 37.91 | 50834 |
| 3 | 58.69 | 50687 | 38.15 | 48317 |
| 4 | 58.69 | 49623 | 38.24 | 49347 |
| 5 | 58.69 | 50801 | 38.33 | 48645 |
| 6 | 58.34 | 49786 | 38.72 | 49987 |
| 7 | 58.34 | 48817 | 38.81 | 49937 |
| 8 | 58.34 | 47671 | 39.09 | 51930 |
| 9 | 58.02 | 46945 | 39.59 | 50833 |
| 10 | 57.93 | 46580 | 39.84 | 53183 |
| 11 | 57.90 | 45265 | 39.98 | 52204 |
| 12 | 57.88 | 44413 | 40.26 | 52691 |
| 13 | 57.84 | 42175 | 40.48 | 53222 |
| 14 | 57.84 | 41082 | 40.81 | 53203 |
| 15 | 57.62 | 40895 | 41.27 | 54192 |

Table 19. Simulation results for Scenario IC.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 59.00 | 60151 | 37.63 | 48198 |
| 2 | 59.26 | 60720 | 37.70 | 46881 |
| 3 | 59.28 | 58923 | 37.99 | 48259 |
| 4 | 59.33 | 61756 | 38.04 | 49206 |
| 5 | 59.34 | 58485 | 38.15 | 49646 |
| 6 | 59.35 | 54360 | 38.35 | 50759 |
| 7 | 59.34 | 53771 | 38.45 | 50299 |
| 8 | 59.34 | 54190 | 38.77 | 51317 |
| 9 | 59.34 | 53258 | 38.92 | 52177 |
| 10 | 59.34 | 51997 | 39.11 | 51267 |
| 11 | 59.33 | 50414 | 39.39 | 51911 |
| 12 | 59.33 | 50004 | 39.67 | 54923 |
| 13 | 59.33 | 48368 | 39.90 | 53637 |
| 14 | 59.29 | 48855 | 40.28 | 53213 |
| 15 | 59.29 | 45641 | 40.44 | 53403 |

Table 20. Simulation results for Scenario ID.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 59.03 | 67923 | 37.61 | 48198 |
| 2 | 59.27 | 66991 | 37.90 | 46847 |
| 3 | 59.30 | 67122 | 37.98 | 48231 |
| 4 | 59.34 | 64590 | 38.04 | 49343 |
| 5 | 59.36 | 64212 | 38.12 | 48326 |
| 6 | 59.36 | 62118 | 38.24 | 48953 |
| 7 | 59.36 | 61298 | 38.43 | 50990 |
| 8 | 59.36 | 61114 | 38.70 | 49938 |
| 9 | 59.36 | 60342 | 38.90 | 51141 |
| 10 | 59.35 | 58089 | 39.09 | 52091 |
| 11 | 59.35 | 55832 | 39.37 | 51955 |
| 12 | 59.34 | 53573 | 39.66 | 53247 |
| 13 | 59.35 | 52751 | 39.87 | 53115 |
| 14 | 59.34 | 52217 | 40.23 | 53257 |
| 15 | 59.35 | 52846 | 40.36 | 53447 |

Table 21. Simulation results of a 36,000 cunit increase in log demand.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 59.03 | 78895 | 37.53 | 45967 |
| 2 | 59.28 | 75906 | 37.70 | 47201 |
| 3 | 59.30 | 74322 | 37.95 | 47152 |
| 4 | 59.34 | 73247 | 38.04 | 50557 |
| 5 | 59.35 | 71415 | 38.10 | 48827 |
| 6 | 59.36 | 68751 | 38.24 | 49971 |
| 7 | 59.36 | 69634 | 38.42 | 49780 |
| 8 | 59.36 | 68032 | 38.70 | 50940 |
| 9 | 59.36 | 66935 | 38.90 | 53803 |
| 10 | 59.36 | 65680 | 39.07 | 51201 |
| 11 | 59.36 | 61998 | 39.35 | 52445 |
| 12 | 59.36 | 63245 | 39.66 | 53868 |
| 13 | 59.36 | 60961 | 39.87 | 53658 |
| 14 | 59.36 | 60982 | 40.18 | 53225 |
| 15 | 59.35 | 59478 | 40.36 | 53904 |

Table 22. Simulation results of a 43,200 cunit increase in log demand.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 59.04 | 83916 | 37.53 | 45967 |
| 2 | 59.28 | 82872 | 37.70 | 47201 |
| 3 | 59.31 | 81519 | 37.95 | 47152 |
| 4 | 59.34 | 78422 | 38.03 | 50557 |
| 5 | 59.36 | 78609 | 38.10 | 48827 |
| 6 | 59.36 | 73856 | 38.24 | 49971 |
| 7 | 59.37 | 76828 | 38.41 | 49780 |
| 8 | 59.37 | 75226 | 38.69 | 50940 |
| 9 | 59.37 | 77766 | 38.90 | 53803 |
| 10 | 59.36 | 72274 | 39.07 | 51201 |
| 11 | 59.36 | 72238 | 39.35 | 52445 |
| 12 | 59.36 | 70442 | 39.66 | 56226 |
| 13 | 59.36 | 65393 | 39.86 | 53658 |
| 14 | 59.36 | 68182 | 40.18 | 53225 |
| 15 | 59.36 | 67240 | 40.35 | 53904 |

Table 23. Simulation results for Scenario IIA.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 57.13 | 41903 | 38.38 | 65425 |
| 2 | 56.92 | 41376 | 38.69 | 69487 |
| 3 | 56.54 | 39358 | 39.64 | 79127 |
| 4 | 56.37 | 38955 | 40.43 | 102578 |
| 5 | 56.25 | 39171 | 40.67 | 101487 |
| 6 | 55.11 | 36335 | 41.63 | 102309 |
| 7 | 54.75 | 36914 | 42.14 | 102521 |
| 8 | 54.93 | 28764 | 42.33 | 103130 |
| 9 | 55.18 | 25377 | 42.57 | 103746 |
| 10 | 55.51 | 27350 | 42.91 | 104368 |
| 11 | 55.78 | 28443 | 43.17 | 104996 |
| 12 | 56.01 | 32450 | 43.41 | 105630 |
| 13 | 56.08 | 26998 | 43.52 | 112007 |
| 14 | 56.16 | 26969 | 43.77 | 106470 |
| 15 | 56.20 | 26002 | 44.01 | 106407 |

Table 24. Simulation results for Scenario IIB.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 57.13 | 41903 | 38.38 | 65425 |
| 2 | 56.92 | 41376 | 38.69 | 69487 |
| 3 | 56.54 | 39358 | 39.64 | 79127 |
| 4 | 56.37 | 38955 | 40.43 | 102578 |
| 5 | 56.25 | 39171 | 40.67 | 101487 |
| 6 | 55.11 | 36335 | 41.63 | 102309 |
| 7 | 54.75 | 36914 | 42.14 | 102521 |
| 8 | 54.93 | 28764 | 42.33 | 103130 |
| 9 | 55.18 | 25377 | 42.57 | 103746 |
| 10 | 55.53 | 32065 | 43.06 | 131068 |
| 11 | 55.79 | 31261 | 43.31 | 139594 |
| 12 | 56.00 | 29335 | 43.58 | 132574 |
| 13 | 56.11 | 26807 | 43.90 | 135385 |
| 14 | 56.17 | 26963 | 44.29 | 134354 |
| 15 | 56.20 | 26002 | 44.61 | 136088 |

Table 25. Simulation results for Scenario IIC.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 57.13 | 41903 | 38.38 | 65425 |
| 2 | 56.92 | 41376 | 38.69 | 69487 |
| 3 | 56.54 | 39358 | 39.64 | 9127 |
| 4 | 56.37 | 38955 | 40.43 | 102578 |
| 5 | 56.25 | 39171 | 40.67 | 101487 |
| 6 | 55.11 | 36335 | 41.63 | 102309 |
| 7 | 54.75 | 36914 | 42.14 | 102521 |
| 8 | 54.93 | 28764 | 42.33 | 103130 |
| 9 | 55.18 | 25377 | 42.57 | 103746 |
| 10 | 55.67 | 31978 | 43.57 | 186146 |
| 11 | 55.94 | 32085 | 43.98 | 184936 |
| 12 | 56.08 | 29282 | 44.36 | 185860 |
| 13 | 56.15 | 26954 | 44.80 | 187584 |
| 14 | 56.19 | 26951 | 45.12 | 187662 |
| 15 | 56.21 | 25996 | 45.51 | 186767 |

Table 26. Simulation results for Scenario IIIA.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 58.86 | 68154 | 37.91 | 65798 |
| 2 | 59.23 | 70954 | 37.93 | 69975 |
| 3 | 59.22 | 70358 | 38.73 | 78787 |
| 4 | 58.07 | 69233 | 40.06 | 101817 |
| 5 | 57.82 | 68139 | 40.32 | 102530 |
| 6 | 57.29 | 65979 | 40.81 | 101922 |
| 7 | 56.74 | 64066 | 41.56 | 104675 |
| 8 | 56.53 | 62595 | 42.07 | 103522 |
| 9 | 56.38 | 60152 | 42.71 | 104023 |
| 10 | 56.32 | 58678 | 43.36 | 104437 |
| 11 | 56.28 | 66124 | 43.68 | 104996 |
| 12 | 56.40 | 56323 | 43.80 | 105630 |
| 13 | 56.62 | 51360 | 44.02 | 106271 |
| 14 | 56.93 | 51790 | 44.32 | 106400 |
| 15 | 57.15 | 54414 | 44.55 | 106400 |

Table 27. Simulation results for Scenario IIIB.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 58.86 | 68154 | 37.91 | 65798 |
| 2 | 59.41 | 68629 | 38.17 | 74039 |
| 3 | 59.41 | 67957 | 39.12 | 81209 |
| 4 | 58.67 | 68966 | 40.63 | 101224 |
| 5 | 58.67 | 67688 | 41.10 | 101646 |
| 6 | 58.39 | 64490 | 41.88 | 102101 |
| 7 | 58.17 | 63177 | 42.78 | 104206 |
| 8 | 58.26 | 61519 | 43.56 | 105091 |
| 9 | 58.41 | 60488 | 44.46 | 104057 |
| 10 | 58.64 | 59166 | 45.30 | 104996 |
| 11 | 58.90 | 59404 | 45.65 | 104996 |
| 12 | 59.43 | 52022 | 46.11 | 105630 |
| 13 | 59.94 | 47646 | 46.56 | 106271 |
| 14 | 60.56 | 47204 | 47.10 | 106400 |
| 15 | 61.08 | 45841 | 47.57 | 106400 |

Table 28. Simulation results for Scenario IIIC.

| SIMULATION YEAR | LOG PRICE ($/CUNIT) | LOG VOLUME (CUNITS) | BOLT PRICE ($/CUNIT) | BOLT VOLUME (CUNITS) |
|---|---|---|---|---|
| 1 | 58.86 | 68154 | 37.91 | 65798 |
| 2 | 59.52 | 65911 | 38.40 | 72833 |
| 3 | 59.75 | 67957 | 39.52 | 83181 |
| 4 | 59.29 | 68966 | 41.21 | 100997 |
| 5 | 59.44 | 63596 | 41.99 | 101384 |
| 6 | 59.44 | 59996 | 43.00 | 101952 |
| 7 | 59.61 | 62282 | 44.04 | 103752 |
| 8 | 60.02 | 60426 | 45.04 | 104512 |
| 9 | 60.50 | 60759 | 46.21 | 103890 |
| 10 | 61.05 | 71473 | 47.27 | 104368 |
| 11 | 61.66 | 50838 | 47.73 | 104996 |
| 12 | 62.60 | 47880 | 48.54 | 105630 |
| 13 | 63.48 | 43041 | 49.27 | 106271 |
| 14 | 64.35 | 42446 | 50.01 | 106400 |
| 15 | 65.33 | 49130 | 50.85 | 117543 |

# *APPENDIX V*

```
//STEP1 EXEC FORTVCG
//FORT.SYSIN DD *
C
C PROGRAMMER: S. CLEMENTS   DATE: JUNE 1, 1987
C
C   ***  THIS PROGRAM DETERMINES THE MARKET EQUILIBRIUM QUANTITIES AND
C   ***  PRICES FOR LOGS AND BOLTS IN SOUTHWEST VIRGINIA.
C
C  DEFINITION OF PROGRAM VARIABLES
C
C  A(1825) - ARRAY FOR ACREAGE IN EACH RESPONSE CELL, ADJUSTED FOR
C            HAULING DISTANCE
C  ACC - ROAD BUILDING COSTS PER CUIT
C  ACCESS(5) - ROAD BUILDING COSTS PER ACRE FOR THE 5 ACCESS CODES
C  ACRE - FRACTION OF ACREAGE CUT IN MARGINAL RESPONSE CELL
C  AGE - STAND AGE
C  BC - SUM OF BOLT FELLING, SKIDDING, AND LOADING COSTS PER CUNIT
C  BEXP - EXPECTED BOLT STUMPAGE PRICE PER CUNIT
C  BOLT - TOTAL VOLUME OF BOLTS SUPPLIED
C  BPD - ABSOLUTE VALUE OF THE DIFFERENCE BETWEEN THE HIGH AND LOW
C        DELIVERED BOLT PRICE PER CUNIT, USED IN SEARCHING FOR
C        EQUILIBRIUM BOLT PRICE
C  BSP1 - REGIONAL BOLT STUMPAGE PRICE IN TIME PERIOD T-1
C  BSP2 - REGIONAL BOLT STUMPAGE PRICE IN TIME PERIOD T-2
C  BTOL - TOLERANCE BOLT VOLUME, EQUALS 5 PERCENT OF THE QUANTITY OF
C         BOLTS DEMANDED.
C  C(365,7) - ARRAY CONTAINING THE ORIGINAL RESPONSE CELL INFORMATION;
C             ARRAY POSITIONS ARE: OWNER TYPE, SITE CLASS, ACCESS CODE,
C             OPERABILITY CODE, STAND AGE, STOCKING PERCENT, AND ACRES.
C  CUT(1825) - ARRAY INDICATING IF A CELL IS HARVESTED IN TIME PERIOD T
C  DADJ(5) - PERCENTAGE OF COMMERCILA FOREST LAND AREA WITH THE FIVE
C            HAULING DISTANCES
C  DBV - DIFFERENCE BETWEEN THE QUANTITIES OF BOLTS SUPPLIED AND
C        DEMANDED, USED TO ALLOCATE VOLUME IN A MARGINAL RESPONSE CELL
C  DIFB - ABSOLUTE VALUE OF THE DIFFERENCE BETWEEN THE QUANTITIES OF
C         BOLTS SUPPLIED AND DEMANDED IN EACH ITERATION
C  DIFL - ABSOLUTE VALUE OF THE DIFFERENCE BETWEEN THE QUANTITIES OF
C         LOGS SUPPLIED AND DEMANDED IN EACH ITERATION
C  DIFBR - RELATIVE DIFFERENCE BETWEEN THE QUANTITIES OF
C          BOLTS SUPPLIED AND DEMANDED IN EACH ITERATION
C  DIFLR - RELATIVE DIFFERENCE BETWEEN THE QUANTITIES OF
C          LOGS SUPPLIED AND DEMANDED IN EACH ITERATION
C  DIF1 - RELATIVE DIFFERENCE BETWEEN THE QUANTITIES OF
C         LOGS SUPPLIED AND DEMANDED IN EACH ITERATION
C  DIF2 - RELATIVE DIFFERENCE BETWEEN THE QUANTITIES OF
C         BOLTS SUPPLIED AND DEMANDED IN EACH ITERATION
C  FELLL - FELLING COSTS PER CUNIT OF LOGS
C  FELLB - FELLING COSTS PER CUNIT OF BOLTS
C  GSS - STAND STOCKING PERCENT
C  HAULB(5) - HAULING COSTS PER CUNIT OF BOLTS FOR FIVE HAULING DISTANCES
C  HAULBD(5) - FIVE HAULING DISTANCES FOR BOLTS; 20, 26, 30, 42, AND 59
C  HAULL - HAULING COST PER CUNIT OF LOGS
C  HB - HIGH BOLT DELIVERED PRICE, USED IN SEARCH FOR EQUILIBRIUM PRICE
C  HC - WEIGHTED HARVESTING COST PER CUNIT IN RESPONSE I, WEIGHS EQUAL
C       KL(1825) AND KB(1825)
```

Figure 11. Program code listing fro the timber supply model.

```
C  HL - HIGH LOG DELIVERED PRICE, USED IN SEARCH FOR EQUILIBRIUM PRICE
C  ITER - ITERATION COUNTER FOR SOLUTION PROCEDURE; THE NUMBER OF
C         ITERATIONS IT TAKES TO FIND EQUILIBRIUM LOG AND BOLT PRICES
C  KB(1825) - RATIO OF BOLT VOLUME TO TOTAL VOLUME PER ACRE IN RESPONSE
C             CELL I
C  KL(1825) - RATIO OF LOG VOLUME TO TOTAL VOLUME PER ACRE IN RESPONSE
C             CELL I
C  LB - LOW BOLT DELIVERED PRICE USED IN SEARCH FOR EQUILIBIUM PRICE
C  LC - LOG HARVESTING COST PER CUNIT, EQUAL TO THE SUM OF FELLING,
C       SKIDDING, AND LOADING COSTS PER CUNIT OF LOGS
C  LEXP - EXPECTED LOG STUMPAGE PRICE PER CUNIT
C  LL - LOW LOG DELIVERED PRICE USED IN SEARCH FOR EQUILIBIUM PRICE
C  LOADB - LOADING COST PER CUNIT OF BOLTS
C  LOADL - LOADING COST PER CUNIT OF LOGS
C  LOGV - TOTAL LOG VOLUME SUPPLIED IN AN ITERATION
C  LPD - ABSOLUTE VALUE OF THE DIFFERENCE BETWEEN THE HIGH AND LOW
C        DELIVERED LOG PRICE
C  LSP1 - REGIONAL LOG STUMPAGE PRICE IN TIME TIME PERIOD T-1
C  LSP2 - REGIONAL LOG STUMPAGE PRICE IN TIME TIME PERIOD T-2
C  LTOL - TOLERANCE LOG VOLUME, EQUAL TO FIVE PERCENT OF THE LOG VOLUME
C         DEMANDED.
C  MC - THE WEIGHTED HARVEST PRICE PER CUNIT AND HARVEST COST PER CUNIT
C  MCID - INDICATES THE NUMBER OF THE MARGINAL RESPONSE CELL; RANGE FROM
C         1 TO 1825
C  MCID1 - INDICATES THE NUMBER OF THE MARGINAL RESPONSE CELL; RANGE FROM
C          1 TO 365
C  M1 - INDICATES IF A RESPONSE CELL IS MARGINAL FOR LOGS OR BOLTS
C  M2 - INDICATES IF THE MARGINAL RESPONSE CELL IS CUT FOR LOGS AND BOLT
C       (M2=1) OR FOR BOLTS ONLY (M2=0)
C  M3(1825 - INDICATES IF A RESPONSE CELL IS CUT FOR LOGS AND BOLT
C            (M3=2) OR FOR BOLTS ONLY (M3=1)
C  OA(1825) - ARRAY IDENTIFYING THE LANDOWNER PROPENSITY TO HARVEST
C  PB - DELIVERED BOLT PRICE PER CUNIT
C  PCNT - NUMBER OF RESPONSE CELLS IDENTIFIED AS PUBLIC OWNED
C  PL - DELIVERED LOG PRICE PER CUNIT
C  PBSP - AVERAGE BOLT STUMPAGE PRICE FOR PUBLIC LANDOWNERS
C  PLSP - AVERAGE LOG STUMPAGE PRICE FOR PUBLIC LANDOWNERS
C  QB - TOTAL QUANTITY OF BOLTS DEMANDED IN TIME PERIOD T; A FUNCTION OF
C       PAPER PRICES (SEE SUBROUTINE BLTDEM)
C  QL - TOTAL QUANTITY OF LOGS DEMANDED IN TIME PERIOD T; A FUNCTION OF
C       DELIVERED LOG PRICE, LAGGED HOUSING STARTS, AND SAWMILL INPUT
C       PRICES (SEE SUBROUTINE LOGDEM)
C  QR - VARIABLE INDICATING THE PERCENTAGE OF LOG VOLUME THAT COULD BE
C       CONSIDERED AS BOLT QUALITY
C  RCI - REAL COST INCREASE, USED TO COMPOUND HARVESTING AND HAULING
C        COST
C  RP - RESERVATION PRICE PER CUNIT
C  R1 - RATIO OF LAST PERIOD'S REGIONAL LOG AND BOLT STUMPAGE PRICES
C  SI - STAND SITE INDEX (BASE AGE 50)
C  SKIDB - SKIDDING COSTS PER CUNIT OF BOLTS
C  SKIDL - SKIDDING COSTS PER CUNIT OF LOGS
C  SP(365,2) - ARRAY CONTAINING STUMPAGE PRICES
C  TCS - WEIGHTED HAULING COSTS PER CUNIT; WEIGHTS ARE KL(1825) AND
C        KB(1825)
C  TIME - TIME PERIOD COUNTER, RANGE 1 TO 15
```

Figure 11 continued

```
C  TOT - TOTAL VOLUME PER ACRE IN TIME PERIOD T
C  TOT1 - TOTAL VOLUME PER ACRE IN TIME PERIOD T
C  TOT2 - TOTAL VOLUME PER ACRE IN TIME PERIOD T + 1
C  VOL(365,2) - LOG AND BOLT VOLUME PER ACRE IN EACH RESPONSE CELL
C  V1 - LOG VOLUME PER ACRE IN TIME PERIOD T
C  V2 - LOG VOLUME PER ACRE IN TIME PERIOD T + 1
C  V2B - BOLT VOLUME PER ACRE IN TIME PERIOD T + 1
C  WC(1825,4) - ARRAY CONTAINING INFORMATION ON TOTAL RECOVERY COSTS FOR
C               EACH RESPONSE CELL;  DATA PER CELL ARE WEIGHTED RECOVERY
C               COSTS PER CUNIT, PERCENTAGE OF ACREAGE FOR HAULING
C               DISTANCE ADJUSTMENT (SEE DADJ(1985)), ORIGINAL RESPONSE
C               CELL NUMBER (RANGE 1 TO 365), AND RECOVERY COST PER CUNIT
C               FOR BOLT ONLY HARVEST OPTION.
C
C  SPECIFY THE VARIABLES
C
      INTEGER K,ITER,TIME,MCID1,MCID
      INTEGER CUT(1825),PCNT,M1,M2,M3(1825)
      REAL SP(365,2),LC,BC,WC(1825,4),VOL(365,2),MC,ACC,RP,HC,TCS
      REAL DADJ(5),ACCESS(4),HAULB(5),KL(1825),KB(1825),OA(1825)
      REAL A(1825),C(365,7),HAULBD(5),R,R2,WT
      REAL LEXP,BEXP,LSP1,LSP2,BSP1,BSP2,FELLB,FELLL,SKIDB,SKIDL
      REAL LOADB,LOADL,HAULL,R1,TOT1,TOT2,V1,V2,V2B,PL,PB,QL,QB
      REAL BOLT,LOGV,SI,AGE,GSS,BIDL,BIDB,CBVOL,CLVOL
      REAL PLMBF,DIF1,DIF2,DIFL,DIFB,LTOL,BTOL,HL,LL,HB,LB
      REAL LPD,ACRE,NET,PLSP,PBSP,QR,RCI,DBV,DLV,BPD
C
C INITIAL VARIABLE VALUES
C
      DATA ACCESS/0.,15.,30.,75./,DADJ/.41,.08,.12,.16,.22/
      DATA HAULBD/20,26,30,42,59/
      DATA LSP1/23.7/,LSP2/22.92/,BSP1/3.8/,BSP2/3.79/
      DATA FELLB/13.88/,FELLL/9.25/,SKIDB/9.86/,SKIDL/6.57/
      DATA LOADB/5.21/,LOADL/3.47/
      DATA PL/58./,PB/35./,QR/0./
      DATA TIME/1/
C
C   PRINT OUTPUT HEADINGS
C
      WRITE(6,110)
  110 FORMAT(' ','YEAR',5X,'PL',7X,'LOG',5X,'PB',7X,'BOLT')
      WRITE(6,111)
  111 FORMAT(' ','----------------------------------------')
C
  200 IF(TIME.GT.15)GO TO 500
C
C  ESTIMATE EXPECTED LOG AND BOLT STUMPAGE PRICES
C
      LEXP=PEXL(LSP1,LSP2)
      BEXP=PEXB(BSP1,BSP2)
      R1=LSP1/BSP1
C
C  RESET VARIABLES TO ZERO
C
      HB=0.
```

Figure 11 continued

```
      LB=0.
      HL=0.
      LL=0.
      M1=0
      M2=0
      MCID = 0
      MCID1 = 0
      K=0
      PLSP = 0.
      PCNT = 0
      ITER=0
C
C  CALCULATE HARVESTING AND HAULLING COSTS
C
      LC = FELLL + SKIDL + LOADL
      BC = FELLB + SKIDB + LOADB
      HAULL = 75.*1.65/7.2
C     HAULL = 75.*(1.65*1.010**(TIME-1))/7.2
      DO 2 J = 1,5
        HAULB(J) = HAULBD(J)*1.65/7.2
C       HAULB(J) = HAULBD(J)*(1.65*1.010**(TIME-1))/7.2
    2 CONTINUE
C
C  READ DATA CARDS (INPUT UNIT = 5) CONTAINING THE FOLLOWING CELL
C  INFORMATION: OWNER TYPE, SITE CLASS, ACCESSIBLITY, OPERABILITY
C  AGE, GROWING STOCK STOCKING, AND ACRES
C
      DO 5 I = 1,365
        IF(TIME.GT.1) GO TO 100
        READ(5,10)(C(I,J),J=1,7)
   10   FORMAT(F2.0,1X,F1.0,1X,F1.0,1X,F1.0,1X,F3.0,1X,F3.0,1X,F4.0)
        IF(C(I,2).EQ.1.OR.C(I,2).EQ.2.OR.C(I,2).EQ.3) C(I,2)=80
          IF(C(I,2).EQ.4) C(I,2)=60
            IF(C(I,2).EQ.5) C(I,2)=45
        IF(C(I,1).EQ.10) C(I,1)=0.120
          IF(C(I,1).EQ.20) C(I,1)=0.100
            IF(C(I,1).EQ.40) C(I,1)=0.084
              IF(C(I,1).EQ.60.OR.C(I,1).EQ.70) C(I,1)=0.096
        IF(C(I,4).EQ.1.OR.C(I,4).EQ.2) C(I,4)=.90
          IF(C(I,4).EQ.3) C(I,4)=1.00
            IF(C(I,4).EQ.5) C(I,4)=1.05
              IF(C(I,4).EQ.7) C(I,4)=1.15
        C(I,5)=C(I,5)+1
C
C  DETERMINE CELL VOLUMES
C
  100   AGE=C(I,5)
        SI=C(I,2)
        GSS=C(I,6)
        TOT1=TVOL(AGE,SI,GSS)
        TOT2=TVOL(AGE+1,SI,GSS)
        V1=VOLLL(AGE,SI,GSS)
        V2=VOLLL(AGE+1,SI,GSS)
        IF(V1.LT.TOT1)GO TO 15
          VOL(I,2)=TOT1*QR
```

Figure 11 continued

```
          VOL(I,1)=TOT1*(1-QR)
          GO TO 20
   15 VOL(I,1)=V1*(1-QR)
      VOL(I,2)=TOT1-V1*(1-QR)
   20 IF(V2.LT.TOT2)GO TO 25
        V2=TOT2*(1-QR)
        V2B=TOT2*QR
        GO TO 30
   25 V2B=TOT2-V2*(1-QR)
      V2 = V2*(1-QR)
C
C  DETERMINE STUMPAGE PRICES
C
      SP(I,2)=(LEXP*V2+BEXP*V2B)/(1.04*(R1*VOL(I,1)+VOL(I,2)))
      SP(I,1)=R1*SP(I,2)
      GO TO 35
   30 SP(I,1)=(LEXP*V2)/(1.04*VOL(I,1))
      SP(I,2)=0.
   35 IF(C(I,1).NE..12)GO TO 5
        PLSP = PLSP + SP(I,1)
        PCNT = PCNT + 1
    5 CONTINUE
      PLSP = PLSP/PCNT
      PBSP = PLSP/R1
      K = 0
C
C   DETERMINE HARVEST AND HAULING COSTS
C
      DO 36 I=1,365
      TOT = VOL(I,1) + VOL(I,2)
      N=IFIX(C(I,3))
      ACC=ACCESS(N)/TOT
      IF(C(I,1).EQ..12)SP(I,1) = PLSP
      IF(C(I,1).EQ..12)SP(I,2) = PBSP
      RCI = 1.0
C     RCI = 1.010**(TIME-1)
      L=0
C
C   DETERMINE COMPOSITE RECOVERY COSTS
C
   45 IF(K.GT.I*4)GO TO 40
        J=I+K
        KB(J)=VOL(I,2)/TOT
        KL(J)=VOL(I,1)/TOT
        RP = SP(I,1)*KL(J) + SP(I,2)*KB(J)
        HC=((LC*KL(J) + BC*KB(J))*C(I,4) + ACC)*RCI
        TCS = HAULL*KL(J) + HAULB(L+1)*KB(J)
        WC(J,1) = HC + RP + TCS
        WC(J,4) = HC + RP + HAULB(L+1)
        WC(J,2)=DADJ(L+1)
        WC(J,3)=FLOAT(I)
        OA(J)=C(I,1)
        IF(TIME.GT.1) GO TO 150
        A(J)=C(I,7)*DADJ(L+1)
  150   IF(C(I,5).LE.30) WC(J,1)=999.
```

Figure 11 continued

```
          K=K+1
          L=L+1
          GO TO 45
   40 K=I*4
   36 CONTINUE
C
C  DETERMINE THE VOLUME OF BOLTS DEMANDED
C
      CALL BLTDEM(TIME,QB)
C
C SELECT CELLS PROFITABLE TO HARVEST
C
   90 IF(ITER.GE.600)GO TO 500
      BOLT=0.
      LOGV=0.
      CALL PROFIT(WC,KB,KL,VOL,A,OA,CUT,BOLT,LOGV,PL,PB,MC,
     1     MCID,MCID1,M1,M2,M3)
      ITER=ITER+1
C
C  DETERMINE IF EQUILIBRIUM HAS BEEN ACHIEVED
C
      CALL LOGDEM(TIME,PL,QL)
C     WRITE(6,*)LOGV,QL,PL,BOLT,QB,PB
   56 DIF1=LOGV-QL
      DIF2=BOLT-QB
      DIFL=ABS(DIF1)
      DIFB=ABS(DIF2)
      LTOL=QL*.05
      BTOL=QB*.05
      IF(DIFL.LE.LTOL.AND.DIFB.LE.BTOL) GO TO 95
        DIFLR=DIFL/QL
        DIFBR=DIFB/QB
C
C  DETERMINE IF A MARGINAL RESPONSE CELL HAS BEEN FOUND
C
        LPD = ABS(HL - LL)
        BPD = ABS(HB - LB)
        IF(HL.NE.0.)GO TO 52
          LPD = 2.
   52   IF(HB.NE.0.)GO TO 51
          BPD = 2.
   51   IF(LPD.LE.0.01.AND.DIFL.GT.LTOL)GO TO 55
          IF(BPD.LE.0.01.AND.DIFB.GT.BTOL)GO TO 65
            IF(DIFLR.LT.DIFBR) GO TO 80
              CALL SEARCH(PL,HL,LL,DIF1)
              GO TO 90
   80       CALL SEARCH(PB,HB,LB,DIF2)
            GO TO 90
   55   IF(BPD.LE.0.01.AND.DIFB.GT.BTOL)GO TO 50
          IF(DIFB.LE.BTOL)GO TO 61
C           PL = HL
            CALL SEARCH(PB,HB,LB,DIF2)
            BPD = ABS(HB-LB)
            IF(BPD.LE..01.AND.DIFB.GT.BTOL)GO TO 50
            GO TO 90
```

Figure 11 continued

```
   61      M1 = 1
           PL = HL
           GO TO 60
   65    IF(DIFL.LE.LTOL)GO TO 62
C          PB = HB
           CALL SEARCH(PL,HL,LL,DIF1)
           GO TO 90
   62    M1 = 2
         PB = HB
         GO TO 60
   50    LOGV = LOGV + (BOLT - QB*.95)
         BOLT = QB*.95
         GO TO 95
C
C  DETERMINE THE MARGIN CELL AND ADJUST PRICE TO HARVEST IT
C
   60 BOLT=0.
      LOGV=0.
      CALL PROFIT(WC,KB,KL,VOL,A,OA,CUT,BOLT,LOGV,PL,PB,MC,
     1     MCID,MCID1,M1,M2,M3)
      IF(M1.EQ.1) CALL LOGDEM(TIME,PL,QL)
C     WRITE(6,*)LOGV,QL,PL,BOLT,QB,PB
      K = MCID
      L = MCID1
      IF(M1.EQ.1) GO TO 70
        IF(M2.EQ.0)CBVOL = VOL(L,2)/100.
          IF(M2.EQ.1)CBVOL = (VOL(L,1)+VOL(L,2))/100.
            DBV = BOLT - QB
            BOLT = QB
            IF(M2.EQ.1)ACRE = DBV/CBVOL
              GO TO 95
   70 CLVOL = VOL(L,1)/100.
      LOGV = QL
C     WRITE(6,*)LOGV,QL,PL,BOLT,QB,PB
      HL = 0.
      LL = 0.
      HB = 0.
      LB = 0.
      GO TO 56
C
C ADJUST CELL ACREAGE FOR HARVEST AND DETERMINE REGIONAL
C  STUMPAGE AVERAGE STUMPAGE PRICE
C
   95 K=0
      DO 120 I=1,365
        C(I,5)=C(I,5)+1
  130   IF(K.GT.I*4) GO TO 115
          J=I+K
          IF(CUT(J).EQ.0) GO TO 125
            IF(J.EQ.MCID)GO TO 122
              A(J)=A(J)*(1-OA(J))
              GO TO 125
  122         A(J) = A(J) - ACRE
  125       K=K+1
        GO TO 130
```

Figure 11 continued

```
  115 K=I*4
  120 CONTINUE
      LSP2=LSP1
      LSP1=.4*PL
      BSP2=BSP1
      BSP1=.11*PB
C     WRITE(6,*)LSP1,BSP1
C
C  PRINT OUTPUT
C
      WRITE(6,112)TIME,PL,LOGV,PB,BOLT
  112 FORMAT('0',1X,I2,5X,F5.2,2X,F7.0,4X,F5.2,3X,F7.0)
      TIME=TIME+1
      GO TO 200
  500 STOP
      END
C
C  FUNCTIONS FOR EXPECTED LOG (PEXL) AND BOLT (PEXP) STUMPAGE PRICES
C
      REAL FUNCTION PEXL(X,Y)
          REAL X,Y
          PEXL=Y+0.61*(X-Y)
      RETURN
      END
      REAL FUNCTION PEXB(X,Y)
          REAL X,Y
          PEXB=Y+0.34*(X-Y)
      RETURN
      END
C
C  FUNCTIONS FOR TOTAL (TVOL) AND LOG (VOLLL) VOLUMES PER ACRE
C
      REAL FUNCTION TVOL(X,Y,Z)
          REAL X,Y,Z
          TVOL=EXP(2.43-62.94/X+.63*Y/X+1.19*ALOG(Z))
      RETURN
      END
      REAL FUNCTION VOLLL(X,Y,Z)
          REAL X,Y,Z
          VOLLL=EXP(.053*X+.051*Y+1.01*ALOG(Z)-4.45)
      RETURN
      END
C
C  SUBROUTINE TO PREDICT THE QUANTITY OF LOGS DEMANDED
C
      SUBROUTINE LOGDEM(T,P,Q)
          REAL P,Q,PMBF,LHS,WTCI,Q1
          INTEGER T
          PMBF=P*2.4
          IF(T.EQ.1)LHS=1756
          IF(T.EQ.2)LHS=1831
          IF(T.EQ.3)LHS=1732
          IF(T.EQ.4)LHS=1737
          IF(T.EQ.5)LHS=1595
          IF(T.EQ.6)LHS=1295
```

Figure 11 continued

```
            IF(T.EQ.7)LHS=1684
            IF(T.EQ.8)LHS=1595
            IF(T.EQ.9)LHS=1607
            IF(T.EQ.10)LHS=1592
            IF(T.EQ.11)LHS=1699
            IF(T.EQ.12)LHS=1586
            IF(T.EQ.13)LHS=1382
            IF(T.EQ.14)LHS=1628
            IF(T.EQ.15)LHS=1691
            LHS = LHS * 1.00
C           IF(T.LE.4)WTCI=1.02537*.98**T
C           IF(T.GT.4)WTCI=.94577*1.010**T
            WTCI=1.02537*1.015**T
            Q1=57491.176-107.8613*PMBF+2.1517283*LHS-27884.9851*WTCI
C           IF(T.LE.5)Q=(Q1*2.4)+14400
C           IF(T.GT.5)Q=(Q1*2.4)+28800
            Q=(Q1*2.4)
        RETURN
        END
C
C   SUBROUTINE TO DETERMINE THE QUANTITY OF BOLTS DEMANDED
C
        SUBROUTINE BLTDEM(T,Q)
        REAL Q1,Q PPI
        INTEGER T
        PPI = 1.074*1.01**T
        Q1 = -15313.39 + 69657.9828 * PPI
        IF(Q1.GT.70000.)GO TO 5
          GO TO 10
      5 Q1=70000.
C    10 IF(T.LE.3)Q1=Q1+22000*1.3654**(T-1)
C       IF(T.GE.4.AND.T.LT.10)Q1=Q1+70000
C       IF(T.GE.10)Q1=Q1+105000
C       Q=Q1*.8
     10 Q=Q1*.8
        RETURN
        END
C
C   SUBROUTINE TO FIND EQUILIBRIUM PRICES
C     BASED ON A BINARY SEARCH APPROACH
C
        SUBROUTINE SEARCH(P,H,L,D)
        REAL P,H,L,D
        IF(D.GT.0) GO TO 5
          L=P
          IF(H.EQ.0.0)GO TO 15
            P=P+.01
            IF(P.LT.H)GO TO 10
              P = L+(H-L)/2
              GO TO 10
     15     P=L+.01
            GO TO 10
      5 H = P
        P = P-.01
        IF(P.GT.L)GO TO 10
```

Figure 11 continued

```
      P = H-(H-L)/2
   10 RETURN
      END
C
C  SUBROUTINE TO DETERMINE WHICH RESPONSE CELLS ARE PROFITABLE TO
C     HARVEST, GIVEN DELIVERED LOG AND BOLT PRICES
C
      SUBROUTINE PROFIT(WC,KB,KL,VOL,A,OA,CUT,BOLT,LOGV,PL,PB,
     1           MC,MCID,MCID1,M1,M2,M3)
      REAL BOLT,LOGV,PL,PB,MLC,NET,NET1,NET2,PVOL,AAC(15),MC
      REAL WC(1825,4),KB(1825),KL(1825),VOL(365,2),A(1825),OA(1825)
      INTEGER MCID,MCID1,K,CUT(1825),M1,M2,M3(1825)
      DATA AAC/16000,17000,17000,17500,17500,18000,18000,18000,
     1         18000,18000,18000,18000,18000,18000,18000/
C     DATA AAC/18000,19000,19000,19500,19500,20000,20000,20000,
C    1         20000,20000,20000,20000,20000,20000,20000/
      MC = 0.
      PVOL = 0.0
      DO 5 I = 1,1825
        NET2 = (PL*KL(I)+PB*KB(I))-WC(I,1)
        NET1 = PB - WC(I,4)
        NET = AMAX1(NET1,NET2)
        K = IFIX(WC(I,3))
        IF(NET.GE.0.0)GO TO 10
   30     CUT(I) = 0
          M3(I) = 0
          GO TO 5
   10   IF(M1.EQ.0) GO TO 20
          IF(M1.EQ.2) GO TO 45
            IF(M1.EQ.1.AND.NET.EQ.NET2) GO TO 45
              GO TO 20
   45   IF(I.EQ.1.OR.MC.EQ.0.)GO TO 15
          IF(NET.GT.MC)GO TO 20
   15        MC = NET
             MCID = I
             MCID1 = IFIX(WC(I,3))
   20        IF(OA(I).NE..12)GO TO 25
               PVOL=PVOL+(VOL(K,1)+VOL(K,2))/100.*A(I)*OA(I)
               IF(PVOL.GE.AAC(T))GO TO 30
   25     IF(NET.NE.NET1)GO TO 35
            M2 = 1
            M3(I) = 1
            BOLT=BOLT+(VOL(K,1)+VOL(K,2))/100.*A(I)*OA(I)
            GO TO 40
   35     M2 = 0
          M3(I) = 2
          BOLT = BOLT + (VOL(K,2)/100.)*A(I)*OA(I)
          LOGV = LOGV + (VOL(K,1)/100.)*A(I)*OA(I)
   40     CUT(I) = 1
    5 CONTINUE
      RETURN
      END
/*
//GO.SYSIN DD *
C  DATA CARDS GO HERE
```

Figure 11 continued

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