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A LINEAR PROGRAMMING MODEL APPLIED TO THE SUPPLY OF PRIMARY HARDWOOD PRODUCTS IN THE UNITED STATES 1990 TO 2030

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A linear programming model applied to the supply
of primary hardwood products in the
United States 1990 to 2030

by

Francis Nwonwu

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
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INTRODUCTION

Problem Statement

Trends of the past decades have shown that the U.S. consumption of certain timber products such as pulpwood, lumber, plywood and boards (particleboard, hardboard and insulating board) exceeded their production. Projections based on expected increases in population, economic activity, and income show that the demand for these products is likely to grow rapidly in the decades ahead and will exceed domestic supply (USDA Forest Service, 1981a).

Rising prices of timber products, particularly softwood timber products, have also been observed in the past (Table 1) and it is expected to continue in the future. This phenomenon in which there is a coexistence of increased demand and rising prices under less supply will likely exert further upward pressures on product prices, thereby making consumers buy less quantity of products at higher prices (see Figure 1). In extreme cases, consumers may switch over to cheaper non-wood products such as concrete, plastics, aluminum, and structural steel. Already, concrete is displacing hardwood lumber in flooring (McKillop et al., 1980), while plastics are replacing wood in furniture making. These substitutions may not be very favorable to the forestry subsector if it continues indefinitely.

Table 1. Producer price indexes for lumber and selected nonwood competing materials, 1950-1977[a] (1967=100)

Year	Softwood lumber		Hardwood lumber		Steel structural shapes		Concrete products	
	Actual	Relative[b]	Actual	Relative	Actual	Relative	Actual	Relative
1950	88.1	107.7	82.1	100.4	56.6	69.2	78.2	95.6
1951	95.6	104.9	88.2	96.8	60.0	65.9	83.3	91.4
1952	95.2	107.4	81.2	91.6	61.3	69.2	83.4	94.1
1953	93.2	106.6	82.8	94.7	64.7	74.0	85.5	97.8
1954	91.8	104.8	81.0	92.5	67.3	76.8	87.1	99.4
1955	97.7	111.3	85.7	97.6	71.0	80.9	88.0	100.2
1956	98.5	103.6	91.1	100.4	76.2	84.0	91.1	100.4
1957	92.6	99.2	86.3	92.5	87.7	94.0	93.6	100.3
1958	90.8	96.0	86.3	91.2	91.4	96.6	94.9	100.3
1959	98.7	104.1	89.9	94.8	93.4	98.5	96.1	101.4
1960	92.7	97.7	90.8	95.7	93.4	98.4	97.2	102.4
1961	87.9	93.0	86.2	91.2	93.4	98.8	97.2	102.9
1962	90.o	95.0	86.0	90.7	93.4	98.8	97.3	102.6
1963	92.1	97.5	88.8	94.0	94.1	99.6	96.5	102.1
1964	93.3	98.5	92.2	97.4	96.2	101.6	95.7	101.1
1965	93.1	96.4	97.4	100.8	96.2	99.6	96.3	99.7
1966	97.7	97.9	108.7	108.9	99.9	100.1	97.7	97.9
1967	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a]Source: Adapted from USDA Forest Service (1981b), Miscellaneous Publication No. 1408, pages 52 and 53.

[b]Derived by dividing the actual price index by the all commodities index x 100.

Table 1. (Continued)

Year	Softwood lumber		Hardwood lumber		Steel structural shapes		Concrete products	
	Actual	Relative	Actual	Relative	Actual	Relative	Actual	Relative
1968	120.7	117.8	104.5	102.0	101.8	99.3	102.6	100.1
1969	134.5	126.3	120.1	112.8	108.1	101.5	106.5	100.0
1970	113.3	102.6	114.6	103.8	115.3	104.4	112.2	101.6
1971	141.6	124.2	113.4	99.5	127.0	111.4	120.6	105.8
1972	167.7	140.8	126.2	106.0	134.6	113.0	125.6	105.5
1973	214.3	159.1	169.0	125.5	140.7	104.5	131.7	97.8
1974	211.4	132.0	189.5	118.4	179.0	111.8	151.7	94.8
1975	200.6	114.7	160.3	91.7	216.3	123.7	170.5	97.5
1976	248.1	135.6	176.0	96.2	227.1	124.1	180.1	98.4
1977	297.4	153.1	200.3	103.1	241.2	124.2	191.8	98.8

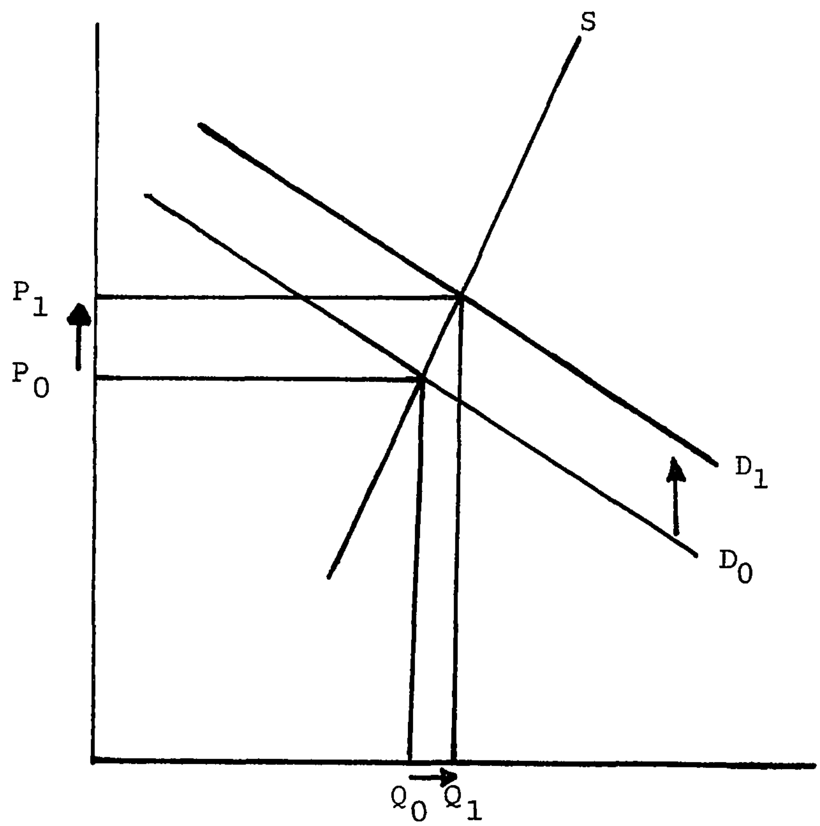

Figure 1. Price and quantity changes with a shift in demand (when the demand changes from D_0 to D_1 and given the supply S, the change in price from P_0 to P_1 is much higher than the change in quantity from Q_0 to Q_1)

The possibility of increasing hardwood timber products supply to augment the supply of softwood timber products has generated a lot of interest in the recent past. It is expected that increased production of hardwood products will help increase the aggregate wood products supply and, consequently, lower prices and prevent further substitution away from timber products. Hair and Spada (1970) have indicated that the U.S. hardwood commercial forestland has the capacity to produce all future hardwood products requirements of the country. There is also an increasing potential for the manufacture of veneer and plywood from the United States hardwoods, especially in the south (Lutz, 1975). Actual and relative prices of hardwood products over the past decades have been fairly constant as shown in Table 1 for hardwood lumber. The figures show a general actual price increase for softwood and hardwood lumber and for steel and concrete. But the relative price of softwood lumber has been on the increase and that of hardwood lumber is fairly constant. Steel has shown only a gentle increase while concrete shows a gentle decline.

Given this attribute of hardwood products, the provision of additional information such as production and supply costs including regional land productivity differentials will go a long way in helping policymakers in exploring the hardwood products supply potentials of the country.

The aim of this study is to develop a cost minimizing model that could help throw more light into the hardwood supply possibilities that will facilitate the meeting of future demands of hardwood products in the United States.

Historical Review

The need for continuous factual and objective analyses of the prospective renewable resource situation has always been of utmost concern to the United States Congress and other government agencies connected with the administration, management, and use of the U.S. forest resources. Congressional interest was first expressed in the Appropriations Act of August 15, 1876. By this Act, $2,000 was appropriated for the employment of an expert to study and report on forest conditions in the country. Other Congressional directives for forestry or timber studies followed on an as-needed basis. The McSweeney-McNary Act of 1927 directed the Secretary of Agriculture to assess, on a continuing basis, the forest situation in the United States.

> Section 9 of this Act authorized and directed the Secretary of Agriculture to cooperate with states, private owners, and other agencies in making and keeping current a comprehensive survey of the present and prospective requirements for timber and other forest products in the United States, and potential productivity of forested land therein and of such other facts as may be necessary in determining ways and means to balance the timber budget of the United States (USDA Forest Service, 1981a).

The Renewable Resource Planning Act of 1974 as amended by the National Forest Management Act of 1976 amended and broadened the McSweeney-McNary Act to include rangelands. Under this legislation, the Secretary of Agriculture is directed to:

> ...prepare a Renewable Resource Assessment.... The Assessment shall be prepared not later than December 31, 1975, and shall be updated during 1979 and each tenth year thereafter, and shall include but not be limited to (1) An analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply and demand and price relationship trends; (2) An inventory, based on information developed by the Forest Service and other Federal Agencies, of present and potential renewable resources, and an evaluation of opportunities for improving their yield of both tangible and intangible goods and services; (3) A discussion of important policy considerations, laws, regulations, and other factors expected to influence and affect significantly the use, ownership, and management of forest, range, and other associated lands.

In response to the legislation, the USDA Forest Service published in October 1981 a report captioned, "An Assessment of the Forest and Range Land Situation in the United States." The Assessment presents an analysis of the present situation and outlook for outdoor recreation and wilderness, wildlife and fish, forest-range grazing, timber, and water. The analysis shows that the nation's demands for outdoor recreation, wildlife and fish, range grazing, timber, and water have been growing rapidly and will continue to rise in the decades ahead.

Today, many local, state, and federal agencies, including private enterprises, in collaboration with the U.S. Forest Service are engaged in managing the U.S. forest resources to meet the present and future timber and associated products requirements of the country.

Factors Influencing Timber Products Demand

Economic indicators such as (1) the rate of growth of the population; (2) gross national product (GNP)--the value of all goods and services produced in the economy in a given time period; (3) disposable personal income (DPI)--the income available for spending by the nation's population; (4) product prices; and (5) other factors like changes in technology do have direct effects on the demand for timber products. Table 2 shows projected values and annual rates of change for population, GNP, and DPI and their corresponding per capita values for the period 1990-2030.

Changes in population affect demand for housing and affect household sizes, all of which impact on timber products demand. Population changes also influence the size of the labor force which is a major determinant of the level of economic activity and related materials use. The Bureau of the Census projections indicate that population is likely to continue to grow fairly rapidly. (The 1980 census reported a 1.0% rate of growth of the population.) The Census Series

Table 2. Projections of population, gross national product (GNP), and disposable personel income (DPI), in the United States, 1990 to 2030--medium projection[a]

	Population		GNP		Per capita GNP		DPI		Per capita DPI	
Year	Millions	ARC[b]	Billions of 1972 dollars	ARC	1972 dollars	ARC	Billions of 1972 dollars	ARC	1972 dollars	ARC
Base year										
1978	218.5	0.7	1,399.2	4.4	6,404	3.6	972.5	4.6	4,449	3.8
Projection year										
1990	243.5	0.9	2,070	3.7	8.500	2.8	1,450	3.7	5,950	2.8
2000	260.4	0.7	2,690	2.7	10,300	2.0	1,880	2.6	7,200	2.0
2010	275.3	0.6	3,440	2.5	12,500	1.9	2,410	2.5	8.750	1.9
2020	290.1	0.3	4,190	2.0	14,440	1.5	2,930	2.0	10,100	1.4
2030	300.3	0.3	5,160	2.1	17,180	1.8	3,610	2.1	12,020	1.8

[a]Sources: Adapted from "An analysis of the timber situation in the United States, 1952-2030" (USDA, Forest Service, 1980). Population: USDC, Bureau of the Census (1977a); Gross national product: USDC, Bureau of Economic Analysis, unpublished data; Disposable personal income: USDA, Forest Service (1980).

[b]ARC = annual rate of change.

II medium projection shows the population of the United States rising by 81 million to 300 million in the year 2030 (USDC, Bureau of the Census, 1977a).

Changes in the GNP have been closely associated with changes in the consumption of most timber products. Projections by the U.S. Department of Commerce, Bureau of Economic Analysis (1979) indicate a GNP of $5,160 billion (1972 dollars) in the year 2030 which will be 3.7 times that of 1978. The associated projection of per capita GNP in the same year would be $17,180 which nearly triples the 1977 average.

The DPI is another important factor that influences the demand for certain timber products, including various grades of paper and board. It also influences household formation, size of dwellings and furniture consumption, all of which are important determinants of the demand for timber products. The DPI is projected to grow from $973 billion in 1978 to $3,610 billion (1972 dollars) in 2030. The corresponding per capita disposable income is projected to rise to $12,020 in 2030, some 2.7 times the 1977 average (USDA, Forest Service, 1980) (see Table 2).

Product prices are significant shifters of demands for the products including their substitutes. The high price of timber, especially softwood timber, is increasingly shifting demands to substitutes such as plastics, concrete and steel. It is a common economic principle that the higher the price of a product, the lower the quantity of it demanded and the lower the price, the higher the quantity. It is hoped that the provision of useful information on how best to increase supply of products will help meet supply goals and prevent unnecessary price increases.

The housing industry is a good indicator of the level of economic activity. An increase in housing starts increases the demand for timber products such as lumber and plywood. New housing has long been the largest single market for lumber products in the United States. In 1976, about 39% of the lumber, 40% of the plywood, and substantial volumes of other wood-based panel products were used for new housing construction (USDA, Forest Service, 1980). The construction of new nonresidential buildings and other structures accounted for about 10% of the lumber and plywood and substantial volumes of the hardboard, insulating board, and particleboard consumed in the country in 1976 (USDA, Forest Service, 1980).

The current recession in the country has precipitated a downturn in the demand for housing. But with the recent indication of a recovery following the fall in interest rates[1],

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[1]The Federal Reserve System (FED) had raised its prime rate (lending rate to commercial banks) to an all-time high of about 12%. It recently lowered this rate to about 9%. The commercial banks in response to this have lowered their rates of interest on loans. This is expected to attract more housing loans and subsequently increase housing demands.

an increase in housing demand and, therefore, timber products, is soon to be experienced.

Technological changes have in many respects influenced the use of timber products through shifts in the use of raw materials including the partial displacement of timber products by steel, concrete and plastics. The development of economical water resistant adhesives for exterior grades of plywood has led to huge increases in plywood use. A new technology has led to large increases of hardwood lumber in pallets and of panel products such as hardboard and particleboard in a wide variety of end uses. According to the USDA, Forest Service (1980), between 1970 and 1976, the value of shipments (in 1972 dollars) of wooden containers, e.g., nailed boxes and crates, wirebound boxes and crates, and veneer and plywood containers, dropped more than 27%, after a rise in the 1960s. This decline apparently reflected the acceleration of the displacement of wooden containers by fiber and plastic containers, metal and fiber barrels and pails, and multiwalled bags following new technological developments.

Factors Influencing Timber Products Supply

The land base issue is a significant factor to consider in managing the commercial forestlands of the United States and in improving their productivity.[1]

Changes in land use have caused fluctuations in forestland areas and this trend is expected to continue in the future. For example, the area of commercial timberland rose from 499 million acres in 1952 to 509 in 1962, and thereafter has declined to the present 482 million acres or nearly two-thirds of the forestland (USDA, Forest Service, 1978). The total area of forest and rangeland (land less than 10% stocked of forest trees of any size) is projected to be about 5% lower by 2030, with decreases of 2% for forestlands (from 736 to 718 million acres) (USDA, Forest Service, 1981a). The decline is in response to land clearing for cropland, pasture land, roads, and residential areas; reservation for other uses such as wilderness and parks; and a slowdown in the area of crop and pasture land reverting to forests. Uncertainties of forestland availability for timber growing cause uncertainties in timber and timber products output.

Institutional policies have to a great extent affected the land base issue and to a reasonable extent caused uncertainty of purpose. Most of the 460 million acres administered by the Bureau of Land Management and the 187 million acres of national forests are called multiple-use lands

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[1]Forestland is classified as commercial if it is capable of producing at least 20 cubic feet of industrial wood per acre per year and not reserved for uses which are not compatible with timber production.

because no overall use priorities have been established (USDA, Forest Service, 1981a). The Wilderness Act[1], for instance, has been the focal point of a controversy which has resulted in more than a decade of uncertainty about lands that will be available for timber production. It has contributed to the scarcity of timber offered for wood products manufacture. Questions often arise as to which lands will be actively managed for multipurposes, including timber production, and which lands will be managed and designated "wilderness areas." The Second Roadless Area Review and Evaluation (RARE II)[2] is another institutional factor that may cause a fall in timber and associated products supply both now and in the future unless it is quickly resolved.

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[1]The Wilderness Act was passed in 1964. By this Act, Congress established a National Wilderness Preservation System composed of federally owned lands designated as "wilderness areas." The Act required all of the areas which had been classified under the Secretary of Agriculture regulations as wilderness, wild, or canoe areas to be designated as wilderness areas. Wilderness, according to the Act, is "an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not stay."

[2]RARE II is a national study completed in 1978 by the Forest Service. The objectives were: (1) to recommend to Congress roadless areas that should be designated as wilderness to help round out the National Wilderness Preservation System; (2) to determine roadless areas that should be made immediately available to nonwilderness uses; (3) to identify areas that require further study. Over 2,600 roadless areas, covering 62 million acres and located in 37 states and Puerto Rico were evaluated by the Forest Service in the study.

RARE II has faced many challenges which could tie up the nonwilderness areas for years to come. More delay of this nature will only worsen an already chaotic situation and prevent improved productivity necessary to supply the wood needs of the people.

The low productivity of the nonindustrial private woodland adversely affects products supply, especially the hardwood products supply, of the country. This portion of the commercial timberland constitutes 278 million acres (Day, 1980) or 58% of the total. This large holding coupled with the low productivity further worsens the supply situation. It has been alleged that the timber-growing potential of private nonindustrial forestland is not being met; a situation that is feared militates against increased timber supply for products manufacture. According to the National Forest Products Association (1982), studies done to ascertain the ownership goals of these individuals, some of whom are farmers, tree farmers, etc., show their woodlands need silvicultural treatments; tenures are short and objectives change as owners change; and there exists a gross inadequacy in regeneration after harvest to the extent that only about one in nine harvested acres are regenerated purposefully.

It is possible that the low productivity of the private nonindustrial sector is related to high interest rates which make the acquisition of production capital more difficult for the private nonindustrial than for industrial woodland owners. It is also likely that conflicts may exist between the industrial or societal management goals and the goals of the private nonindustrial owners. In general, uncertainties of product supplies do exert upward pressures on prices. It has been reported that, in the South where timber supply is mostly from private nonindustrial woodlands, timber prices rose 289% between 1970 and 1980 (National Forest Products Association, 1982). Such a rise in timber prices is expected to be transmitted to the resulting timber products.

By 1981, about 975,000 people were engaged in primary wood products production (USDC, Bureau of the Census, 1982), many in rural areas where timber is the only raw material available to support the total economy. With demands for timber, plywood, woodpulp, and other products increasing more rapidly than available timber supplies, timber and timber product prices continue to rise. The growing needs for raw materials for housing and other economic developments in the country might therefore be met in part by greater use of substitutes for timber such as steel, concrete, aluminum, and plastics. This alternative involves problems of high energy requirements, pollution impacts, trade and payment imbalances, and accelerated depletion of nonrenewable resources (McKillop, 1978). For instance, the value of U.S.

imports of hardwood lumber and shaped hardwoods stood at about 5 million dollars in 1979, while the value of exports to the same region in the same year stood at only 1 million dollars (United Nations, 1981).

The Role of Hardwoods

The expected growth in population and the rate of economic activity as already indicated would mean that the United States will be faced not only with the task of meeting the resource demands of an additional population, but the demands of a larger population with a much greater purchasing power. Faced with the problem of (1) increasing demand for timber and its related products, (2) the rising price of softwood timber and softwood timber products, and (3) the increasing substitution of nonwood materials in the construction industry with all the attendant problems and the burden to the society, the need for an immediate solution arises. A feasible solution lies with intensifying the production of hardwood products to augment the highly priced softwood products and the energy consuming and pollution-prone nontimber competitors.

Prospects for increased hardwood use have been noticed in several areas, namely: (1) Rapid growth of pallet-based warehousing and loading systems has created a major hardwood lumber market. (2) Fiberboard made from aspen is successfully competing with softwood plywood in structural use.

(3) New pulping technologies some of which were discussed by Nwonwu (1981) have efficiently utilized hardwood with increased yield of pulp. For instance, the Neutral Sulphite Semichemical (NSSC) process and the Sulphate (kraft) process are two pulping processes which now utilize hardwoods efficiently to produce semichemical and sulphate pulps, respectively. Both processes have the flexibility of mixed pulping with long fiber materials such as softwoods to achieve increased pulp strength. The NSSC is also capable of pulping 100% hardwood. (4) Political moves to revamp and improve the railroad system are growing and railroads ride on treated hardwood cross ties in most parts of the United States. As indicated by the USDA, Forest Service (1980), nearly 1.5 billion board feet of lumber, about four-fifths in the form of ties, and 25 million square feet (3/8 inch basis) of plywood were used by the railroad industry in the construction of new track and the maintenance of existing track and rolling stock in 1976. (5) A new panel product (board) called structural flakeboard or waferboard made from hardwoods is already entering the U.S. markets from Canada and from U.S. producers. (6) Housing provides the stimulus for numerous purchases of manufactured goods including household furniture which is a key manufacturing use of hardwood lumber, veneer and plywood, hardboard and particleboard.

Hardwoods have the ability of quick and easy succession especially after clear cutting, yet in mixed stands, softwoods appear more favored. For instance, among the undesirables which a silviculturist wants to control in a forest stand are "competing hardwoods." Yet the U.S. annual imports of hardwood products have been on the increase. Although not large in terms of cubic volume and limited to select hardwood species, net imports of hardwood plywood and veneer showed rapid increases, rising from 5 million cubic feet (roundwood equivalent) in 1950 to 165 million cubic feet in 1977 (USDA, Forest Service, 1981b).

Hardwood Timber Products Supply Alternatives

Thus far, most studies including optimization techniques done in relation to forestry and forest industry decision making have been mostly in respect to the more highly priced softwoods: softwood lumber, softwood veneer and plywood, softwood pulpwood etc. Hardwoods have received minimal coverage in this regard. Given that the United States is a net importer of hardwood timber and related products and net exporters might in future form cartels to raise prices (OPEC[1] is a good example). A continued importation in the fact of increasing prices when products could possibly

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[1]OPEC stands for Organization of Petroleum Exporting Countries. It is a 13-member organization that fixes and attempts to maintain a high price for the members' crude oil by regulating their crude oil supply.

be produced cheaper domestically constitutes a drain in foreign exchange. Questions as to how best to meet the future demand of timber and other wood products through increased hardwood production to augment the softwood supply arise again and again. Several alternatives have always been considered among which are whether hardwood supply should be increased by one or a combination of some of the following:

1. Increasing the intensity of management applied to land currently producing hardwood timber,
2. Increase land area allocated to hardwood timber production,
3. Increase imports of hardwood timber products,
4. Increase domestic production with minimum or no imports,
5. Improve utilization of hardwood timber.

An attempt to determine the best policy or combination of policies to be adopted and what resource allocation will be optimum to meet the future demands of hardwood timber products in the United States at minimum cost is the theme of this study.

OBJECTIVES

The broad objective of this study is to develop a linear programming model to minimize the cost of meeting the future demand of hardwood lumber, veneer and plywood, pulpwood and particleboard in the period 1990 to 2030.

The specific objectives include:

1. To determine the minimum costs of supplying the products that will meet the forecast demands for each year of the projection period in constant (1972) dollars.
2. To test the model's sensitivity to possible changes in export and import costs of the hardwood products.
3. To find out the effect on the optimum solution of changes in the regional budget constraints.
4. To discuss the applicability of the model to other economies.

REVIEW OF PREVIOUS STUDIES

Much research is currently being directed towards the hardwood timber products economy of the United States. Worthy of special mention is the intensive research on hardwood utilization going on at the Forest Products Laboratory in Madison, Wisconsin. Ownership patterns and management objectives of hardwood forestlands have been studied extensively by several government agencies as a means of increasing the productivity of the private nonindustrial forestland owners who own a large proportion of the hardwood forestlands and whose management objectives are not well defined.

Hair and Spada (1970) have reported that, in the 1970s, the hardwood forests of the United States could support an increased level of cutting in view of the intensification in forest management and improved utilization practices. They also reported that the hardwood forestlands have the capacity to produce enough hardwood timber to meet future demands of timber products if managed intensively. But in the absence of appropriate management, and with the projected demands for hardwood lumber, veneer and plywood, rising more rapidly than projected supplies, the United States may have to turn toward the hardwood tropical forests of Latin America, Africa and Asia as sources of supply for high quality hardwood products.

In his study, Lutz (1975) reported an excess growth over cut of 4.7 billion board feet of hardwood veneer logs, an indication that there may be a potential for expanding the hardwood veneer industry in the country. In the same study, Lutz found that the consumption of domestic hardwood plywood has shown a moderate growth over the last 20 years. Thus, while the domestic hardwood veneer industry has remained relatively constant, demand and use of hardwood plywood in the United States has shot up.

The Forest Service periodically updates current demand and price situations of forest products and often makes future projections. One of such projections has indicated that hardwood plywood will increase in use by about 80% between 1970 and 1990. Phelps (1977), in his skepticism about the future supply of hardwood timber (and consequently hardwood timber products), states that recent increases in relative prices for hardwood timber suggest that the projection of timber supply probably overstates the volume of timber and especially of sawtimber that is economically accessible and available for use. For example, much of the projected supply according to him is in species and low-quality trees for which markets are currently limited. Much of the demand, on the other hand, is for species such as select white and red oak, sweetgum, yellow birch, hard maple, walnut, black cherry and for larger sized hardwood sawtimber that is suitable for the manufacture of high-quality lumber or veneer. Such species occur as widely dispersed trees or groups of trees that may not be economically harvestable. Phelps (1977) was also of the opinion that a substantial part of the hardwood timberland is also in privately owned tracts that are held primarily for recreation or other purposes not compatible with timber and associated products production.

In their study on wood products substitutes, McKillop et al. (1980) identified steel, aluminum, and concrete as competing substitutes for lumber and plywood in the construction industry. They estimated that a 20% rise in the price of stumpage (and an associated 14% rise in saw-log price) would lead to decreases in lumber and plywood output of 70 million board feet and 300 million square feet, respectively, and will result in a gain in steel output of some 70,000 tons. Cross price elasticities of demand[1] obtained in the study indicated that the highest value of 0.79 was observed for the effect of lumber price on steel consumption. This, according to the authors, means that a 1 percentage increase in the average price of lumber will result in a .79% increase in the average consumption level

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[1]Cross price elasticity of demand relates the proportionate change in the quantity of one good demanded to the proportionate change in the price of another good. It can be mathematically expressed as:

$$\epsilon_{21} = \frac{p_1 \partial q_2}{q_2 \partial p_1}$$, where ϵ_{21} = cross price elasticity of good 2 with respect to good 1; p_1 = price of good 1; p_2 = price of good 2; ∂p_1 = fractional change in the price of good 1; ∂q_2 = fractional change in the quantity of good 2.

of steel over the estimation period. Further studies on this issue of substitution by USDA, Forest Service (1973) reveal that other factors that contribute to the substitution away from timber products include revisions to building codes, changes in relative prices, increasing labor costs in the construction industry, and technological developments in the plastic and metal industries. In an earlier study, McKillop (1978) had analyzed the possible impacts of the substitution for timber on certain economic activities such as: (1) consumer expenditures, (2) housing programs, (3) output and employment in the forest industries, and (4) environmental effects. He concluded that the prospect for continued timber products use is high because of the fact that the manufacture of materials which compete with wood products requires substantially more energy and leads to considerably greater levels of pollutant emissions.

Studies Involving Linear Programming Application

Despite a relatively recent origin, linear programming (LP) is now used extensively on a wide variety of forestry problems. Management in the typical forest products company is correspondingly faced with increasing complex decisions of optimum product mix. Whether a specific species, size, and grade log should be converted into products such as lumber, veneer, plywood or be managed for pulp is one of such problems. Within each of these categories also, a multitude of products can be produced which differ according to quality and dimensions. Such complex decision problems have been solved by the use of LP models. Among the many applications of LP in the forest products industry are in the areas of general forest management and harvesting, lumber and plywood manufacture, paper machine and corrugator scheduling and balancing, and distribution analyses.

Specific applications of LP have been seen in several studies. This all-important tool was used in the Interregional Timber Model (ITM) study of Holley et al. (1975) to simulate changes in the softwood forest economy. In this study, LP performed the function of allocating regional softwood timber supplies to meet national product requirements under a specified set of constraints. The now-popular Timber Resource Allocation Method (Timber RAM) is a practical application of LP in forest multiple-use management. Developed by Navon (1971), Timber RAM is a computerized method for developing long-range forest management plans. The inputs and outputs estimated by Timber RAM are limited to timber, land area, and related costs and revenues. It simplifies the planning task by shifting to computers the burden of calculating plans with which planners and managers can determine whether policies governing the multiple-use management of forestland are mutually consistent. When policies are consistent, Timber RAM makes it possible to estimate the inputs required and the outputs produced should these policies be carried out efficiently. It also permits evaluation of current policies and can be used to develop new policies. It will indicate whether, with current and expected technology, a policy could be carried out and at what cost or whether it can be carried out only by modifying related policies, and tells the extent of the modification. According to the author, Timber RAM is rather a combination which is consistent with specified constraints and which maximizes or minimizes a particular index of performance. Managers and planners in applying it, therefore, must evaluate alternative combinations of activities by determining the extent to which each combination meets social, economic, and ecological needs and political realities.

Forest Planning Model (FORPLAN) succeeds Timber RAM as a new development in the mathematical programming approach to multiple-use management of forest resources. Developed by Johnson et al. (1980), FORPLAN is used for forest resources allocation and activity scheduling under multiple-use and sustained-yield constraints. The system uses LP to evaluate a forest planning alternative on a national forest. Inputs consist of resource inventory and yield tables, acreages, management prescriptions, and sustained-yield and multiple-use constraints. The output consists of series of tables and graphs depicting the optimal resource flows, i.e., the management activities and corresponding acres which optimize the chosen management objectives.

Plywood manufacturing is one area where LP has been used extensively. Donnelly (1966) has efficiently used LP to coordinate the three major technical divisions of this industry, namely, forestry, manufacturing and sales. Each of these has varying degrees of autonomy, yet they share strong interdependences as the output of one section is input to the next. Close coordination avoids costly repercussions in sequencing raw material allocation and product mix. The LP formulation builds in coordination by defining an overall objective function that incorporates the economies (advantages) and diseconomies (disadvantages) external to each technical section individually.

Turner (1966) applied LP to chip, fiber and pulp marketing. In his study of the Weyerhaeuser pulp mills which produce market pulps in the Northwest Region of the United States, he used LP to maximize total profit under a situation where total orders exceeded total mill capacity. A complementary use of LP and Goal Programming (GP)[1] was employed by Field et al. (1980) in their study on "The Procedure for Timber Harvesting." This technique, according to the authors, is capable of providing solutions for a variety of problems like single objective LP problems; short and long

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[1]Goal Programming is another mathematical model which attempts to minimize the deviations among desired goals within a given set of constraints. While LP follows an optimization behavior pattern, GP follows a satisfying behavior pattern (Sposito, 1975).

term goals; multiple decision criteria such as volume maximization; present network maximization; present net cost minimization, and such conflicting goals as harvest stability, growing stock regulation, and the impacts of other forest resources on the management.

Steur and Schuler (1978) have used LP to prepare preliminary management plans for a 10,522 acre Swan Creek subunit of the Mark Twain National Forest in Missouri. Their objective was to manage a mixed hardwood and softwood forest for timber production, dispersed recreation, hunting forest species, hunting open land species and for grazing. Ware and Clutter (1971), in their study on the "Mathematical System for the Management of Industrial Forests," developed a model for selecting an optimum harvesting schedule that will provide a sufficiently stable wood flow pattern. The result is expected to aid forest managers who are constantly faced with the problem of providing a reasonably stable and continuing yield of forest products. However, they warned that harvest schedules obtained by selecting the management regimes of maximum total present value from various cutting units will seldom provide a sufficiently stable wood flow pattern. This implies that some stands must be harvested in accordance with a nonoptimal cutting schedule. Developing a model for determining which stands to harvest suboptimally and which suboptimal schedules to use was the theme of their study.

METHODOLOGY

Scope of Study

This study covers only hardwood products. However, reference is made to softwoods when the need for comparative analysis arises. To ensure clarity of reporting and to avoid double counting in calculations, only the primary hardwood timber products, namely: lumber, veneer and plywood, pulpwood and then particleboard, are studied. The study does not include standing timber and it also precludes secondary and tertiary manufacture of wood products. The study looks at the projected demand for these products as forecast by the Forest Service for the period 1990 to the year 2030 and attempts to construct an LP model which will meet the demands (consumption, import and export demands) of products for each year of the projection period at minimum cost. It does not include the period before 1990 nor the one beyond 2030.

Study Area

The study area encompasses the continental United States which is broken up into three timber-producing sections: the North, the South, and the West. The North comprises the Lake States, North Central States, Middle Atlantic and New England regions. The South is composed of West Gulf, Central Gulf, South Atlantic and East Gulf regions. The West consists of the Rocky Mountains made up of Northern Rocky Mountains and Southern Rocky Mountains, and the Pacific Coast made up of Pacific Northwest which includes Alaska, and Pacific Southwest regions. There are altogether 12 regions which form the basic units used in this study for hardwood timber products demand and supply analysis (see Figure 2).

Hardwood timber production and processing are unevenly distributed over the regions. The North and the South are the two sections with the principal hardwood producing regions. Forest Service statistics of 1977 show there are 249 million acres of hardwood commercial timberland by forest types or 51.4% of the total United States commercial timberland in the East (North and South) and only 14.9 million acres or 3.1% of the national total in the West (Rocky Mountain and Pacific Coast) (USDA, Forest Service, 1980). The Forest Service has forecast that by the year 2030, 3.5 billion cubic feet of hardwood timber or 39% of the hardwood timber supply will come from the North, 5.4 billion cubic feet or 60% of hardwood timber will come from the South and only .1 billion cubic feet or 1% of hardwood timber will come from the West.

Commercial timberlands in all the regions have experienced significant diversions to highways, reservoirs, urban development and other nontimber uses. The reductions have

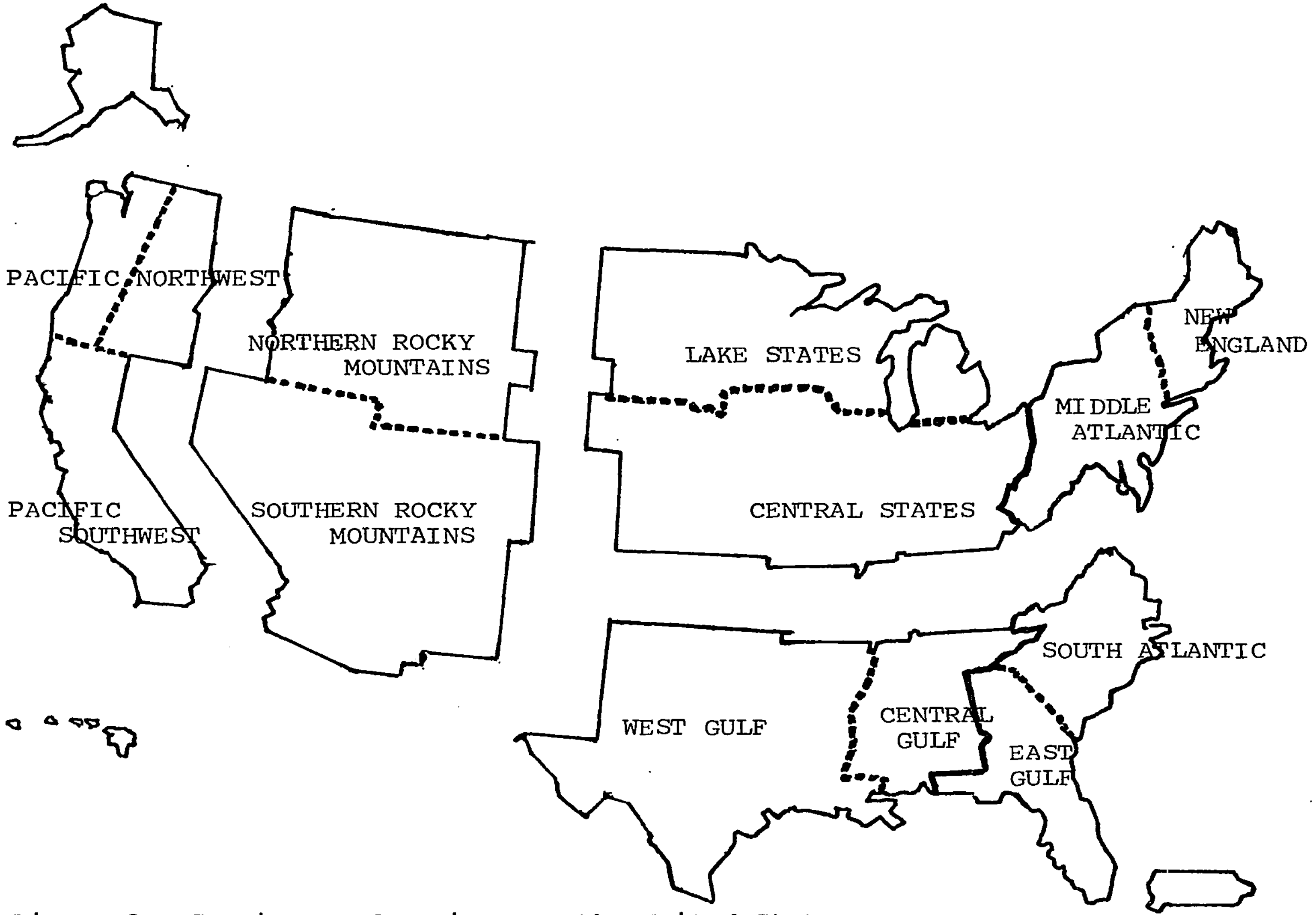

Figure 2. Sections and regions of the United States

been largest in the North, where most of the population and economic activities are located. It is assumed in the study, that no more additions to the forestland needed for production should take place in the future, that all regions carry out their production activities only on the existing forestland areas or less.

Supply and Demand Regions

Hardwood supply and hardwood demand regions have been defined for the 12 regions of the country. For purely economic reasons, primary manufacturing facilities are inextricably located in close proximity to timber supplies. Hence, most primary manufacturing plants are located close to the hardwood timber sources. As transportation costs significantly affect industrial location and the geographical pattern of resource use in the hardwood timber economy, raw materials are not transported through great distances. Invariably, most hardwood products producing regions automatically become supply regions of primary products. Only the finished products which are less bulky could be shipped to distant markets. Nearness to market entails distinct econmies to processing facilities. Consequently, the hardwood producing regions of the North and South have no problem meeting their hardwood timber requirements and or the requirements for the manufactured hardwood products. A large proportion of hardwood products surpluses are shipped from the North and South to the hardwood deficient regions of the West.

Criteria Used to Determine Supply and Demand Regions

Several criteria could be used to determine supply and demand regions. They include (1) the hardwood commercial timberland of the regions, (2) the total hardwood growing stock volume of the regions, (3) the net supply (domestic production less consumption) of the regions. The last criterion was used in this study because of the availability of data and the ease of calculation of its variables. All regions with positive net supply are classified as supply regions, while those with negative net supply are classified as demand regions. Based on this criterion and using the U.S. Forest Service statistics of 1977 on hardwood removals (production) and hardwood products outputs (consumption) as contained in USDA, Forest Service (1980), the two Rocky Mountain Regions--Northern Rocky Mountain and Southern Rocky Mountain regions--primarily fall under demand regions. The two regions produced 93 and 2,961 thousand cubic feet of hardwood roundwood and consumed 312 and 3,165 thousand cubic feet of hardwood roundwood, respectively. The Pacific Southwest region is also treated as a demand region because of its relative low hardwood output and its high consumption potential. The remaining 9 regions produced more hardwood roundwood than they consumed and therefore are supply regions. The supply regions include New England, Middle Atlantic, Lake States, Central States, South Atlantic, East Gulf, Central Gulf, West Gulf, and Pacific Northwest (see Figure 3).

The Costs

The costs associated with this study encompass all costs incurred in the production process; the value and cost of imports plus delivery costs from the point of production to the point of further conversions or to the point of final consumption. They include (1) fixed costs (FC)--costs that do not vary in the short run and must be incurred with or without production. Machinery, buildings, land, equipment, and interests on machinery and equipment fall under fixed costs. (2) Variable costs (VC)--costs that arise as a result of the production and change according to the volume of production. Such cost items as stumpage costs, wages and salaries, net road costs, taxes, operating costs for machinery and equipment, e.g., fuels and maintenance come under variable costs. The sum of all fixed costs over all products and across all producing regions yields the total fixed cost (TFC). The VC summed over all products and over all producing regions yields the total variable costs (TVC).

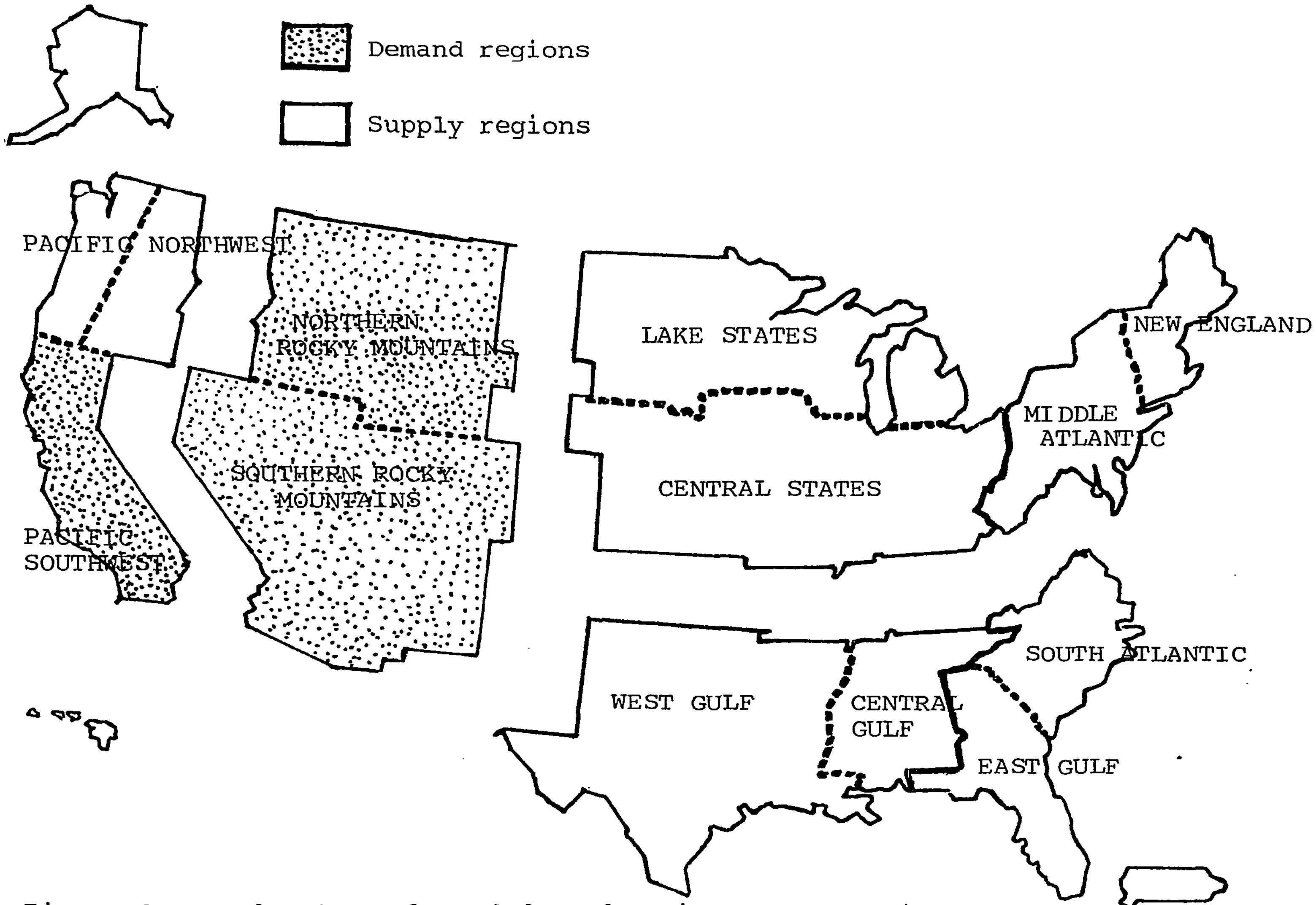

Figure 3. Hardwood supply and demand regions of the United States

Three main cost generating activities have been identified and applied to the supply of the products under study. They include production, import and transportation activities. The TC obtained by summing the TFC and TVC for each of these activities becomes the total cost function which the model will attempt to minimize.

Estimating the Cost Coefficients

Data on costs are difficult to obtain as some establishments often withhold cost information to avoid disclosing company operations. When available, costs vary among and even within regions for identical products and activities. Differences in product physical quality plus varying distances for product transportation are some of the factors that contribute to cost differentials. Data limitations make it impossible to have an individual region's cost coefficients for the products. Thus, each product has its cost coefficient for each of the activities production, import and transporation applied across all regions.

Production Cost Coefficient

Two methods of costing have been employed in determining the unit cost of producing each of the products studied. For the lumber, veneer and plywood, and particleboard, the unit costs were calculated from cost figures published by the U.S. Department of Commerce, Bureau of the Census in the 1977 Census of Manufactures for the Wood Products Industries. The production cost items include payrolls,[1] Cost of materials,[2] and new capital expenditures.[3] All three cost items[4] are summed over all regions to obtain the total production cost for each product. Per unit production cost is obtained by dividing the total production cost by the total national output of the product in 1977. The resulting figure is the

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[1]Payrolls include the gross earnings paid in the calendar year to all employees on the payroll of operating manufacturing establishments. It includes all forms of compensation such as salaries, wages, commissions, dismissal pay, all bonuses, vacation and sick leave pay, and compensation in kind prior to deductions. It excludes proprietor's pay and payments to members of Armed Forces carried on the active payroll of manufacturing establishments.

[2]Cost of materials refers to direct charges actually paid or payable for items such as raw materials consumed or put into production during the year, including freight charges and other direct charges incurred in acquiring the materials. It includes the cost of materials or fuel consumed.

[3]New capital expenditures include permanent addition and major alterations to manufacturing establishments, and machinery and equipment used for replacement and additions to plant capacity. It excludes that portion of expenditures not used for manufacturing, and plants and equipment acquired free of charge.

[4]For more detailed information on payrolls, cost of materials, and new capital expenditures, see USDC, Bureau of the Census (1977b), Census of Manufacturers, Volume II, Appendix B.

production cost coefficient which will be converted to constant 1972 dollars[1] and applied to the objective function in the model.

A slightly different costing technique has been applied in the case of pulpwood. This is because pulpwood, except for pulpwood chips, is delivered to the mill as roundwood without further processing. Therefore, it does not qualify as a manufactured product to go into the Census of Manufacturers. Moreover, the coverage on pulpwood chips did not classify the products into softwoods and hardwoods. The alternative method involved taking the average of delivered costs and f.o.b.[2] car costs for hardwood pulpwood in all producing regions. The difference between the two costs gives a fair approximation of the transportation cost. The f.o.b. cost includes stumpage and harvesting costs; the stumpage cost will include plantation establishment and maintenance costs. Stumpage cost therefore constitutes part of the per cord cost of pulpwood delivered to the mill. This argument is further supported by United Nations, FAO (1973)

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[1]Current expenditures are converted to 1972 dollars by dividing with the GNP Implicit Price Deflator for government purchases (1972 = 100) x 100. The base year for current expenditures in this study is 1977 with an implicit price deflator of 144.8.

[2]f.o.b. stands for free-on-board. The f.o.b. cost is the cost of product less freight (transportation) and insurance costs.

who also figured stumpage cost in a similar manner. In its publication, "Guide for Planning Pulp and Paper Enterprises" (United Nations, FAO, 1973, p. 96), it evaluated stumpage cost for plantation-grown trees based on the actual cost of growing wood rather than on the market price at the time of cutting as follows:

Stumpage rate	=	Plantation establishment costs and interest on these costs	+	Plantation maintenance costs and interest charges	+ A reasonable allowance for profit and risk associated with plantations

Import Cost Coefficient

Import costs include both the c.i.f.[1] values of the imported commodities and the import duties paid for them. Import values and duties for the hardwood products for 1977 were obtained from "U.S. Commodity Exports and Imports as Related to Output 1977" while the corresponding import quantities were obtained from "U.S. Imports for Consumption and Genera Imports" both of which are published by the U.S. Department of Commerce, Bureau of the Census. Total import quantities and costs are obtained for each commodity and per unit import cost obtained by dividing the total import cost by the total quantity imported.

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[1]c.i.f. stands for cost insurance and freight. The c.i.f. value of a commodity implies the cost of purchase of the commodity in the exporting country plus freight, insurance, and other charges paid to bring it to the first port of arrival in the importing country.

Transportation Cost Coefficient

Information gathered from literature and from personal interview with lumber companies reveal that transportation of all these commodities is done by trucking. The Federal Government transport deregulation stipulates a trucking cost of $2.53 per 100 lbs of load for a minimum truck load of 40,000 lbs. Further costs incurred in transporting products include about $60 stop-over cost at an average of one stop-over per trip plus topping cost of about $30. This is the form of costing applied to lumber, veneer and plywood and particleboard transportation. For pulpwood, the difference between the delivered cost and the f.o.b. car cost is taken as the transportation cost. The costs per pound are converted to costs per board foot or cubic foot in the case of lumber, square feet in the case of veneer and plywood, and particleboard, and cords for pulpwood by using appropriate conversion factors.

It is worth noting that cost figures calculated with these methods described may not be free of errors arising from double counting. This is possible because a product at the end of one production line may be used as an input in another. Secondly, the opportunity cost involved in engaging in a particular production process may not be adequately represented in the costing technique employed. However, it is hoped that the sensitivity analysis of the model will help authenticate the data and methods used.

Basic Linear Programming Model

Linear programming (LP) is one of the many forms of mathematical programming, the others being nonlinear programming, GP, game theory etc. LP, unlike classical optimization, attempts to solve problems in which the optimizer faces inequality constraints. Such inequality constraints could be of the form $f(x,y) \lesseqgtr C$ rather than $f(x,y) = C$, where $f(x,y)$ is a function expressed in x and y and C is a constraint. We can say more specifically that instead of requiring a producer to spend the exact amount of his factor of production, say land, labor or capital, the LP framework will allow him the freedom of spending either the exact amount or less or more if he so chooses. By so doing, the LP model liberalizes the constraint requirement. The term linear programming stems from the assumption that both the objective function and the constraint inequalities are linear.

A general LP model expressed in matrix notation can be stated as follows:

Maximize (Minimize)	$Z = C'X$	(objective function)
Subject to	$AX \lesseqgtr b$	(constraint set)
	$X \geq 0$	(nonnegativity constraint)

where:

Z = revenue or cost function to be maximized or minimized

C' = (1 x n) row vector of objective function coefficients where C_j represents the contribution to revenue or cost by a unit of the jth variable $(j = 1,2,\ldots,n)$

X = (n x 1) column vector of activities where X_j represents the amount of the jth variable produced

A = (m x n) matrix of activity coefficients where a_{ij} represents the amount of resource i produced by each unit of the jth variable $(i = 1,2,\ldots,m)$

b = (m x 1) column vector of constraints where b_i represents the amount of resource i available for use. A, C, b (a_{ij}, C_j, b_i) are known, while X (X_j) is unknown.

Sensitivity Analysis

The researcher is often interested in knowing how changes in the values of activity variables affect the optimal solution. An implicit assumption in the LP model is that the values of a_{ij}, C_j and b_i are known with certainty, but this is not always the case. To ensure that this assumption is not violated, a sensitivity analysis is performed to establish some confidence in the model and its results. The more the model parameters can vary in value over a given range without affecting the optimal solution, the more suitable the model will be for optimization.

The behavior of the model to changes in the production, import and transportation costs would be analyzed via the sensitivity analysis. Changes in production cost could arise from higher wages, higher cost of materials and higher interests on capital; import costs could increase through higher purchase prices and higher import duties; transportation costs could increase through higher fuel and energy costs. Let us suppose that some of the production requirements or capacities or transportation costs are changed by a small amount. We would want to know how the minimum total cost is affected. A new solution will be sought under the new conditions and, if the new solution is a basic solution,[1] then it is an optimum solution and the model yields a reliable optimal solution. If the solution is nonbasic, it follows that the new solution is supoptimal and the solution is unreliable.

Two most popular techniques often used in testing the sensitivity of an LP model are Range Analysis and Parametric Programming. Both of these two techniques are discussed briefly below.

Range Analysis

A range analysis is one method of testing the sensitivity of an LP model, the other being parametric programming. After an optimal solution has been obtained, the procedure RANGE (MPSX control option) is used to perform a post-optimal or sensitivity analysis of the objective function coefficients

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[1]A basic solution is defined as one having at least mn - m - n + 1 zeros where m is the number of rows and n is the number of columns in the activity matrix.

including right-hand-side (RHS) resource or constraint levels. The range analysis extends the information provided in the conventional (first) optimal solution by revealing when the problem should be rerun because of cost changes, and/or adjustments in the RHS constraints that would affect the solution.

A more detailed discussion of the "Range Analysis" and its output will be discussed under Model Verification Computer Runs. The Mathematical Programming System (MPSX) package for range analysis is shown in Appendix B.

Parametric Programming

Parametric programming is a post-optimality procedure that enables the researcher to investigate what happens to the optimal solution when cost or resource coefficients are systematically varied. At each increment of change, a new optimal solution is obtained. The process involves the replacement of a chosen coefficient or vector with a new coefficient or vector which is the sum of the replaced value and a multiple of the corresponding value of a change vector.

Before going into the mathematical illustration of the procedure, certain key elements of the procedure are hereby defined. They are:

(1) XPARDELT defines the parameter interval or incremental value after which a solution is printed. It is usually a positive value with a decimal point in it.

(2) XPARAM specifies the beginning value of the parameter. The value is always a zero with a decimal point initially.

(3) XPARMAX specifies the maximum value of the change to be added to the old value.

(4) CHROW indicates the change row.

(5) CHCOL indicates the change colum.

Algebraically, a parametric programming on the objective function can be expressed as follows:

$$OBJ_i = OBJ_1 + XPARAM_i(CHROW_1)$$

where:

OBJ_i = new objective function at i^{th} parametrization

OBJ_1 = initial objective function

$XPARAM_i$ = value of XPARAM at i^{th} parametrization (initially set equal to zero)

$CHROW_1$ = change row specified (Row 1 or objective function row in this case)

$$1 \leq i \leq n$$

where:

$$n = \text{maximum multiple given by } \frac{XPARMAX}{XPARDELT}$$

For example, if the initial objective function is as shown in Table 3, suppose the change row is α_3 and β_4 for C_{13} and C_{14}, respectively and, if $XPARAM_i$ = 5.0, then OBJ_2 = OBJ_1 + 5 ($CHROW_1$) as shown in Table 4.

Table 3. Parametric programming on objective function coefficients

	Columns				
	C_1	C_2	C_3	C_4	C_5
OBJ_1	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}

where:

C_j = column number

C_{ij} = activity coefficient

Table 4. New objective function coefficients following parametrization of old objective function coefficients

	Columns				
	C_1	C_2	C_3	C_4	C_5
OBJ_2	C_{11}	C_{12}	$C_{13}+5\alpha_3$	$C_{14}+5\beta_4$	C_{15}

Further description of all MPSX parametric programming packages used in this study is contained in the section on Results and Discussion, and in Appendix B.

THE MODEL

The U.S. Department of Agriculture, Forest Service (1980) has projected the demand[1] for different groups of forest products for the period 1990 to 2030. The projections were based on certain assumptions about the expected future economic and technological changes. Among the assumptions made are: (1) a steady future growth in population, (2) increased GNP and DPI, (3) rising product prices, (4) better utilization through improved technology.

In this study, four hardwood products out of many whose demands have been projected have been chosen for study. They include hardwood lumber, veneer and plywood, pulpwood, and particleboard. The study aims at developing a cost minimizing LP model for efficient resource allocation to meet the projected demands (domestic production, exports and imports) at minimium costs given a set of regional constraints for 12 regions in the U.S. The constraints include (1) regional hardwood forest land area, (2) hardwood products manufacturing labor requirement, (3) budget, (4) domestic commodity demand,

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[1]Demand as used by U.S. Forest Service and in this study implies quantity needed. Hence, demand means quantity needed for consumption. Demand in this context is different from the economics meaning where demand means the quantity consumers are willing to purchase at a given price. Unless otherwise stated, the U.S. Forest Service version of demand will be used throughout this study.

(5) import[1] demand, and (6) export[2] demand. The minimum costs (in 1972 dollars) of supplying the products under the above constraints will be determined for the years 1990, 2010, and 2030. Minimum costs for the intermediate years 2000 and 2020 will be deduced from the results. Costs are reduced by this selective interpolation since computer costs for running the model for five forecast times (years) across all 12 regions are expected to be high. Minimum costs thus determined will be plotted over the projection years to better visualize the cost trend over those years. To accomplish this forecasting, a national hardwood LP model is developed. The model is based on demand and supply regions. Thus, the continental United States is divided into nine hardwood "supply" regions, that is, regions with high productive capacity that historically produce more of the specified hardwood products than they consume, and three "demand" regions, or regions with historically low productive capacity, whose consumption requirements exceed their production. The technique used in determining the supply and demand regions has been discussed under Methodology. The supply and demand regions as used in the model formulation are shown in Figure 3. The regions as they are utilized in the

[1]Import as used here represents the purchase of hardwood products from outside the United States.

[2]Export implies the sale of hardwood products by the United States to other countries. The two words are distinct from transportation or transfer which will be used later in the study to represent the sale or movement of hardwood products among regions in the United States.

study are the same divisions used by the USDA, Forest Service.

The 12 regions combined constitute the market regions for which supply costs are determined. The USDA, Forest Service Regional Experiment Stations located in these regions provide the primary source of data. Commodity supply[1] and demand forecasts of wood products as often done by U.S. Forest Service are made with such data as the base. This study uses data provided by one of such forecasts.

Objective Function

The objective function is to minimize the total cost of supplying the projected demand of four hardwood product groups, namely: lumber, veneer and plywood, pulpwood and particleboard. In three future times 1990, 2010, 2030 of the projection period, 1990-2030, and under specified land, labor, budget, and commodity demand constraints, domestic demand, import and export, the optimal production and import and export schedule which minimizes total costs will be determined. The relevant cost items in the objective function include: production, import and transportation costs. Since no specific export (e.g., export tax) has been reported, export cost is not treated separately and has been accounted for only through the production and transportation costs of that portion of total

[1]Supply as used by U.S. Forest Service and in this study stands for quantity produced and distributed. It is distinct from the economic interpretation of supply which implies the quantity producers are willing to sell at a specified price. The U.S. Forest Service definition of supply will be used throughout this study unless otherwise stated.

output meant for export.

Land Constraint

Land equations are defined for the 12 regions and for each product type. The model requires that total acres of commercial forestland as determined by the area of commercial timberland by forest type committed to hardwood production should not exceed the available hardwood commercial timberland in the region and overall in the nation. The implicit assumption in the model is that production will be limited only to the current hardwood commercial timberland. The future expectation is that commercial forestland acres will decline (USDA, Forest Service, 1981a). The possibilities of further land addition or acquisition from noncommercial timberland, marginal lands and unstocked land are completely ruled out. Thus, the present hardwood commercial timberland becomes the upper limit of the land constraint. This means that the commercial timberland area to be used in production should be less than or equal to the area currently available.

Commodity Demand Constraint

Commodity demand restraints are defined for each of the 12 regions. A greater than and equal to restraint is placed on the products demand of each region. In other words, the quantity of each of the four products demanded in any region is entered as the lower limit in the model to ensure that the demand requirements are fully met. The model expects the demands to be met, or exceeded, where possible, provided the overfulfillment in one region does not cause unfulfillment or underfulfillment in other regions. Also, the sum of regional demands at a given point in time does not exceed the total national demand for the period.

The quantities of commodity demanded in the regions are determined by the relative size of the regions' population. The 1980 population census figures were used to calculate the regional products demand used in the model.

The percentages of the regional population were applied to the national demand for each of the products to derive demand shares per product for each region in any year of the projection period. Thus, regions with high population have high demand shares and those with less population have less share of the total national commodity demand requirement.

Budget Constraint

The budget constraint for each region in a given year is the maximum total cost (in 1972 dollars) of producing and importing the demand quantity and transporting or exporting any excess (for a supply region), and producing and importing the demand quantity (for a demand region). It is, therefore, dependent on the productive capacity of the region. A region with high hardwood products productive capacity, like the South Atlantic, has a higher annual budget of $1735 million than another region with a low hardwood products productive capacity such as the Southern Rocky Mountain, with only about $4 million.

Regional production capacities which determine the budget constraints are determined by the 1977 output capacity of the regions as published by the U.S. Forest Service (1980). Capacities for the hardwood products manufacture were determined with the 1977 Forest Statistics of the U.S. as contained in USDA, Forest Service (1980). Outputs of the primary source of the products determine region's capacity as follows: lumber production capacity is determined by output of sawlogs; veneer and plywood production capacity by output of veneer logs; pulpwood production capacity by pulpwood timber output; and particleboard production capacity by the output of logging residues.

Labor Constraint

According to USDC, Bureau of the Census (1977a), medium population projections, the population of the U.S. might rise at an annual rate of 1.2% to 300 million in 2030. As earlier discussed, U.S. population serves both as the force influencing consumption and the labor base and thus affects the demand of products and the cost of production. The labor force engaged in primary wood products manufacture is often published in the annual issues of the U.S. Abstract of Statistics. But the portion of the labor force ascribed to hardwood products manufacture is often difficult to determine. Since total population has no direct effect on the labor force and not all segments of the population can be engaged in wood products manufacture, the labor constraint has been estimated by multiplying the production in the region of a given product by the estimated labor coefficient of the product. The sum of these products for all commodities represents the labor constraint for the region.

The population as a force influencing consumption has been used to determine the regional demands of products by multiplying total national demand of a product by the regional percentages of the national population.

Export Constraints

There is no interregional export restraint for the nine supply regions but the three demand regions are not expected to export since historically they are net consumers of hardwood products, lacking capacity to produce the quantity demanded. The supply regions could increase the volume of their domestic or international exports, thus expanding their market share or capturing new markets.

The total exports of all regions in any year are to be less than or equal to the projected quantity for the country for that year. Regional exports for products are proportional to their production capacities and budget constraints.

Import Constraint

Import constraints are specified for all 12 regions. Total U.S. imports are apportioned to the regions in accordance with their relative population sizes as determined by the 1980 population census. All regions can import hardwood products based on their needs. In the main, most imports are expected to enter the three demand regions where consumption exceeds productive capacity.

The projected quantity of each product for each year of the study acts as the lower limit for imports. This implies that total imports may be greater than or equal to the projected quantity, especially if the product is cheaper when imported than produced locally.

Mathematical Structure of the Model

The LP model including the variables and parameters that comprise the model are described in summation form as follows:

$$\text{Minimize } Z = \sum_{i=1}^{12} \sum_{j=1}^{4} C_{ijt} X_{ijt} + \sum_{i=1}^{9} \sum_{j=1}^{4} p_{ikjt} P_{ikjt} + \sum_{i=1}^{12} \sum_{j=1}^{4} m_{ijt} M_{ijt} \qquad (1)$$

where:

(1) the first component is the production costs, with c_{ijt} representing per unit cost of producing product j in region i in year t; X_{ijt} is the production activity, i.e., production of product j in region i in year t where there are four products and 12 producing regions;

(2) the second component represents the transportation costs with p_{ikjt} representing per unit cost of transporting product j from region i to region k in year t; P_{ikjt} represents the transportation activity such as transporting product j from region i to region k in year t ($1 \leq k \leq 12$);

(3) the third component stands for the import costs in which m_{ijt} represents per unit cost of importing product j in region i in year t; M_{ijt} is the import activity which may represent the import quantity of product j into region i in year t.

The total cost, Z, is to be minimized subject to:

1. Hardwood commercial timberland area in region i committed to the production of all four products

$$\sum_{j=1}^{4} a_{ij}X_{ij} \leq L_i \quad , \qquad i = 1,\ldots,12 \tag{2}$$

2. Total commercial timberland in all 12 regions in the United States

$$\sum_{i=1}^{12} \Sigma \sum_{j=1}^{4} a_{ij}X_{ij} \leq L_T \tag{3}$$

3. Budget constraint for region i in year t

$$\sum_{j=1}^{4} \pi_{ijt} X_{ijt} \leq K_{it} \tag{4}$$

4. Total national budget constraint in year t

$$\sum_{i=1}^{12} \sum_{j=1}^{4} \pi_{ijt} X_{ijt} \leq K_{Tt} \tag{5}$$

5. Hardwood products demand in region i in year t

$$\sum_{j=1}^{12} h_{ijt} \leq D_{it} \tag{6}$$

6. Total national hardwood products demand

$$\sum_{i=1}^{12} \sum_{j=1}^{4} h_{ijt} N_{it} \leq D_{Tt} \tag{7}$$

7. Labor constraint in region i in time t for hardwood production

$$\sum_{j=1}^{4} r_{ijt} X_{ijt} \leq N_{it} \tag{8}$$

8. Total U.S. labor constraint for hardwood production

$$\sum_{i=1}^{12} \sum_{j=1}^{4} r_{ijt} X_{ijt} \leq N_{Tt} \tag{9}$$

9. Hardwood products export for region i in time t

$$\sum_{j=1}^{4} e_{ijt} \leq E_{it} \tag{10}$$

10. Total national hardwood products export in time t

$$\sum_{i=1}^{9} \sum_{j=1}^{4} e_{ijt} \leq E_{Tt} \qquad (11)$$

11. Hardwood products imports for region i in time t

$$\sum_{j=1}^{4} m_{ijt} \geq M_{it} \qquad (12)$$

12. Total national hardwood products import in time t

$$\sum_{i=1}^{12} \sum_{j=1}^{4} m_{ijt} \leq M_{Tt} \qquad (13)$$

and

13. Nonnegativity constraints required of all decision variables

$$X_{ij},\ P_{ij},\ m_{ij} \text{ etc. } \geq 0 \quad . \qquad (14)$$

where:

Z = total cost which includes production, transportation and import costs of providing the forecast demand of all four products in each year of the projection period.

C_{ijt} = cost per unit of production of product j for region i in year t
(i = 1,2,...,12)
(j = 1,2,...,4)
(t = 1990, 2000,..., 2030)

X_{ijt} = production activity for project j for region i in time t

p_{ijt} = cost per unit of transportation for product j in region i in time t

P_{ijt} = transportation activity for product j for region i in time t

a_{ij} = land productivity coefficient of product j for region i in time t

L_i = hardwood commercial timberland area in region i

L_T = total hardwood commercial timberland area of United States

π_{ijt} = per unit capital requirement for the supply (production import and transportation) of product j for region i in time t

K_{it} = budget constraint for region i in time t

K_{Tt} = total national budget constraint in time t

h_{ijt} = quantity of product j demanded in region i in time t

D_{it} = hardwood products demand for region i in time t

D_{Tt} = total U.S. demand for hardwood products in time t

e_{ijt} = quantity of product j exported by region i in time t

E_{it} = export of all four products for region i in time t

E_{Tt} = total national export of hardwood products in time t

m_{ijt} = quantity of product j imported by region i in time t

M_{it} = import of all four products for region i in time t

M_{Tt} = total national imports of all hardwood products in time t

General Structure of the Model

The cost minimizing LP model for the supply of the specified hardwood products has a matrix broken down into five row groups and five column activity groups. The rows are (1) resource constraint rows, (2) domestic demand rows, (3) import demand rows, (4) export demand rows, (5) identity rows (see Table 5). The column activities include (1) production, (2) import, (3) export, (4) transportation, and (5) demand activities (see Table 6). The activity coefficients used are shown in Table 7, while the regional resource productivity coefficients are shown in Table 8. This general structure of the model is illustrated in Figure 4.

			COLUMNS					
			Activity					
		Row type	1 CjPit	2 CjIit	3 CjEit	4 CjTit	5 CjDit	RHS
Resource Rows	R_{1ijt}	L						
	R_{2ijt}	L						
	R_{3ijt}	L						
Commodity Domestic Demand	C_{1it}	G						
	.	G						
	C_{jit}	G						
Commodity Import Rows	C_{1it}	L						
	.	L						
	C_{jit}	L						
Commodity Export Rows	C_{1it}	G						
	.	G						
	C_{jit}	G						
Commodity Identity Rows	C_{1it}	E						
	.	E						
	C_{jit}	E						

Where: C = commodity name, R = resource name, P = production,
I = import, E = export, T = transportation, D = demand,
L = less than, G = greater than, E = equal to,
i = number of regions, j = number of products,
t = time period, RHS = right hand side of the equation
i = 1,2,...,12; j = 1,...,4; t = 1990, 2000, ..., 2030

Figure 4. General structure of the model

Table 5. Row names and unit of measure used in the model

Serial no.	Name	Description	Unit of measure
1	LAND	Commercial hardwood forestland	Thousand acres
2	LABOR	Production workers	Thousand persons
3	BUDG	Capital available for production and distribution	Million dollars
4	LUMBS	Domestic demand of lumber	Billion board feet
5	VPLYS	Domestic demand of veneer and plywood	Billion sq. ft. 3/8" basis
6	PULPS	Domestic demand of pulpwood	Million cords
7	PARTS	Domestic demand of particleboard	Billion sq. ft. 3/8" basis
8	LUMBI	Lumber import	Billion board feet
9	VPLYI	Veneer and plywood import	Billion sq. ft. 3/8" basis
10	PULPI	Pulpwood import	Million cords
11	PARTI	Particleboard import	Billion sq. ft. 3/8" basis
12	LUMBE	Lumber export	Billion board feet
13	VPLYE	Veneer and plywood export	Billion sq. ft. 3/8" basis
14	PULPE	Pulpwood export	Million cords
15	PARTE	Particleboard export	Billion sq. ft. 3/8" basis
16	LUMID[a]	Lumber identity	Billion board feet
17	VPLID[a]	Veneer and plywood identity	Billion sq. ft. 3/8" basis
18	PULID[a]	Pulpwood identity	Million cords
19	PARID[a]	Particleboard identity	Billion sq. ft. 3/8" basis

[a]The identity row ensures that the quantity supplied equals quantity demanded in each region, i.e., (production + import) less (export + domestic consumption) = zero.

Table 6. Activity columns of the model

Serial no.	Name	Description	Unit of measure
1	LUMB	Lumber production	Billion board feet
2	VPLY	Veneer and plywood production	Billion sq. ft. 3/8" basis
3	PULP	Pulpwood production	Million cords
4	PART	Particleboard production	Billion sq. ft. 3/8" basis
5	LUMBI	Lumber import	Billion board feet
6	VPLYI	Veneer and plywood import	Billion sq. ft. 3/8" basis
7	PULPI	Pulpwood import	Million cords
8	PARTI	Particleboard import	Billion sq. ft. 3/8" basis
9	LUMBE	Lumber export	Billion board feet
10	VPLYE	Veneer and plywood import	Billion sq. ft. 3/8" basis
11	PULPE	Pulpwood export	Million cords
12	PARTE	Particleboard export	Billion sq. ft. 3/8" basis
13	LUMBT	Lumber transportation	Billion board feet
14	VPLYT	Veneer and plywood transportation	Billion sq. ft. 3/8" basis
15	PULPT	Pulpwood transportation	Million cords
16	PARTT	Particleboard transportation	Billion sq. ft. 3/8" basis
17	LUMBD	Lumber demand	Billion board feet
18	VPLYD	Veneer and plywood demand	Billion sq. ft. 3/8" basis
19	PULPD	Pulpwood demand	Million cords
20	PARTD	Particleboard demand	Billion sq. ft. 3/8" basis

Table 7. Activity cost coefficients used in the model

Serial no.	Activity	Cost coefficient[a]	Unit of measure
1	LUMBP	0.076	Dollar(s)/board feet
2	VPLYP	0.628	Dollar(s)/sq. ft. 3/8" basis
3	PULPP	17.6	Dollar(s)/cord
4	PARTP	0.0345	Dollar(s)/sq. ft. 3/8" basis
5	LUMBI	0.394	Dollar(s)/board feet
6	VPLYI	0.199	Dollar(s)/sq. ft. 3/8" basis
7	PULPI	6.0	Dollar(s)/cord
8	PARTI	0.0898	Dollar(s)/sq. ft. 3/8" basis
9	LUMBE	0[b]	Dollar(s)/board feet
10	VPLYE	0[b]	Dollar(s)/sq. ft. 3/8" basis
11	PULPE	0[b]	Dollar(s)/cord
12	PARTE	0[b]	Dollar(s)/sq. ft. 3/8" basis
13	LUMBT	0.076	Dollar(s)/board feet
14	VPLYT	0.0276	Dollar(s)/sq. ft. 3/8" basis
15	PULPT	3.1	Dollar(s)/cord
16	PARTT	0.0967	Dollar(s)/sq. ft. 3/8" basis

[a]Coefficient is the cost in 1972 dollars of providing a unit of the product under the specified activity, e.g., the first item indicates that it costs 0.076 dollars (1972) to produce one board foot of lumber.

[b]The zero coefficient for lumber, veneer and plywood, pulpwood and particleboard exports implies that zero export cost is assumed for the four products.

Table 8. Regional resource productivity coefficients for products used in the model

Ser. no.	Resource	Reg. no.	Region name	Coefficient: Lumber	Veneer and plywood	Pulp-wood	Particle-board	Unit of measure/ unit of product
1	LAND	1	New England	0.4	1.8	0.2	0.5	Acres
2	"	2	Middle Atlantic	5.7	6.5	0.4	0.3	"
3	"	3	Lake States	0.2	3.4	0.2	1.1	"
4	"	4	Central States	0.2	5.7	1.1	0.6	"
5	"	5	South Atlantic	0.1	1.5	0.2	0.3	"
6	"	5	East Gulf	0.3	1.0	0.3	0.3	"
7	"	7	Central Gulf	0.2	2.8	0.1	0.5	"
8	"	8	West Gulf	0.2	4.1	0.2	0.5	"
9	"	9	Pacific Northwest	0.4	8.0	1.3	1.2	"
10	"	10	Pacific Southwest	1.6	0	2.2	0.6	"
11	"	11	Northern Rocky	21.3	519.1	0	111.2	"
1	"		Mountain					
12	"	12	Southern Rocky Mountain	7.2	338.6	73.4	21.0	"
13	LABOR[a]	NA[b]	NA	0.004	0.02	0.117	0.0009	Person(s)
14	BUDGET[a]	NA	NA	0.076	0.628	17.6	0.0345	Dollars (1972)

[a]Implies that the same resource productivity coefficient obtains for the specified product in all regions.

[b]NA stands for not applicable.

MODEL VERIFICATION COMPUTER RUNS

A test model was constructed and run with the Mathematical Programming System (MPSX) to test its validity using data for 1990 and two (West Gulf and East Gulf) of the 12 geographic regions. Essentially, this technique aims at utilizing the principle of optimizing a subset of a function when the function is large. For example, if a function f(x) is to be minimized, one can minimize a smaller function g(x) where g(x) is a member of or contained in f(x). The economic importance of this technique includes (1) ease of manipulation, (2) less computer time and therefore lower cost, and (3) simplicity in understanding and error debugging.

Production, export, import, interregional transporation, and demand activities were specified for the two regions now referred to as region 1 (West Gulf) and region 2 (East Gulf). The rows specified include (1) resource rows, (2) domestic demand rows, (3) import rows, (4) export rows, and (5) identity rows. All four products, lumber, veneer and plywood, pulpwood and particleboard were used. The model is a cost minimizing one, with the intent to reduce annual imports, increase annual production and possibly increase annual exports. Thus, the row types (whether less than, greater than, or equality for constraints) described for the rows are as follows: (1) less than for the resource constraint rows,

(2) greater than for the domestic demand constraint rows, (3) less than for the import constraint rows, (4) greater than for the export constraint rows, and (5) equality for identity rows.

Figure 4 shows the rows and row types as specified in the model. Early runs with the imports at the lower limits ($\geq$, having greater than row types) and the exports at the upper limit ($\leq$, having less than row types) resulted in infeasibilities. It was not until the imports were put at the upper limits ($\leq$) and the exports at the lower limits ($\geq$) that feasible optimal solutions were obtained. Results obtained with data for year 1990 are discussed in the next chapter. The results indicate that the minimum total cost (in 1972 dollars) of producing, importing, exporting and transporting the products needed in 1990 is about $121 million. In doing this, region 1 used about 2949 thousand acres or 10.9% of the available forest land; 7.5 thousand units of the estimated labor requirement or 44% of it; and $120 million or 12.7% of the estimated capital requirement. Region 2 used about 538 thousand acres or about 3% of estimated available land; 0.8 thousand units of labor or 3% of the estimated labor requirements; and $1.3 million or 0.1% of the estimated capital requirement.

The apparent low productive capacity of region 2 could be explained with the fact that both regions 1 and 2 are supply regions with some excess capacity (ability to produce more than the required quantity). It is shown in the result that a lot of transportation of excesses took place from region 1 to region 2. Therefore, region 2 just used resources enough to produce the difference between the transportation quantity and its own demand. Thus, no interregional transportation of commodities took place from region 2 to region 1.

A full discussion of the LP output will be made in the Results chapter of the study. Meanwhile, a pictorial representation of the LP matrix for this simplified version of the model using two regions is shown in Figure 5.

A post-optimality analysis was performed on the simplified model using Range Procedure to test model sensitivity. The Range Analysis computes the interval of values over which each row activity, column activity, and objective function coefficient can be changed without altering the optimal basis. Information of this nature is useful in determining the stability of a solution and the effects of cost changes on the optimal solution. The analysis also helps in the interpretation of the shadow price (marginal effects of a change in a vector reflected in the rows solution by "dual activity", and in the columns solution by "reduced costs".

The output from a Range Analysis usually contains four sections:

		LUMB1	VEPLY1	PULP1	PART1	LUMBI1	VEPLYI1	PULPI1	PARTI1	LUMBE1	VEPLYE1	PULPE1	PARTE1	LUMBT12	VEPLYT12	PULPT12	PARTT12	LUMBD1	VEPLYD1	PULPD1	PARTD1	LUMB2	VEPLY2	PULP2	PART2	LUMBI2	VEPLYI2	PULPI2	PARTI2	LUMBE2	VEPLYE2	PULPE2	PARTE2	LUMBT21	VEPLYT21	PULPT21	PARTT21	LUNBD2	VEPLYD2	PULPD2	PARTD2	Z1
OBJ1	N	U	T	B	U	T	T	A	U					U	U	A	U					U	T	B	U	T	T	A	U					U	U	A	U					
R011	L	T	A	T	T																																					E
R021	L	V	U	T	W																																					E
R031	L	U	T	B	U	T	T	A	U					U	U	A	U																									D
R041	G																	1																								D
R051	G																		1																							C
R061	G																			1																						C
R071	G																				1																					C
R081	L					1																																				B
R091	L						1																																			C
R101	L							1																																		C
R111	L								1																																	B
R121	G									1																																B
R131	G										1																															A
R141	G											1																														C
R151	G												1																													B
R161	E	1				1				-1				-1				-1																1								
R171	E		1				1				-1				-1				-1																1							
R181	E			1				1				-1				-1				-1																1						
R191	E				1				1				-1				-1				-1																1					
R012	L																					T	1	T	T																	E
R022	L																					V	U	T	W																	E
R032	L																					U	T	B	U	T	T	A	U					U	U	A	U					D

```
R042   G                                                                           1       C
R052   G                                                                             1     C
R062   G                                                                               1   D
R072   G                                                                                 1 D
R082   G                                                   1                               B
R092   L                                                     1                             C
R102   L                                                       1                           B
R112   L                                                         1                         A
R122   G                                                           1                       B
R132   G                                                             1                     A
R142   G                                                               1                   B
R152   G                                                                 1                 B
R162   E                           1                1      1      -1      -1      -1
R172   E                             1                1      1      -1      -1      -1
R182   E                               1                1      1      -1      -1      -1
R192   E                                 1                1      1      -1      -1      -1
```

Legend:

Symbol			
Z	Less	than	.000001
Y	.000001	thru	.000009
X	.000010		.000099
W	.000100		.000999
V	.001000		.009999
U	.010000		.099999
T	.100000		.999999
1	1.000000		1.000000
A	1.000001		10.000000
B	10.000001		100.000000
C	100.000001		1,000.000000
D	1,000.000001		10,000.000000
E	10,000.000001		100,000.000000
F	100,000.000001		1,000,000.000000

Minimum = .900000E-03   Maximum = .584022E+07

Figure 5. Pictorial representation of the LP matrix

1. Section 1, contains rows at limit level. Here the restraint rows where the slack or disposal activity is at zero level are reported. The resource restraints presented in this section are those fully used in the plan and therefore limiting.
2. Section 2, contains columns at limit level. This section is concerned with those activities which have been left out of the plan. They are usually at a lower limit of zero.
3. Section 3, contains rows at intermediate level. This section provides an analysis of restraints with slack activities at nonzero levels.
4. Section 4, contains columns at intermediate level. This section analyzes real activities, which are in the basis.

Outputs for Sections 1, 2, 3, and 4 of the Range Analysis and a more detailed discussion of the option are shown in Appendix A.

The results of the Range Analysis did show that the model is valid and has adequate sensitivity to be used for optimization. Further verification of the model sensitivity to authenticate the claims made from the Range Analysis was later performed on the full model with the use of a parametric programming technique.

After testing and validating the model's usefulness as a tool for optimization, the model was enlarged to include all 12 regions and all their (1) resource (land, labor and budget) constraints; (2) demand (domestic, import and export) constraints; and (3) the activities (production, import, export and transportation). Data for three future times (1990, 2010, 2030) out of the period 1990 to 2030 were used to run the program. The use of the two extreme periods and a middle year will facilitate the derivation of the trend in the remaining years while reducing computer costs. The results and their discussions are covered in subsequent sections.

RESULTS AND DISCUSSION

Overall, results for 1990, 2010 and 2030 show that all demand and supply requirements except lumber and particleboard imports were fully met in the nine supply regions and partially met in the three demand regions. Lumber and particleboard imports in all three periods (1990, 2010 and 2030) for the 12 regions came into the solution at the zero level. The three demand regions, in addition to failing to meet the lumber and particleboard imports, could not fully meet their veneer and plywood and pulpwood import demands.

The procedure BOUNDS was called to attempt to bring lumber and particleboard imports into the solution at their declared values. In so doing, the lumber import and also the particleboard import constraints in respective regions were forced to the lower limits and intended to enter the solution as such. This implies making lumber and particleboard imports in each region greater or equal to the region's annual import demand for the product. This is intended to eliminate zero level of importation for each of the two products which has hitherto been the case in all the regions.

The procedure BOUNDS showed the solution was infeasible. Infeasibilities occurred in the demand regions where the budget constraints were exceeded and the optimal solution (minimum cost) changed from $4709 million to $7688 million. Moreover, pulpwood import in the regions which was met in the former solution was forced out of the solution after the lumber and particleboard imports were bounded. One major reason why the model would "want to" eliminate lumber and particleboard importation is that import costs, as specified, in the model for lumber and particleboard are higher than their corresponding production costs. For instance, lumber import costs $0.394 per board foot while its production cost is $0.076 per board foot in 1972 dollars. Also, particleboard import costs $0.0898 per square foot while its production costs only $0.0345 per square foot.

An alternative approach to finding a solution to the problem would have been to parameterize the budgets of demand regions simultaneously with the BOUNDS procedure. But the procedure BOUNDS cannot be parameterized. Besides, earlier parametric programming performed in all regions' budgets and on demand regions' budgets separately could not force lumber and particleboard imports into solution. It follows, therefore, that the model suggests costs to be minimized through domestic production of lumber and particleboard and not imports of the two commodities.

Before proceeding to the specifics about regional resource and commodity uses over time, a description of the LP output is necessary. This will facilitate a better understanding of subsequent discussions. First, a solution has to be feasible and optimal before the output could be of any use in decision-making. A typical LP output consists of two sections: (1) Section 1 - Rows, and (2) Section 2 - Columns.

Section 1 - Rows

This section contains eight columns. The first five columns are explained as follows: (1) NUMBER represents an internal identification or numeric name of the rows; (2) ROW stands for user's name; (3) AT indicates the status of the vector in the solution; (4) ACTIVITY is the value the row takes in the solution; (5) SLACK ACTIVITY is the value of underuse or overuse activity associated with the requirement. For a more detailed discussion of the first five columns of the output, see Appendix A.

Columns six through eight have only one entry per row unlike their counterparts in the Range Analysis output. The sixth column, LOWER LIMIT, is the lower limit (lowest limit required) of a "greater than" (G) requirement or "equality" (E) constraint. The seventh column, UPPER LIMIT, indicates the limit (highest value required) of resources available or commodity needs for a "less than" (L) or equality (E) constraint.

The eighth column, DUAL ACTIVITY, is the shadow price[1]

[1]Shadow price for a resource is the value of that resource in its next best alternative use.

or marginal value product (MVP)[1] associated with a one-unit reduction in the resource availability for a "less than or equal to" constraint, or a one-unit increase in the resource or product level for a "greater than or equality" constraint. A zero value under this column indicates a shadow price of zero, showing that the resource or restraint is in excess supply. A negative sign after the entry implies that tightening the resource restraints would lessen the optimum value.

Section 2 - Columns

This section has a format similar to Section 1. The first four columns are self-explanatory. The first, NUMBER stands for internal identification, the second, COLUMN is the user's identification code for the activities, the third, AT, identifies the status of activities or the column vectors in the solution.

The fourth column, ACTIVITY, is the level at which the activity enters the solution; the fifth, INPUT COST, gives

---

[1]Marginal Value Product (MVP) for a resource is the market value of that resource. It is a produce of the marginal physical product (MPP) of that resource and the price. For example, the marginal value product for labor (MVPL) is a product of the marginal physical product of labor (MPPL) and the wage rate (W) which is the price of labor. Thus, MVPL = MPPL x W. For capital, the price is the interest rate or the alternative rate of return (ARR) of capital.

the value of the activity in the objective function. Columns six and seven are the LOWER LIMIT and UPPER LIMIT, respectively, and show the lower and upper limits for the activities.

The eighth and last column, REDUCED COST, gives the change in value of the objective function that would result if one unit of an activity, currently not in the optimal solution, is forced into the solution. If a zero appears under this column, i.e., a zero reduced cost, an "A" often precedes the corresponding row of the printout. It is an indication that an alternative optimum solution exists or, in the case of transportation activity, that the requirement has been met through an alternative source.

Period I Results

Results for year 1990 show that it will cost about $4709 million (1972 dollars) to produce, transport, export and import the demand quantities of hardwood lumber, veneer and plywood, pulpwood and particleboard. The annual quantities of these products for the nation in this year stand as follows:

(1) For lumber - 10.1 billion board feet domestic demand, 0.4 billion board feet import demand, and 0.2 billion board feet export demand;

(2) For veneer and plywood - 5.8 billion square feet

(3/8" basis) domestic demand, 3.6 billion square feet import demand, and 0.05 billion square feet export demand;

(3) For pulpwood - 36.7 million cords domestic demand, 1.3 million cords import demand, and 1.3 million cords export demand;

(4) For particleboard - 15.5 billion square feet (3/8" basis) domestic demand, 0.10 billion square feet import demand, and 0.20 billion square feet export demand.

To accomplish this in all the regions, resources were used at varying degrees. In all, capital and labor appear to be limiting factors in most regions as many regions either used up all their capital and labor constraints or have less slack activities for the two resources than for land. Land does not appear to be limiting. In no region was the land resource restrictive. Indeed, there are more slack activities for land in every region than the activities (quantities utilized). This is an indication that, given enough of the limiting resources, the potential for significant increases in product output exists.

The expected resource available, actual quantities used and percentage uses of the resources (land, labor and capital) for all 12 regions are shown in Tables 9, 10, and 11. In the case of land, many factors may be responsible for the commer-

Table 9. Regional hardwood forestland availability and use in Period I, 1990

Region number	Region	Expected land available[a]	Actual land used[b]	% used[b]
		---(1000 acres)---		
1	New England	17204.9	2006.96	11.7
2	Middle Atlantic	42532.6	24344.27	57.2
3	Lake States	35182.8	2334.18	6.6
4	Central States	41973.4	6023.93	14.4
5	South Atlantic	31964.2	598.40	1.9
6	East Gulf	19063.2	99.70	5.2
7	Central Gulf	36328.5	822.39	2.3
8	West Gulf	36761.1	2366.37	6.4
9	Pacific Northwest	27419.0	1222.06	4.5
10	Pacific Southwest	4608.0	506.09	11.0
11	Northern Rocky Mountain	1557.2	1418.20	91.1
12	Southern Rocky Mountain	6094.3	2191.30	36.0

[a]Expected available hardwood timberland was estimated with the commercial timberland area of each region based on forest type. This method may overstate the hardwood commercial timberland.

[b]Actual acreage used and percentage used appear to be low probably because of the method used to estimate the expected available acreage. This, therefore, does not mean that a large surplus of forestland exists. It only means that the merchantable growing stock volume might be produced on this portion of land while the remaining section might contain immature growing stock.

Table 10. Regional hardwood products manufacturing estimated labor availability and use in Period I, 1990

Region number	Region	Expected labor available[a]	Actual labor used[b]	% used[b]
		--(1000 persons)--		
1	New England	12.59	12.59	100
2	Middle Atlantic	18.45	18.45	100
3	Lake States	18.92	9.62	50.8
4	Central States	18.38	18.38	100
5	South Atlantic	34.72	6.92	19.9
6	East Gulf	26.35	9.20	34.9
7	Central Gulf	23.41	5.37	22.9
8	West Gulf	16.99	11.87	69.9
9	Pacific Northwest	4.63	3.37	72.8
10	Pacific Southwest	0.257	0.257	100
11	Northern Rocky Mountain	0.008	0.008	100
12	Southern Rocky Mountain	0.072	0.072	100

[a]Expected labor available was estimated with the 1977 Census of Manufactures labor productivity data applied to expected future production. The need to incorporate labor productivity over time is recognized but it may require the use of a model like dynamic programming which is beyond the scope of this study.

[b]The actual and percentage labor use should be viewed with some caution and should not be taken to mean the existence of labor shortages in hardwood primary products manufacture. The method of estimation may have underestimated the labor availability.

Table 11. Regional hardwood products manufacture estimated capital availability and use in Period I, 1990

Region number	Region	Expected capital available[a]	Actual capital used[b]	% used[b]
		-(million 1972 dollars)----		
1	New England	636.0	636.0	100.0
2	Middle Atlantic	1101.3	1050.57	95.39
3	Lake States	950.3	443.31	46.65
4	Central States	937.4	937.4	100.0
5	South Atlantic	1735.2	269.76	15.55
6	East Gulf	1328.6	443.78	33.4
7	Central Gulf	1236.5	210.45	17.02
8	West Gulf	5945.9	553.27	9.3
9	Pacific Northwest	253.2	131.52	51.9
10	Pacific Southwest	29.1	29.1	100.0
11	Northern Rocky Mountain	0.44	0.44	100.0
12	Southern Rocky Mountain	3.6	3.6	100.0

[a]Expected capital available has been calculated from per unit cost of performing each activity (production, import and transporation) and the expected activity level for each product in the future. It is possible that capital requirement may be underestimated by this method.

[b]The importance of capital as indicated by the high level of use may have been overstated by the estimating technique above.

cial forestland use variations. For instance, in a region with high productive capacity, more land will be needed to meet production requirement like in Middle Atlantic. Low land usage might arise from high land productivity for hardwood production as is the case in South Atlantic. However, more land may be used in regions of low productive capacity that have low capital budget. Such is the case with the demand regions of Pacific Southwest, Northern Rocky Mountain and Southern Rocky Mountain regions where substantial amounts of land have been used. These regions also have low land productivity for hardwood production and this is a possible factor that will add to more land usage in the two regions. Also, it is possible that since hardwood commercial forestland regional acreages were based on forest types, substantial acreages of nonhardwood forestlands may have been classified under hardwood forestland where hardwoods are the dominant species. Thus, the hardwood forestland availability may have been overstated.

Labor appears to be limiting as many regions used up all their labor allocations. The seeming high usage may result from an underestimation of the labor requirement which makes the actual and, consequently, the percentage labor used appear rather high. The labor production coefficients for the four products are very much lower numerically than for capital or land, hence the lower numerical value for labor used relative to that of land and capital. Compare the labor productivity coefficients for lumber, veneer and plywood, pulpwood and particleboard with those of land and capital as shown in Table 12. It is clear from these data that relatively smaller quantities of labor will be needed in the manufacture of any of the products.

Table 12. Labor, land and capital production coefficients for hardwood products in all regions

Resource	Production coefficient[a]			
	Lumber (bd ft)	Veneer and plywood, sq ft (3/8" basis)	Pulpwood (cord)	Particleboard, sq ft (3/8" basis)
Labor	0.004	0.02	0.117	0.0009
Land	0.4	1.8	0.2	0.5
Capital	0.076	0.628	17.6	0.0345

[a]Implies that one unit of each of the products specified is produced with the corresponding unit(s) of labor, land and capital resources. For example, one board foot of lumber is produced with 0.004 person (labor), 0.4 acre (land) and 0.076 dollar (capital).

It is also possible that the labor availability may not have been underestimated. Instead, the high labor usage may be portraying the labor intensive characteristic of primary wood products manufacturing. Regions 1, 2 and 4 and the demand regions used up all their labor in this period. Those three supply regions are among the highest producers of products transported to other regions. The demand regions try hard to produce as much of their needed products as their resources would permit. The activities of supply and demand increase their labor demands.

In the case of capital, the behavior of the model indicates that capital is limiting; an indication that hardwood products manufacturing in particular and wood products manufacturing in general are capital intensive. The capital limiting process was clear from the fact that five out of the 12 regions used up all their capital. The apparent capital limiting effect prompted the performing of a parametric programming on the budget constraints, the results of which will be discussed in a later chapter.

Period II Results

Results in the second period (2010) show that the minimum cost of meeting the demand (domestic, import and export0 requirements of all hardwood products has risen slightly to $5852 million (1972) dollars. This higher cost arises, however, from an increased demand which takes place in the second period. The annual demand quantities of products in the second period are as follows:

1. Lumber comprises 12.9 billion board feet of domestic demand, 0.80 billion board feet of import, and 0.40 billion board feet of export demand;
2. Veneer and plywood comprises 6.6 billion square feet (3/8" basis) of domestic demand, 4.05 billion square feet import demand, and 0.050 billion square

feet of export requirement;

3. Pulpwood comprises 53.4 million cords of domestic demand, 1.3 million cords of import demand, and 0.9 million cords of export demand;
4. Particleboard comprises 21.7 billion square feet (3/8" basis) of domestic demand, 0.2 billion square feet of import demand, and 0.3 billion square feet of export demand.

With the exception of lumber and particleboard imports, all other activities were fully met in the supply regions. The demand regions, in addition to failing to meet lumber and particleboard import demands, could not meet their veneer and plywood, and pulpwood import demands. This problem was considered attributable to the low budget allocation in the demand regions. An upgrading of the budget constraints of the demand regions through a post-optimality analysis proved this assumption right and increased the capability of demand regions in handling their veneer and plywood plus particleboard imports. A complete description of this process is provided in a later discussion on post-optimality analysis. Products transportation between supply regions are not apparent but the demand regions have received supplies of products indiscriminantly from the supply regions.

Resources use in this second period shows the same pattern as described for the first period. Labor and capital are again found limiting as many regions used all (100%) of their labor and capital while land appears not limiting. Tables 13, 14, and 15 show the land, labor and capital requirement, actual use and percentage use in Period II for all regions. The apparent limiting effect of labor and capital may represent the high labor and capital requirement of the wood products industry.

Period III Results

Results in the third period (2030) show that the minimum total cost in 1972 dollars of producing, transporting, importing and exporting the respective quantities of hardwood products is $7264 million. Resources use in all the regions in producing the products indicates a remarkable increase in resource use over and above those used in periods I and II. Tables 16, 17 and 18 show land, labor and capital availability and uses, respectively.

Annual demand for the hardwood commodities in all regions for the year 2030 which have thus been met at anticipated prices include:

1. For lumber - 16.0 billion board feet domestic demand, 1.0 billion board feet import demand, and 0.5 billion board feet export demand;
2. For veneer and plywood - 7.2 billion square feet (3/8" basis) domestic demand, 3.9 billion square

Table 13. Regional hardwood forestland availability and use in Period II, 2010

Region number	Region	Expected land available[a]	Actual land used[b]	% used[b]
		----(1000 acres)----		
1	New England	17204.9	2450.14	14.24
2	Middle Atlantic	42532.6	30841.92	72.54
3	Lake States	35182.8	3065.88	8.7
4	Central States	41973.4	7742.42	18.45
5	South Atlantic	31964.2	769.32	2.41
6	East Gulf	19063.2	1246.87	6.54
7	Central Gulf	36328.5	1054.49	2.9
8	West Gulf	36761.1	3030.79	8.2
9	Pacific Northwest	27419.0	1681.23	6.13
10	Pacific Southwest	4608.0	721.74	15.67
11	Northern Rocky Mt.	1557.2	1482.67	95.21
12	Southern Rocky Mt.	6094.3	2921.74	47.94

[a]Forestland availability may have been overstated through the use of forest type for estimation.

[b]Actual and percentage acreages used may be low because of the method used to estimate the available timberland.

Table 14. Regional hardwood products manufacturing expected labor availability and use in Period II, 2010

Region number	Region	Expected labor available[a]	Actual labor used[b]	% used[b]
		--(1000 persons)--		
1	New England	14.87	14.87	100.0
2	Middle Atlantic	22.8	22.8	100.0
3	Lake States	22.55	11.98	53.1
4	Central States	22.42	22.42	100.0
5	South Atlantic	40.26	8.60	21.4
6	East Gulf	30.88	9.96	32.3
7	Central Gulf	28.17	6.7	23.8
8	West Gulf	20.59	14.72	71.5
9	Pacific Northwest	5.67	4.2	74.1
10	Pacific Southwest	0.350	0.35	100.0
11	Northern Rocky Mountain	0.011	0.011	100.0
12	Southern Rocky Mountain	0.087	0.087	100.0

[a]The technique used to estimate labor availability may have understated the labor needed for hardwood products manufacture.

[b]The actual labor used and the percentage use may appear high because of the labor requirement estimation technique.

Table 15. Regional hardwood products manufacture exported capital availability and actual use in Period II, 2010

Region number	Region	Expected capital available[a] --(million	Actual capital used[b] 1972 dollars)----	% used[b]
1	New England	785.4	785.4	100.0
2	Middle Atlantic	1447.6	1312.59	73.38
3	Lake States	1788.7	558.59	31.23
4	Central States	1204.4	1204.4	100.0
5	South Atlantic	2158.5	334.86	15.5
6	East Gulf	1635.1	502.22	30.7
7	Central Gulf	1574.4	261.06	15.58
8	West Gulf	1216.2	681.63	56.05
9	Pacific Northwest	328.2	164.53	50.13
10	Pacific Southwest	41.5	41.5	100.0
11	Northern Rocky Mountain	0.46	0.46	100.0
12	Southern Rocky Mountain	4.8	4.8	100.0

[a]The method used to estimate capital requirement may have underestimated the capital needs for hardwood products manufacture.

[b]The level of use indicates capital is highly limiting. But this may be due to underestimation of the capital requirement.

Table 16. Regional hardwood commercial forestland availability and use in Period III, 2030

Region number	Region	Expected land available[a] (1000 acres)	Actual land used[b] (1000 acres)	% used[b]
1	New England	17204.9	3053.38	17.75
2	Middle Atlantic	42532.6	38970.11	91.62
3	Lake States	35182.8	3772.18	10.72
4	Central States	41973.4	9178.41	21.87
5	South Atlantic	31964.2	949.77	2.77
6	East Gulf	19063.2	1183.19	6.21
7	Central Gulf	36328.5	2000.82	5.50
8	West Gulf	36761.1	3320.22	9.03
9	Pacific Northwest	27419.0	2214.26	8.08
10	Pacific Southwest	4608.0	874.78	18.98
11	Northern Rocky Mt.	1557.2	1557.2	100.0
12	Southern Rocky Mt.	6094.3	3530.43	57.93

[a]The use of forest type to estimate hardwood forestland area may overestimate the available land area.

[b]Errors in estimating expected forestland area may cause actual and percentage land area used to appear relatively small.

Table 17. Regional hardwood products manufacturing labor availability and actual use in Period III, 2030

Region number	Region	Expected labor available[a]	Actual labor used[b]	% used[b]
		--(1000 persons)--		
1	New England	16.64	16.64	100.0
2	Middle Atlantic	26.76	26.76	100.0
3	Lake States	25.78	15.24	57.1
4	Central States	26.23	26.23	100.0
5	South Atlantic	46.66	10.83	23.2
6	East Gulf	34.54	12.83	37.1
7	Central Gulf	32.45	9.70	29.9
8	West Gulf	23.79	17.73	74.5
9	Pacific Northwest	6.62	6.62	100.0
10	Pacific Southwest	0.43	0.43	100.0
11	Northern Rocky Mountain	0.13	0.13	100.0
12	Southern Rocky Mountain	0.10	0.10	100.0

[a]The estimation of labor availability with base year (1977) labor productivity and future output requirement may underestimate the labor availability since the dynamics of labor including population growth indexes are not available.

[b]The actual labor use and therefore the percentage labor use may appear high following the labor availability estimation technique.

Table 18. Regional hardwood products manufacture estimated capital availability and actual use in Period III, 2030

Region number	Region	Expected capital available[a]	Actual capital used[b]	% used[b]
		---(million 1972 dollars)---		
1	New England	894.6	894.6	100.0
2	Middle Atlantic	1713.4	1713.4	100.0
3	Lake States	1387.4	704.46	50.78
4	Central States	1411.4	1411.4	100.0
5	South Atlantic	2477.6	408.28	16.50
6	East Gulf	1845.4	479.07	25.96
7	Central Gulf	1842.6	500.48	27.16
8	West Gulf	1427.2	709.35	49.70
9	Pacific Northwest	386.4	386.4	100.0
10	Pacific Southwest	50.3	50.3	100.0
11	Northern Rocky Mountain	0.57	0.57	100.0
12	Southern Rocky Mountain	5.8	5.8	100.0

[a]Regional capital availability was estimated from the product of the unit cost of an activity, e.g., transportation and the quantity of product transported. This is summed over all activities (product transportation and or import) for all products.

[b]The actual and percentage capital use may be high if capital availability is underestimated.

feet import demand and 0.05 billion square feet export demand;

3. For pulpwood - 70.7 million cords domestic demand, 1.3 million cords import demand, and 0.7 million cords export demand;
4. For particleboard - 1.1 billion square feet (3/8" basis) domestic demand, 0.2 billion square feet import demand and 0.3 billion square feet export demand.

More information on national resource and demand constraints in all years of the projection period are contained in Appendix C.

Capital and labor again were found to be the most limiting of the resources as indicated by seven out of the twelve regions in each case exhausting their budget and labor to meet their annual products requirements. Land in this period again appears not limiting. Relatively small quantities of the resource were used leaving seemingly large quantities of unused resources. Expected resource requirements, actual and percentage uses by regions for the third period are shown in Tables 16, 17, and 18.

Basically, the same explanation as was made in the first two periods for the use of resources also holds true for this period. Hardwood forestland availability may have been overstated by estimating hardwood commercial forestland with a forestland classification based on forest types. The labor force in hardwood products manufacturing may have been underestimated as many regions used up all the labor allocated to them. High labor use may also reflect the labor intensity inherent in primary wood products manufacture.

Further, the capital requirement by region may have been underestimated as many regions did exhaust their available capital. Note, however, that no region required additional capacity, thus warranting a negative slack activity. However, further investigation of the sufficiency of the available capital was carried out by performing a sensitivity analysis on the budget. The results of the analysis will be discussed in the next section under Post-Optimality Analyses. With land showing no limitations, it was considered unnecessary to perform any sensitivity analysis through parametric programming on land values. The high labor use percentage generated a thought about whether a parametric programming analysis would be performed on labor use in each region. But, since labor cost does not enter directly into the objective function, varying the quantity of labor may not have much effect on the total cost. The idea of parameterizing the labor constraint was therefore considered unnecessary.

Apart from fulfilling the production, export, and import requirements (for veneer and plywood, and pulpwood) and the demand requirements of all products in the twelve regions, extensive interregional transfers of products has occurred.

These transfers occur from the supply regions to the demand regions during the three time periods 1990, 2010, and 2030. Most transportation (transfer) activities have taken place more especially between supply and demand regions rather than among supply regions. The trend observed for all three periods and depicted in Figure 6 is that: New England transports veneer and plywood to Pacific Southwest and particleboard to Southern Rocky Mountain. Middle Atlantic transports lumber to Pacific Southwest, Northern Rocky Mountain and Southern Rocky Mountain. Lake States only transports pulpwood to Pacific Southwest. Central States transports pulpwood to Pacific Southwest, and veneer and plywood to Northern Rocky Mountain and Southern Rocky Mountain.

South Atlantic did not undertake any interregional transfers, instead, the surpluses produced were always exported. East Gulf only transports veneer and plywood to Pacific Southwest. Central Gulf, like East Gulf, only transports particleboard to Pacific Southwest. West Gulf transports pulpwood and particleboard to Northern Rocky Mountain only.

The last of the supply regions, Pacific Northwest, supplies veneer and plywood to its neighbor, Pacific Southwest. The quantity flow of products from supply to demand regions in the three periods are shown in Tables 19, 20, and 21. Figure 7 shows the annual national budget constraints and calculated minimum costs for the projection period.

Figure 6. Transportation of products from supply regions to demand regions (lu represents lumber transportation, vp represents veneer and plywood transportation, pp represents pulpwood transportation, pb represents particleboard transportation)

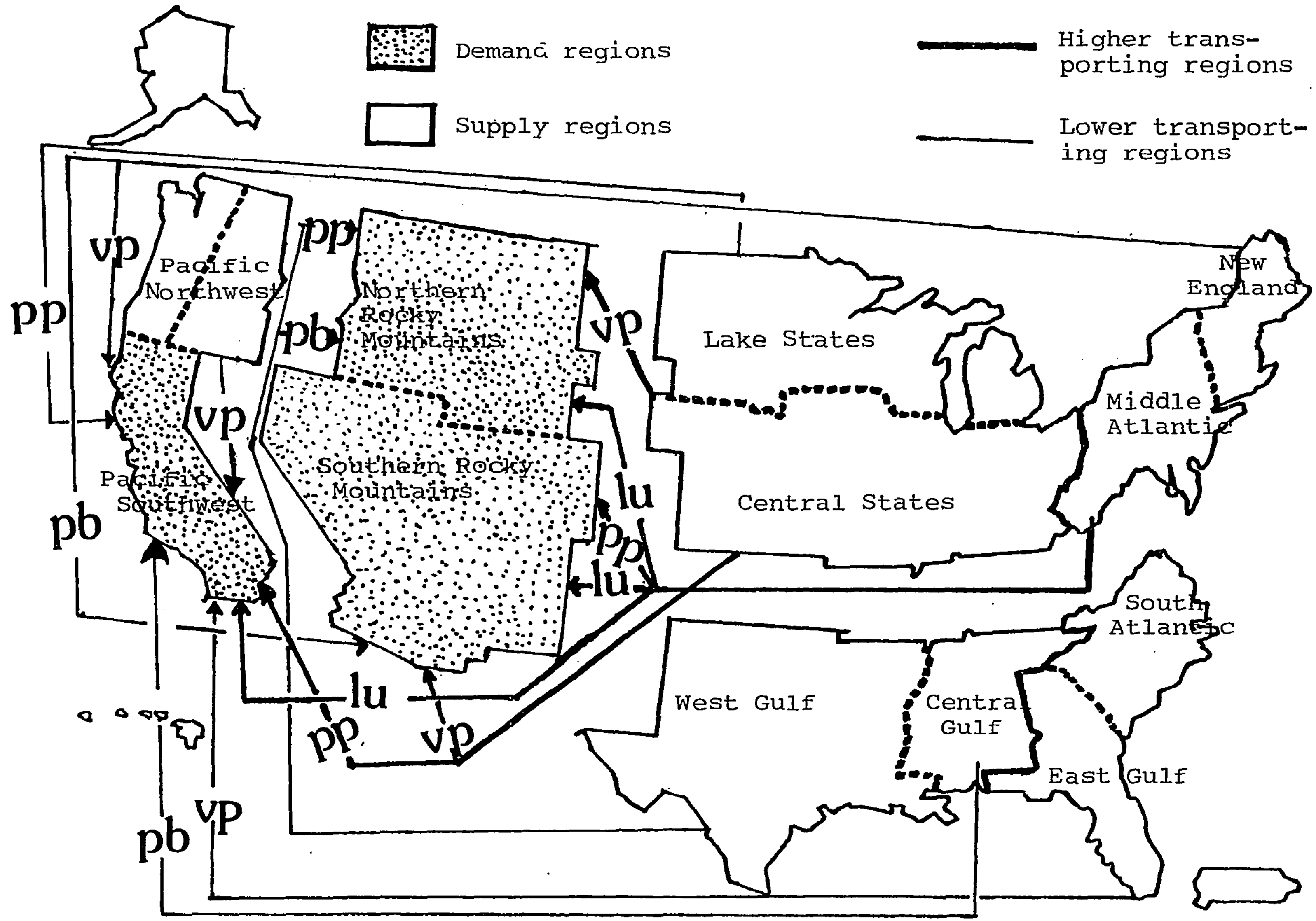
Demand regions
Supply regions
Higher transporting regions
Lower transporting regions
Pacific Northwest
Northern Rocky Mountains
Lake States
New England
Middle Atlantic
Pacific Southwest
Southern Rocky Mountains
Central States
South Atlantic
West Gulf
Central Gulf
East Gulf
vp
pp
pb
lu

Table 19. Transfer of products from supply to demand regions, Period I, 1990

Supply region	Demand region	Product and quantity transferred: Lumber (Million bd. ft.)	Veneer and plywood (Million sq. ft. 3/8"basis)	Pulpwood (1000 cords)	Particleboard (Million sq. ft. 3/8"basis)
New England	Pacific Southwest		515		
	Southern Rocky Mt.				530
Middle Atlantic	Pacific Southwest	1100			
	Northern Rocky Mt.	100			
	Southern Rocky Mt.	414			
	Southern Rocky Mt.			1500	
Lake States	Pacific Southwest			4000	
Central States	Northern Rocky Mt.		1		
	Southern Rocky Mt.		250		
East Gulf	Northern Rocky Mt.		57		
Central Gulf	Pacific Southwest				848
West Gulf	Northern Rocky Mt.			380	
	Northern Rocky Mt.				142
Pacific Northwest	Pacific Southwest		117		

Table 20. Transfer of products from supply to demand regions, Period II, 2010

		Product and quantity transferred			
		Lumber	Veneer and plywood	Pulpwood	Particleboard
Supply region	Demand region	Million bd. ft.	Million sq. ft. 3/8"basis	1000 cords	Million sq. ft. 3/8"basis
New England	Pacific Southwest		610		
	Southern Rocky Mt.				750
Middle Atlantic	Pacific Southwest	1400			
	Northern Rocky Mt.	130			
	Southern Rocky Mt.	533			
	Southern Rocky Mt.			2200	
Lake States	Pacific Southwest			5500	
Central States	Pacific Southwest			3600	
	Northern Rocky Mt.		66		
	Southern Rocky Mt.		270		
Central Gulf	Pacific Southwest				1170
West Gulf	Northern Rocky Mt.			530	
	Northern Rocky Mt.				204
Pacific Northwest	Pacific Southwest		100		

Table 21. Transfer of products from supply to demand regions, Period III, 2030

		Product and quantity transferred			
		Lumber	Veneer and plywood	Pulp-wood	Particle-board
Supply region	Demand region	Million bd. ft.	Million sq. ft. 3/8"basis	1000 cords	Million sq. ft. 3/8"basis
New England	Pacific Southwest		650		
Middle Atlantic	Pacific Southwest	1750			
	Pacific Southwest		380		
	Northern Rocky Mt.	160			
	Southern Rocky Mt.	66			
	Southern Rocky Mt.		42		
	Southern Rocky Mt.			2900	
Lake States	Pacific Southwest			7700	
Central States	Northern Rocky Mt.		72		
	Southern Rocky Mt.		250		
East Gulf	Pacific Southwest		80		
Central Gulf	Pacific Southwest				1400
West Gulf	Northern Rocky Mt.			690	
	Northern Rocky Mt.				247
Pacific Northwest	Pacific Southwest		13		

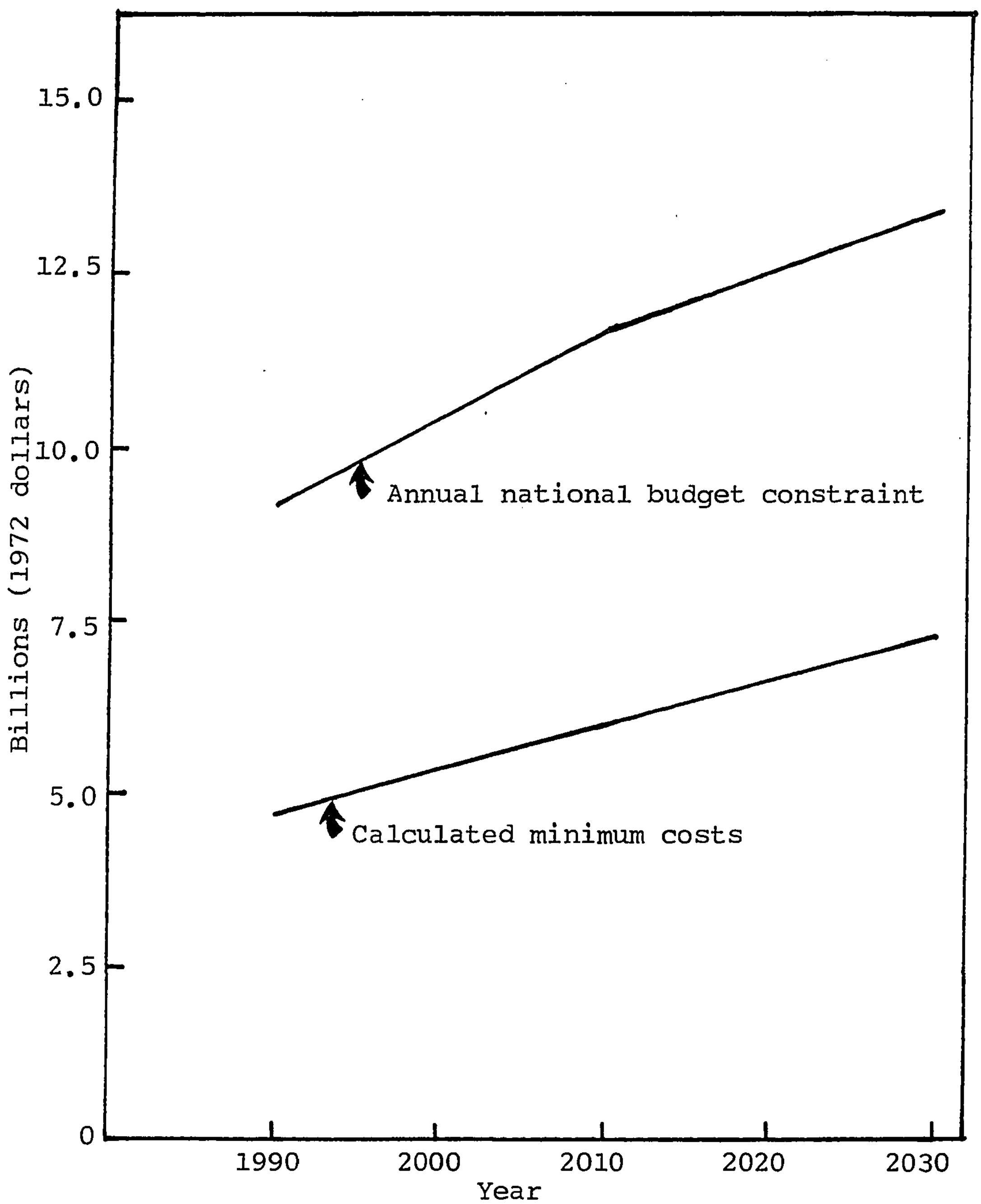

Figure 7. Annual national hardwood production budget constraints and calculated annual minimum costs for the projection period 1990-2030

The minimum cost calculated for the production, import and distribution of the four hardwood products for the base year 1977 shows a cost of $4557 million (1972 dollars). This compares closely with the actual cost of $4000 million in 1972 dollars incurred for the production and import only (excluding distribution) of the same products in 1977 as reported by USDC, Bureau of the Census (1977b; 1978). Estimated labor use of 64 thousand persons for the three activities is slightly less than the actual figure of 66 thousand persons as reported in the 1977 Census of Manufacturers (USDC, Bureau of the Census, 1977b).

Calculated minimum costs for both the base year and the projection years show that costs rise with the increase in demand for products in future years. Land and labor used also show the same rising trends. For more information on costs and resource uses in the base year and projection years, see Appendix D.

POST-OPTIMALITY ANALYSIS

The range analysis discussed earlier had shown that the model is capable of maintaining solution optimality over a wide range of activity costs, resource technical coefficients and resource limits or requirements and (RHS value) variations. However, the need to better understand and quantify specific resource changes and policies as affecting the optimal solution is necessary. To this end, several parametric programming analyses were performed on the model's variables to determine precisely the model's sensitivity to cost and certain policy changes. The results obtained from these operations are described in subsequent sections.

Model Response to Budget Increases in All Regions

The sensitivity of the model was verified by parameterizing the budget component of the RHS vector. The MPSX procedure PARARHS[1] was applied to the budget rows of all 12 regions to determine the effect of budget increases on total cost and the level of activities. Second, the procedure was applied to ascertain if the budget increase influences lumber and particleboard imports which hitherto have not entered the optimal solution.

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[1]PARARHS is a parametric programming option which increments or decrements any specified row value(s) of the right-hand side vector of an LP model by specific values over indicated intervals.

The total budget constraint for all regions in 1990 was increased by $1 billion each time up to a maximum of $8 billion. Each increment is apportioned to regions in the ratio of their initial budget constraints. This incremental change represents a doubling of the total initial budget limit of all regions in the first projection period. Optimal solutions are obtained after each increment.

Results obtained show that budget increases favored both demand and supply regions. The productive capacity of the demand regions increased, allowing them to produce more of the products they originally purchased from other regions. The supply regions now have less transfer obligations to the demand regions as the latter now produce more of the products they consume than hitherto. Since the implicit assumption of this model is for transporting regions to pay transportation costs of products shipped to demand regions and pass that on to demand regions in the prices they pay, the minimum total costs reduced with the budget increments. Less land and labor were used in all supply regions. This is probably due to the decrease in their production following a reduction in their transportation activities as the demand regions increase their productive capacity and production.

Budget increases also raised the import capability of one of the demand regions--Northern Rocky Mountain. Pulpwood import in this region reached its upper limit of 13,000 cords.

Only 0.6 million square feet of veneer and plywood out of the desired 35.5 million square feet was imported in this region.

The other two demand regions, Pacific Southwest and Southern Rocky Mountain, could not meet any of their import requirements for the four products. Since Northern Rocky Mountain could raise its import capacity as the budget was increased it follows that all demand regions might likely increase their production and import capacities if given adequate budgets.

The initial limitation of demand regions in meeting their import requirements is attributable to budgetary constraints. Therefore, separate budget increments were applied to the demand regions alone. The model response to this parameterization is described in the next section.

Results in the other two periods, 2010 and 2030, indicate the same trends of increasing productive and import capacities in the demand regions and an overall reduction in total cost through the reallocation reduction in resource use (capital, labor and land) in the supply regions as they reduce their outputs formally meant for shipment to the demand regions.

These incremental budget increases did not, however, force the lumber and particleboard imports to enter the solution in any of the regions for the three projection time periods. This observation further supports the earlier conclusion that these products are better produced domestically than imported. Tables 22, 23, and 24 illustrate quantities of land, labor, and capital utilized in the 12 regions with increases in budget constraints. Figure 8 shows the values of the minimum costs associated with increases in the budget constraint for all regions.

From Table 22, we can see that Region 1 probably used less land previously because of capital limitations. The introduction of more capital caused it to quickly attain the optimum land requirement which it maintained. Regions 2 and 3 initially utilized more land to facilitate the production of commodities supplied to other regions. With increase in productive capacity in demand regions, their shipment productions declined, thus land was reduced until the optimum areas of 24276.9 and 2333.4 thousand acres were attained. Region 4 probably had initial capital constraint to operate at full capacity. With the addition of more capital, it acquired more land and quickly reached the optimum land requirement. Later, land requirement started declining perhaps due to increasing productivity in the demand regions which cut back on its supply to demand regions.

Regions 5 and 7 produced for own demand and export and no shipments to other regions. Hence, the activities of the demand regions did not affect their land utilization. Regions 6 and 8 initially produced and transported larger quantities

Table 22. Regional land utilization with increases in budget for all regions in 1990

Budget constraint (billion 1972 dollars)	Supply regions				
	1	2	3	4	5
		Land area used (1000 acres)			
9.0	2000.7	24344.3	2334.2	6023.9	598.4
10.0	2025.9	24277.0	2333.5	6850.0	598.4
11.0	2025.8	24276.9	2333.4	6353.5	598.4
12.0	2025.6	24276.9	2333.4	6354.9	598.4
13.0	2025.6	24276.9	2333.4	6354.1	598.4
15.0	2025.6	24276.9	2333.4	6353.2	598.4
16.0	2025.6	24276.9	2333.4	6352.3	598.4
17.0	2025.6	24276.9	2333.4	6351.5	598.4

Supply regions				Demand regions		
6	7	8	9	10	11	12
Land area used (1000 acres)						
999.7	822.4	2366.4	1322.1	506.1	1418.2	2191.3
925.4	822.4	2361.6	1322.1	540.9	1514.9	2373.9
908.0	822.4	2356.7	1322.1	575.7	1557.2	2556.5
890.6	822.4	2352.4	1322.1	610.4	1557.2	2739.1
873.2	822.4	2348.0	1322.1	645.2	1557.2	2921.7
855.8	822.4	2343.7	1322.1	680.0	1557.2	3104.4
838.4	822.4	2339.3	1322.1	714.8	1557.2	3287.0
821.0	822.4	2335.0	1322.1	749.6	1557.2	3469.6
803.6	822.4	2330.6	1322.1	784.3	1557.2	3652.2

Table 23. Regional labor utilization with increases in budget for all regions in 2010

Budget constraint (billion 1972 dollars)	Supply regions									Demand regions		
	1	2	3	4	5	6	7	8	9	10	11	12
	Labor used (1000 persons)											
9.0	18.3	26.9	9.6	24.8	8.9	9.2	5.4	11.9	3.4	.76	.01	.16
10.0	18.7	26.7	9.2	26.1	6.9	8.0	5.4	11.8	3.4	.81	.01	.10
11.0	18.6	26.7	9.1	26.5	6.9	7.9	5.4	11.7	3.4	.86	.01	.10
12.0	18.5	26.7	9.1	26.6	6.9	7.9	5.4	11.7	3.4	.90	.01	.11
13.0	18.5	26.7	9.1	26.6	6.9	7.8	5.4	11.7	3.4	.97	.01	.13
14.0	18.5	26.7	9.1	26.6	6.9	7.7	5.4	11.7	3.4	1.0	.01	.13
15.0	18.5	26.7	9.1	26.6	6.9	7.7	5.4	11.6	3.4	1.1	.01	.14
16.0	18.5	26.7	9.1	26.6	6.9	7.7	5.4	11.6	3.4	1.1	.01	.15
17.0	18.5	26.7	9.1	26.6	6.9	7.6	5.4	11.6	3.4	1.2	.01	.16

Table 24. Regional capital utilization and total cost with increases in budget in all regions in 1990

Budget constraint (billion 1972 dollars)	Min. total cost	Supply regions			
		1	2	3	4
		Capital used (million 1972 dollars)			
9.0	4709.2	636.0	1050.8	443.3	937.4
10.0	4702.7	681.0	1043.8	376.4	1003.4
11.0	4696.1	669.8	1035.9	360.5	1069.4
12.0	4689.6	642.8	1035.9	360.5	1096.2
13.0	4683.1	642.8	1035.9	360.5	1096.2
14.0	4676.6	642.8	1035.9	360.5	1096.0
15.0	4670.0	642.8	1035.9	360.5	1095.9
16.0	4663.8	642.8	1035.9	360.5	1095.8
17.0	4657.0	642.8	1035.9	360.5	1095.7

Supply regions					Demand regions		
5	6	7	8	9	10	11	12
Capital used (million 1972 dollars)							
269.8	443.8	210.5	553.3	131.5	29.1	.44	3.6
269.8	398.9	210.5	552.0	131.5	31.1	.47	3.9
269.8	391.3	210.5	519.8	131.5	33.1	.50	4.2
269.8	383.6	210.5	518.6	131.5	35.1	.53	4.5
269.8	376.0	210.5	517.5	131.5	37.1	.56	4.8
269.8	368.4	210.5	516.4	131.5	39.1	.59	5.1
269.8	360.8	210.5	515.2	131.5	41.1	.62	5.4
269.8	353.2	210.5	514.0	131.5	43.1	.65	5.7
269.8	345.6	210.5	512.9	131.5	45.1	.68	6.0

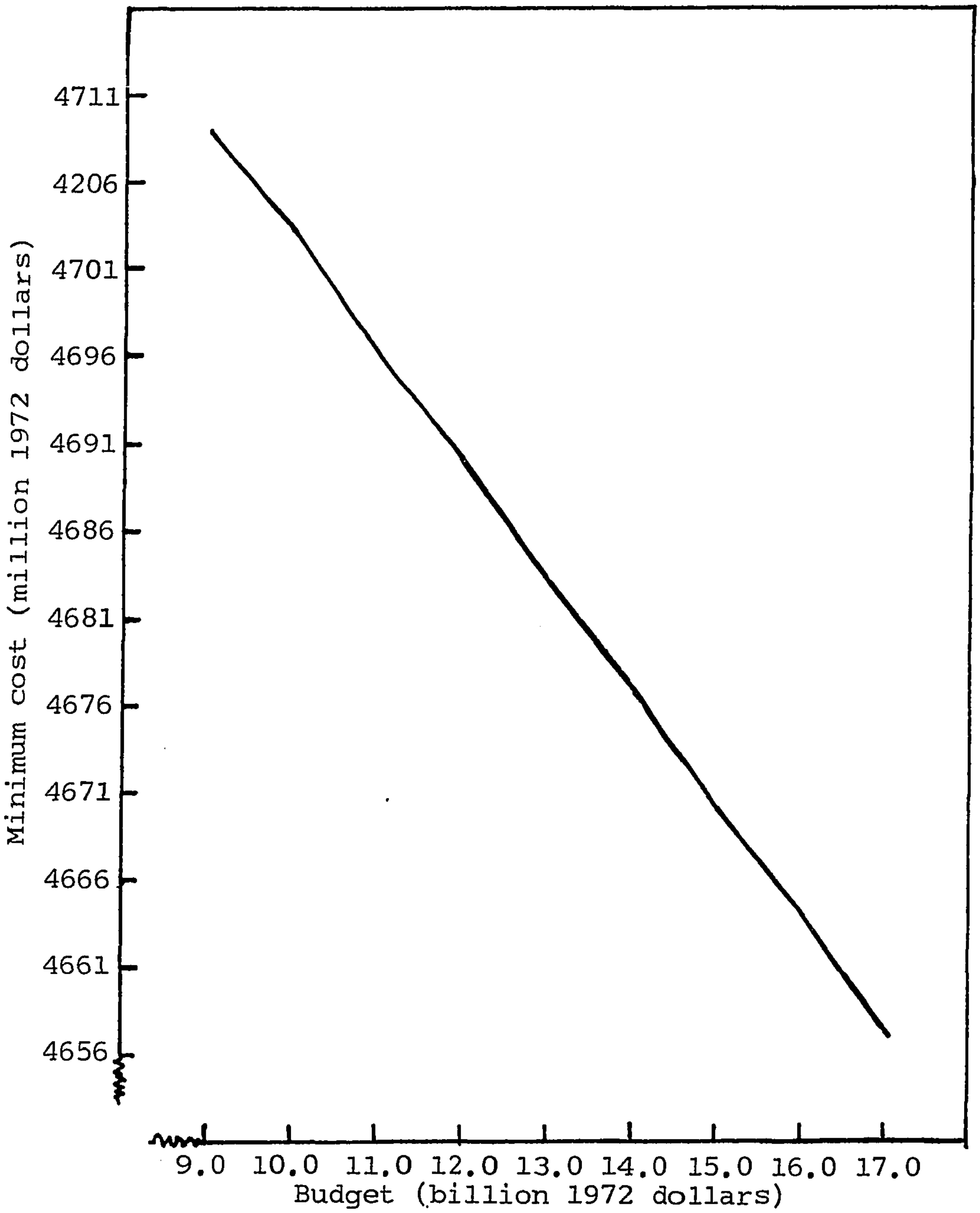

Figure 8. Minimum costs resulting from increases in the budget of all regions in 1990

of products to demand regions and utilizing higher acreages. Later, with increasing capacity in demand regions, shipments from these two regions (6 and 8) reduced causing the acreages used to decline.

Regions 10, 11 and 12 are the demand regions whose acreages increased as their productive capacity increased, following the addition of more capital to their budgets.

From Table 23, inferences could be made as follows: Regions 1 and 4 initially operated below optimum labor requirement. Budget increases made them acquire optimum labor quantities that were maintained as production activity increased in demand regions. Regions 2, 3, and 5 operated at higher labor initially but later reduced labor to a constant lower level as they probably cut back on production meant for shipment to other regions.

Regions 6 and 8 started out with higher labor and gradually declined as they cut back on shipment to demand regions who have now stepped up their production. Regions 7 and 9 maintained production on the same amount of labor irrespective of the increase in the budget. Region 11, as a demand region, is expected to have expanded production with increases in budget and, consequently, used more labor. The constant labor use by this region could be because it is endowed with the production of particleboard and needs the same amount of labor (.01 thousand units) or 10 units to produce 12.75 million square feet (3/8" basis) at the initial budget level of $9 billion and 14.0 million square feet (3/8" basis) at budget level $17 billion. Regions 10 and 12 are demand regions who acquired more labor to increase their productive capacity as their budgets increased, hence the steady rise in labor use in the two regions.

Table 24 could be interpreted as follows: Region 1 may have had initial capital limitations but later attained optimum capital requirement with budget increments. Thereafter, it neither increased nor reduced output and henceforth has constant budget requirement despite the addition of more capital. Regions 2 and 3 initially transported products to the demand regions but their shipment quotas continued to decline as demand regions increased their productive capacity.

Region 4 may have had an initial budget limitation in carrying out its activities. However, it acquired more capital later and attained the maximum capital requirement. As demand regions increased their output, the supply from this region to the demand regions declined. Regions 5, 7, and 9 did not have any initial capital limitations and do not supply products to the demand regions. They just have enough capital to fulfill their own demand requirements, hence, their capital use remained constant. Regions 6 and 8 supply products to demand regions but their supply declined as demand regions increased their productivity.

The three demand regions initially had capital limitations, As more capital was injected into the system, they increased the level of their production and import activities by acquiring more capital.

Model Response to Increases in Budget in Demand Regions Only

The exhaustion of the total budget in each of the three demand regions over the three time periods and the failure of all three regions to meet their import demands provided some further investigations.

To examine the effect of budget increases on production and imports, a parametric programming procedure was performed. The total budget for the three demand regions: Pacific Southwest, Northern Rocky Mountain and Southern Rocky Mountain was incremented by $10 million up to a maximum of $100 million and distributed among the regions. The proportions are 88, 1 and 11% for the Pacific Southwest, Northern Rocky Mountain, and Southern Rocky Mountain, respectively. For a complete description of the PARARHS procedure, see Appendix B.

Results are as follows:

1. The total cost of the optimal solution reduced to $4681 million from the initial value of $4709 million.
2. Particleboard production in region 10 rose from 843.5 million square feet to 1098 million square feet, the output of the same product in region 11

rose from 12.8 million square feet to 14 million square feet, while the production in region 12 rose from 104.3 million square feet to 136 million square feet.

3. Veneer and plywood, and pulpwood imports in region 11, which were not in the basis, entered the solution at 0.0446 million square feet for veneer and plywood and 0.013 million cords (the upper limit) for pulpwood.

Subsequent increases in the budget showed further reductions in total costs and increased production and import activities for the three demand regions. More land and more labor resources are required to the extent that at the introduction of $60 million, two of the three demand regions, Northern Rocky Mountain and Southern Rocky Mountain, had reached the upper limit of their land constraints at 1557.2 and 6094.3 acres, respectively. Thus, as from this moment, land rather than capital became the constraining resource. Moreover, the supply regions had slight, but progressive, reductions in both the amount of land and labor used.

With the introduction of the maximum value, $100 million, into the demand regions budget constraints, the results indicate:

1. The total cost reduced to $4461 million from $4709 million.

2. Particleboard production in Pacific Southwest rose to 1700 million square feet, the production of the same product in Northern Rocky Mountain rose to 14 million square feet, while Southern Rocky Mountain particleboard production rose to 290 million square feet.

3. Veneer and plywood imports rose further to 290 million square feet in Pacific Southwest, 6 million square feet in Northern Rocky Mountain, 21 million square feet in Southern Rocky Mountain. Pulpwood reached the upper limit of its import in the three regions.

Table 25 shows the quantities of particleboard[1] output in demand regions with increases in budget in Period I. The minimum costs associated with increases in the budget constraint are shown in Figure 9. This result exposes the flaw in a budgetry policy that allocates more capital to regions based on their existing endowments. The model has shown that, if equal opportunities are given to any two sectors irrespective of the existing conditions, that the sector without prior advantage could take advantage of the new situation and improve its productivity. In other words, resource allocation

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[1]The demand regions are best endowed for particleboard production. Their responses to budget increases are depicted through increased particleboard production.

Table 25. Particleboard outputs in demand regions with increases in budget in 1990

Budget constraint (billion 1972 dollars)	Region 10	Region 11	Region 12
	Particleboard output (million sq. ft. 3/8" basis)		
9.0	843.5	12.8	104.3
10.0	901.4	13.6	113.0
11.0	959.4	14.0	121.7
12.0	1017.4	14.0	130.4
13.0	1075.4	14.0	139.1
14.0	1133.3	14.0	147.8
15.0	1191.3	14.0	156.5
16.0	1249.3	14.0	165.2
17.0	1307.2	14.0	172.9

should be based on need rather than endowment or what currently exists.

Model Response to the Introduction of Export Cost

It has been assumed in the model that no export costs beyond those of normal production are incurred for the export quantities of products. A popular policy decision in most countries is to prevent or tax the export of raw materials. However, they encourage the exports of finished products to

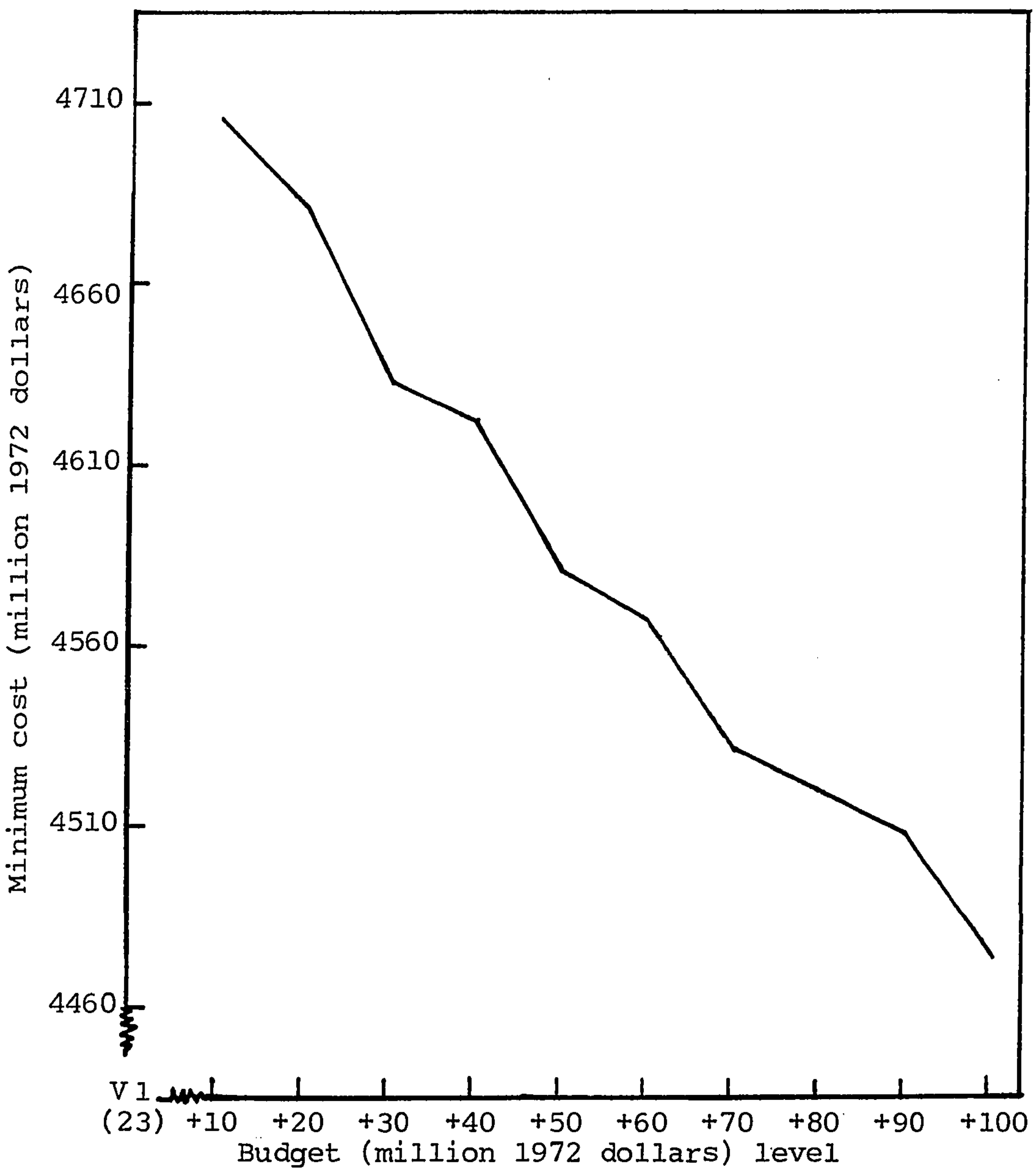

Figure 9. Minimum costs associated with increases in budget in demand regions in 1990

increase the returns to labor. Other expected effects of such a policy is to increase domestic supply and ensure the availability of raw materials for domestic industries. Secondly, such an increase in supply is often expected to reduce domestic prices.

The model's sensitivity to an introduction of export costs such as taxes was explored. The MPSX post-optimality option PARAOBJ[1] was applied to the optimal solution. The export activity was parameterized by introducing lump sums of money into the objective function as export costs in all the regions. This implies that the objective function (see equation 1) to a new form which includes export costs for all four products as follows:

$$\text{Minimize } Z = \sum_{i=1}^{12} \sum_{j=1}^{4} c_{ijt}X_{ijt} + \sum_{i=1}^{12} \sum_{j=1}^{4} p_{ijt}P_{ijt}$$

$$+ \sum_{i=1}^{12} \sum_{j=1}^{4} m_{ijt}M_{ijt} + \sum_{i=1}^{12} \sum_{j=1}^{4} e_{ijt}E_{ijt}$$

subject to all the constraints as already described (t = 1990, 2000, ..., 2030).

Where: The first three components represent the production, transportation and import activities, respectively, as have here been explained earlier on page 56.

[1]PARAOBJ is a parametric programming option that is used to test the sensitivity of an LP model to changes (increases or decreases) of some or all the coefficients in the objective function.

The export component can be described as follows:

e_{ijt} = per unit cost of export of product j in region i in period t; (j = 1,2,...,4) (i = 1,2,...,12)

E_{ijt} = export activity representing the quantity of product j exported from region in in time t (i = 1,2,...,9).

The costs are distributed among products in the proportion of their import costs which are: 0.004, 0.034, 0.96, and 0.001 for lumber, veneer and plywood, pulpwood and particleboard, respectively. First, the sum of $10 million, then $200 million, and finally, $500 million was introduced.

Results for 1990 show that no change occurred in both the objective function (minimum cost), and in the quantity of products exported or transported from supply to demand regions. Also, imports in the 12 regions did not show any change.

It was expected that the introduction of export cost would cause:

1. A reduction in the quantity exported,
2. An increase in domestic supply, and
3. An increase in the minimum cost.

But, since the introduction of export cost did not produce any change, it is possible that, given the wide range of the model, the export quantity is small relative to import and production and that changes of the magnitude described would not cause a change in the optimal solution.

To ensure a budget sufficient to support the new export costs, and that the model insensitivity to export costs was not due to budget deficits, the option PARARIM[1] was performed on the optimal solution. Thus, the objective function and the budget were simultaneously incremented by $2 billion dollars up to a maximum of $10 billion.

Results obtained with simultaneous increases in export cost and the budget constraint still show that the model is insensitive to export costs as no changes in export quantities were observed for all regions. Instead, the demand regions only increased their production of particleboard, the product with the highest productive capacity.

The supply regions also cut back on their production and transportation of the same product to other regions. Total cost fell from the original value of $4709 million dollars to $4644 million on the addition of the maximum incremental value of $10 billion to each of the objective function and the budget in 1990. Figure 10 shows the minimum costs resulting from the introduction of export cost and increases to budget.

It is likely that budget increase influences increased production in the demand regions rather than the export cost. Reduction of total cost may arise from supply regions reducing

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[1]PARARIM is an option that increments or decrements the objective function and the RHS simultaneously. In this case, the export cost component of the objective function was increased simultaneously with the budget component of the RHS.

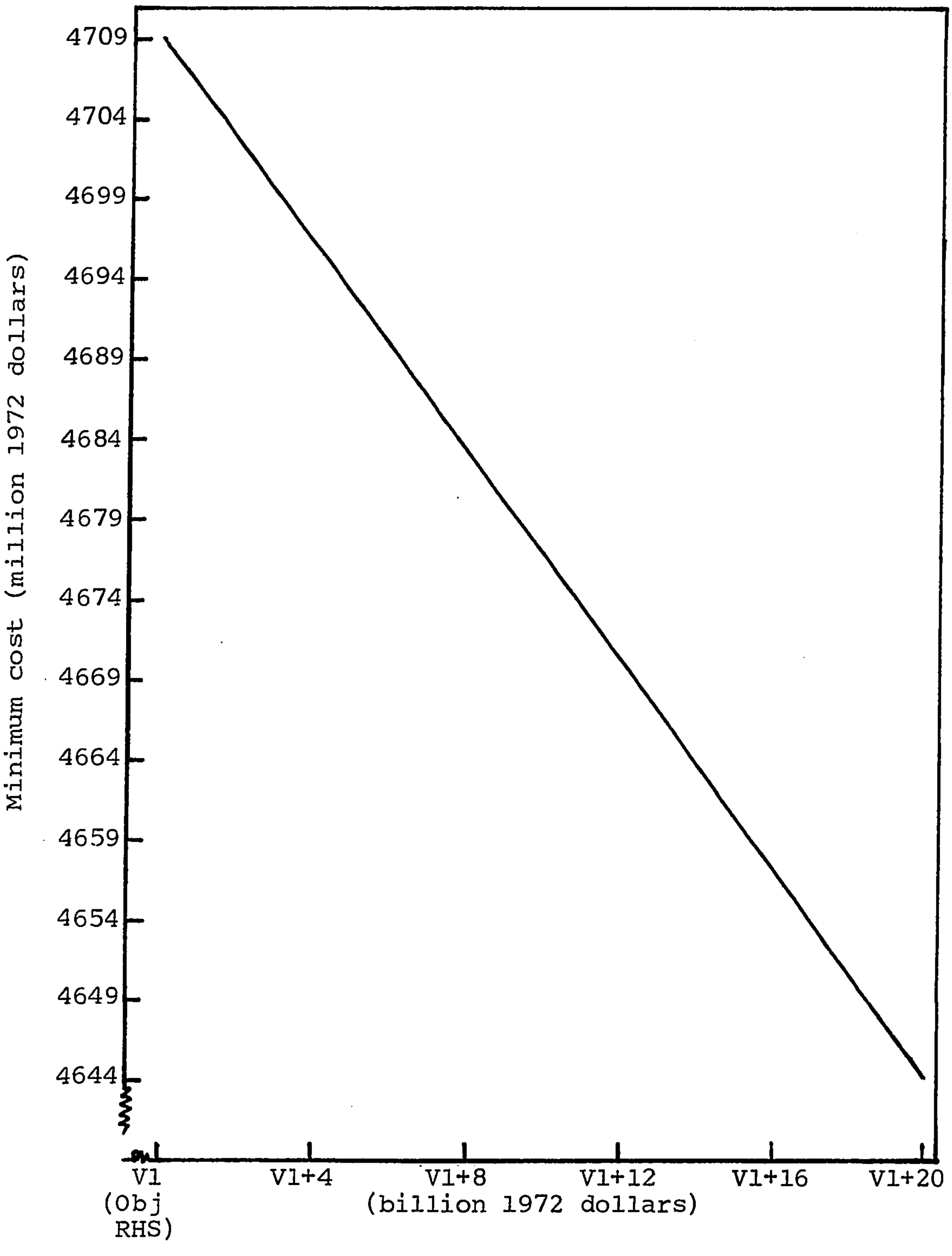

Figure 10. Minimum costs associated with the introduction of export cost and with increases in the budget constraint in 1990

their outputs, saving resources and therefore the costs that would have been incurred if such resources were used in production.

Results obtained for 2010 and 2030 show the same reduction in total costs with the addition of the maximum amount of $10 billion to both the objective function and the budget constraint. The minimum cost in Period II changed from the original value of $5852 million to $5787 million; that of Period III changed from $7264 million down to $7199 million. The values of minimum total costs associated with several parametric programming procedures and options is shown in Figure 11.

Apparently in this study, an increase in export costs has no deterring effect on the quantity of products exported.

Model Response to Increases in Import Cost

In a "free market" type of economy, international trade is allowed and commodities flow freely between countries. This flow occurs generally in accordance with the theory of comparative advantage. However, if a balance of payment or balance of trade problem is envisaged, the country with the deficit initiates some control measures such as a ban of or reduction in imports from other countries. Protectionism as practiced by some governments goes beyond the basic conservation of foreign exchange to protecting domestic industries. Many governments representing both developed and developing nations have practiced controlled imports of certain commodities at a point in time.

Model sensitivity to possible changes in import cost simulating a protectionist import policy was investigated by incrementing the import cost for all four products by $1.0 million dollars up to a maximum of $10 million dollars. The option PARAOBJ was used. Each increment is distributed among products based on the ratios of their import costs. So, 0.4, 3.4, 96, and 0.1% of the increment was distributed to lumber, veneer and plywood, pulpwood, and particleboard, respectively.

It was hypothesized that higher import costs which are supported by sympathetic budget increases may not result in model responsiveness. Also, the maximum increase of $10 million may have been too low to stimulate changes in the optimal solution. For these two reasons, further tests were performed on the optimal solution. With the use of the option PARARIM, both the budget and the import costs were simultaneously increased at the same time. For every $2 billion dollar increase in import cost in year 1990, the budget was increased by the same amount up to a maximum of $10 billion.

Results show that at this level of import cost, veneer and plywood, and pulpwood imports were forced out of the optimal solution. Recall that lumber and particleboard import have not entered the optimal solution. And that it was interpreted to mean that cost will be minimized by producing lumber and particleboard domestically rather than through imports. Domestic production of all four products increased while imports stopped. On the whole, it was observed that (1) lumber production in region 1 rose from .56 billion board feet to 1.8 billion board feet; (2) more resources--land, labor and capital--were used. For instance, region 1 commercial forestland use rose from 888 thousand acres to 2047.8 thousand acres; labor rose from 6.0 thousand persons to 15.4 thousand persons; capital rose from $267.2 million to $620.5 million (1972 dollars). (3) interregional products transfers increased in some regions for certain products, e.g., lumber transportation from region 1 to region 10 rose from an initial zero level to 1.1 billion board feet. (4) The minimum total cost rose, however, from $4709.2 million to $5857.8 million. Tables 26, 27, and 28 show land, labor, and capital use resulting from increases in import costs and budget constraints. Table 29 shows particleboard outputs in the demand regions resulting from the same import cost and budget increases while Figure 11 shows corresponding values of the minimum costs associated with the same increases.

It has been shown that the critical point (the values of import cost and budget at which veneer and plywood and pulpwood imports in all regions are forced out of the optimal solution) lies between $10 million and $2 billion. Such a point was not determined in this study. It may make an

Table 26. Land area used with varying values of import costs and budget constraints in 1990

Budget (billion 1972 dollars)	Region											
	1	2	3	4	5	6	7	8	9	10	11	12
	Land area used (1000 acres)											
Initial cost and budget (V1)	888	24278	2333	5660	1747	746	1247	2029	1322	506	1418	2191
V1 + 4.0	2048	21878	2361	8481	2240	984	1676	3558	2231	576	1557	2557
V1 + 8.0	2039	21878	2333	9630	1950	984	1618	3558	2231	654	1557	2922
V1 + 12.0	2029	21878	2333	10778	1648	984	1560	3558	2231	715	1557	3287
V1 + 16.0	2021	21878	2333	11926	1346	984	1501	3558	2231	784	1557	3652
V1 + 20.0	2011	21878	2333	12131	1291	984	1444	3558	2231	854	1557	4017

Table 27. Labor use with varying values of import cost and budget constraints

Budget (billion 1972 dollars)	Region											
	1	2	3	4	5	6	7	8	9	10	11	12
	Labor used (1000 persons)											
Initial cost and budget (V1)	6.0	27.1	9.2	22.7	22.3	8.5	6.1	11.1	3.4	0.76	0.010	0.09
V1 + 4.0	15.4	35.6	9.3	33.4	29.3	13.2	9.5	18.6	5.7	0.86	0.014	0.10
V1 + 8.0	15.4	35.6	9.2	37.5	25.4	13.2	9.4	18.6	5.7	0.97	0.017	0.43
V1 + 12.0	15.3	35.6	9.2	41.5	21.4	13.2	9.3	18.6	5.7	1.1	0.020	0.14
V1 + 16.0	15.3	35.6	9.2	45.5	17.3	13.2	9.2	18.6	5.7	1.18	0.023	0.16
V1 + 20.0	15.3	35.6	9.2	46.3	16.6	13.2	9.1	18.6	5.7	1.28	0.027	0.17

Table 28. Capital use with varying values of import cost and budget constraints

Budget (billion 1972 dollars)	Region 1	2	3	4	5
	Capital used (million 1972 dollars)				
Initial cost and budget (V1)	267.2	1101.3	360.5	937.4	789.3
V1 + 4.0	620.5	1150.0	365.9	1069.4	1019.9
V1 + 8.0	618.1	1150.0	360.5	1201.4	893.1
V1 + 12.0	615.7	1150.0	360.5	1333.4	761.1
V1 + 16.0	613.3	1150.0	360.5	1465.4	629.1
V1 + 20.0	610.9	1150.0	360.5	1489.1	605.4

Region						
6	7	8	9	10	11	12
Capital used (million 1972 dollars)						
333.2	321.8	433.9	131.5	29.1	0.44	3.6
436.2	381.9	595.4	180.7	33.1	0.50	4.2
436.2	366.7	595.4	180.7	37.1	0.56	4.8
436.2	351.5	595.4	180.7	41.1	0.62	5.4
436.2	336.3	595.4	180.7	45.1	0.68	6.0
436.2	321.1	595.4	180.7	49.1	0.74	6.6

Table 29. Particleboard output in demand regions resulting from increases in import cost and budget constraint in 1990

Objective function and budget (billion 1972 dollars)	Region 10	Region 11	Region 12
	Particleboard output (million sq. ft. 3/8" basis)		
Initial objective function and budget (V1)	843.5	12.8	104.3
V1 + 4.0	959.4	14.0	121.7
V1 + 8.0	1075.4	13.8	139.1
V1 + 12.0	1191.3	13.6	156.5
V1 + 16.0	1307.2	13.5	173.9
V1 + 20.0	1423.2	13.3	191.3

interesting study to attempt determining the set of import costs and budget values that correspond to such a point.

In the second period, an increase of $10 billion in import cost and a corresponding increase in budget caused increased domestic production and higher level resource use with a consequent increase in the minimum total cost from $5852 million to $7110.6 million. The same production and resource use trend was observed for the third period with the minimum total cost rising from $7264 million to $8458 million.

In general, with respect to increases in export and

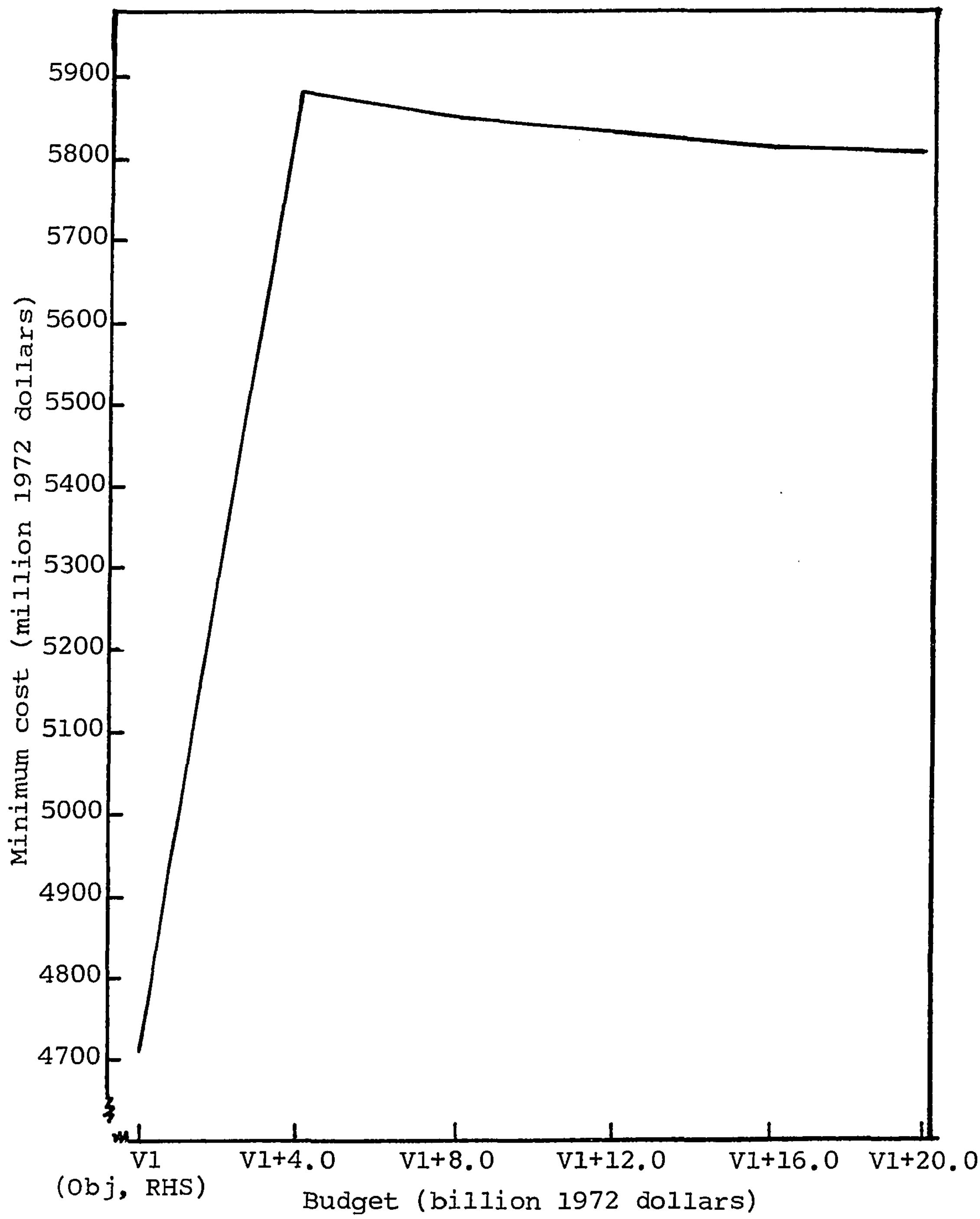

Figure 11. Minimum costs associated with increases in import cost and the budget constraint in 1990

import costs, cost minimization was better achieved with increased export costs than with increased import costs. This is indicated by the lower values of total costs attained with export increases than with import increases when the objective function and the budgets were increased by the same amount. See Figures 10 and 11.

Table 26 shows that region 1 initially imported some of its products and produced the rest on 888 thousand acres of land. With increases in import cost, it acquired more land to produce also the import quantity. After attaining the maximum of 2048 thousand acres, land use started declining probably because of cutbacks on production intended for other regions. Region 2 initially used high land area to meet its own and shipment demands. Later, it cut back on acreage as its shipment to demand regions reduced.

Regions 3, 6, 8, and 9 increased their land use to meet their production obligations. Thereafter, the land area declined to an optimum which was maintained by each of the four regions. Region 5 initially used more land to meet product transfer obligations to demand regions. But its demand for land declined later, following increased production in demand regions.

Region 4 and the three demand regions acquired more land to produce enough to substitute for import quantities as import costs increased.

From Table 27, we can see that regions 1 and 3 initially did not have the optimal labor requirement. With increased import cost and budget, they used more labor, reached a maximum and later declined to the optimum amount. Regions 2, 6, 8, and 9 rose from their suboptimal labor level to their respective optimum levels. Regions 5 and 7 increased their labor use, reached a maximum and later started declining. The decline may have arisen from reduced shipments to demand regions.

Region 4 as well as the demand regions increased their labor use with increases in their output levels.

In Table 28, a trend similar to what happened with land and labor takes place. Regions 1, 5 and 7 probably had initial capital limitations. With the introduction of more capital, and at higher import cost, they acquired more capital to increase domestic production. They reached a maximum, then started to cut down on capital probably because their shipments to demand regions are decreasing. Regions 2, 3, 6, 8, and 9 might have had initial capital limitation and may have imported some reasonable quantity of the products they consume. With higher import costs and increased capital, these regions acquired more capital for increased domestic production. Thereafter, they attained the optimum capital requirement level and maintained that same level of capital irrespective of further increases in capital and costs.

Region 4 and the demand regions (regions 10, 11 and 12) all have steady rise in capital use. Region 4 has a high productive capacity for all products, and transports a lot of products to the demand regions. The demand regions are producing to meet their own demands and to substitute for the import quantity and, therefore, are using more capital. Thus, while the demand regions increase their production, region 4 still supplies the difference between the demand and production in the demand regions. Hence, all four regions have steady capital increases.

Model Response to Simultaneous Increases in Export and Import Costs and in the Budget Constraint

The model was tested for its sensitivity to simultaneous increase in the export and import costs and the budget constraint. The post-optimality option PARARIM was again applied to the optimal solution. The import costs and export costs were increased by $4 billion each time up to a maximum of $32 billion each while the budget was increased by the sum of the two increments. Both the import and export costs are distributed among the four products in the ratio of their import costs and applied to product values in the three periods 1990, 2010, and 2030.

It was observed in 1990 that (1) the minimum total cost increased from $4709 million to $5951 million with $4 billion dollar increase in import and export costs. But further increments caused a decline in minimum cost. And at the maximum increment of $32 billion each, or $64 billion total, the minimum total cost had fallen to $5669 million (see Figure 12); (2) resources (land, labor and capital) use increased; (3) imports of all four products ceased while exports were unaffected; (4) domestic production of all four products increased; (5) annual output in the demand regions increased as supply regions cut down on outputs meant for shipment to other regions. Tables 30, 31, and 32 show changes in land, labor and capital use with simultaneous introduction of export cost, increase in import cost, and increase in the budget constraint for all regions.

Total costs for 2010 and 2030 with the same increases in import cost and budget, plus the introduction of export costs show the same trend as in 1990. The final costs in the year 2010 and year 2030 at the introduction of the maximum amount of $64 billion were $6961 million and $8298 million, respectively. These two values are, however, higher than the pre-parameterized values of the objective function (minimum cost) of $5852 million in period 2 and $7264 million in period 3, respectively.

The increase in the minimum total cost could arise for many reasons: (1) The substitution of domestic production for imported products would cause an increase in cost as pulpwood and veneer and plywood which have been shown

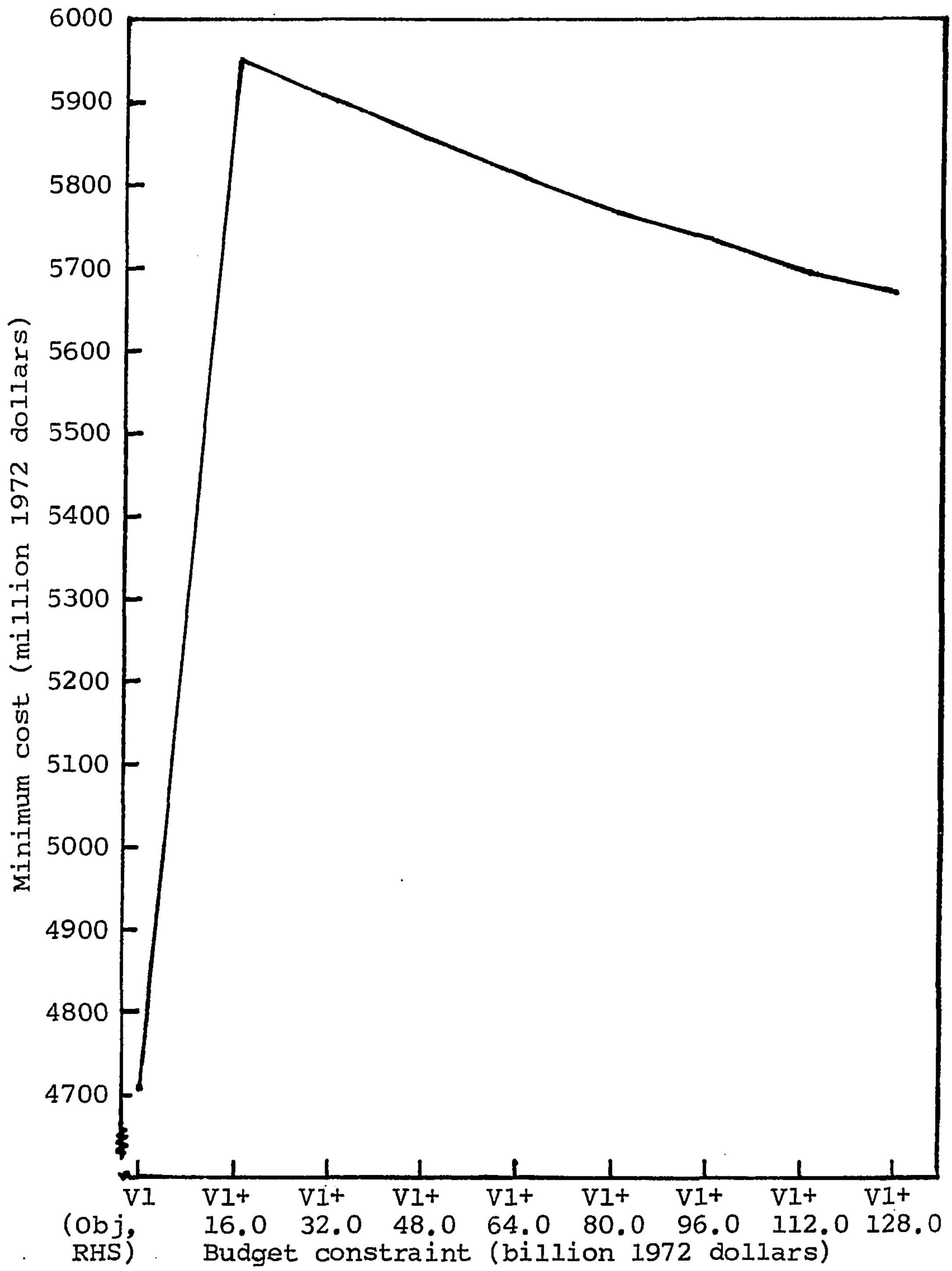

Figure 12. Minimum cost associated with increases in export and import costs and in budget constraint in 1990

Table 30. Land area used at varying values of import and export costs, and budget constraints

Budget (billion 1972 dollars)	Supply regions 1	2	3	4	5
		Land area used (1000 acres)			
Initial cost and budget constraint (V1)	1153.2	24278.1	2333.4	4662.4	598.4
V1 + 16.0	1950.9	21877.7	3371.4	8527.8	934.0
V1 + 32.0	1914.2	21877.7	3371.4	8527.8	934.0
V1 + 48.0	1892.8	21877.7	3371.4	8527.8	934.0
V1 + 64.0	1892.8	21877.7	3371.4	8527.8	934.0
V1 + 80.0	1892.8	21877.7	3871.4	8527.8	934.0
V1 + 96.0	1892.8	21877.7	3371.4	8527.8	934.0
V1 + 112.0	1867.1	21877.7	3371.4	8527.8	934.0
V1 + 128.0	1783.0	21877.7	3371.4	8527.8	934.0

Supply regions				Demand regions		
6	7	8	9	10	11	12
Land area used (1000 acres)						
1617.1	822.4	2524.6	1322.1	506.1	1418.2	2191.3
1855.3	1309.6	3820.6	2230.9	784.3	1557.2	3652.2
1844.7	1309.6	3628.3	2230.9	1015.1	1557.2	5113.0
1760.6	1309.6	3628.3	2230.9	1015.1	1557.2	6094.3
1667.0	1309.6	3628.3	2230.9	1015.1	1557.2	6094.3
1573.3	1309.6	3628.3	2230.9	1015.1	1557.2	6094.3
1479.7	1309.6	3628.3	2230.9	1015.1	1557.2	6094.3
1410.4	1309.6	3628.3	2230.9	1117.5	1557.2	6094.3
1397.2	1309.6	3628.3	2230.9	1454.4	1557.2	6094.3

Table 31. Labor used at varying values of import and export costs, and budget constraints

Budget (billion 1972 dollars)	Supply regions									Demand regions		
	1	2	3	4	5	6	7	8	9	10	11	12
	Labor used (1000 persons)											
Initial cost and budget constraint (V1)	6.3	27.1	9.1	20.0	6.9	26.2	5.4	12.0	3.4	0.76	0.010	0.09
V1 + 16.0	15.0	35.6	15.3	33.6	11.4	31.3	8.9	19.0	5.7	1.18	0.013	0.16
V1 + 32.0	14.9	35.6	15.3	33.6	11.4	31.0	8.9	18.7	5.7	1.52	0.013	0.22
V1 + 48.0	14.9	35.6	15.3	33.6	11.4	29.4	8.9	18.7	5.7	1.52	0.013	0.26
V1 + 64.0	14.9	35.6	15.3	33.6	11.4	27.5	8.9	18.7	5.7	1.52	0.013	0.26
V1 + 80.0	14.9	35.6	15.3	33.6	11.4	25.6	8.9	18.7	5.7	1.52	0.013	0.26
V1 + 96.0	14.9	35.6	15.3	33.6	11.4	23.8	8.9	18.7	5.7	1.52	0.013	0.26
V1 + 112.0	14.6	35.6	15.3	33.6	11.4	32.4	8.9	18.7	5.7	1.78	0.013	0.26
V1 + 128.0	13.8	35.6	15.3	33.6	11.4	22.1	8.9	18.7	5.7	2.60	0.013	0.26

Table 32. Capital used at varying values of import and export costs, and budget constraints

Budget (billion 1972 dollars)	Supply regions 1	2	3	4	5
	Capital used (million 1972 dollars)				
Initial cost and budget constraint (V1)	298.0	1101.3	360.5	780.8	269.8
V1 + 16.0	556.2	1150.0	492.8	1074.6	366.7
V1 + 32.0	547.1	1150.0	492.8	1074.6	366.7
V1 + 48.0	541.0	1150.0	492.8	1074.6	366.7
V1 + 64.0	541.0	1150.0	492.8	1074.6	366.7
V1 + 80.0	541.0	1150.0	492.8	1074.6	366.7
V1 + 96.0	541.0	1150.0	492.8	1074.6	366.7
V1 + 112.0	531.3	1150.0	492.8	1074.6	366.7
V1 + 128.0	499.3	1150.0	492.8	1074.6	366.7

Supply regions				Demand regions		
6	7	8	9	10	11	12
Capital used (million 1972 dollars)						
960.0	210.5	363.8	131.5	29.1	0.44	3.6
1127.7	285.8	664.3	180.7	45.1	0.68	6.0
1117.8	285.8	613.9	180.7	61.1	0.92	8.4
1061.6	285.8	613.9	180.7	77.1	1.2	10.8
1000.2	285.8	613.9	180.7	93.1	1.4	13.2
938.8	285.8	613.9	180.7	109.1	1.6	15.6
877.4	285.8	613.9	180.7	125.1	1.9	18.0
832.0	285.8	613.9	180.7	141.1	2.1	20.4
823.3	285.8	613.9	180.7	157.1	2.4	22.8

to be cheaper imported are now produced domestically. The extent to which this affects the total cost depends on how many regions still import preferred grades of lumber and particleboard. (2) Increased use of capital, land and labor following intensified domestic production will increase the cost of resources used, thereby causing total cost to increase. (3) Since exportation still occurs despite increases in export cost, the total cost is bound to increase.

Figure 13 summarizes the national budget contraints and the minimum costs observed before and after some post-optimality analyses.

Model Application to Other National Economies

Hardwood production appears to pose problems for both developed and developing countries. Hardwood's diverse ecological types, its multipurpose uses and manufacturing peculiarities often make data on supplies difficult to get and keep. For instance: (1) hardwoods are used for the production of both tangible forest products like lumber, veneer and plywood, pulpwood etc., and intangibles such as recreation and watershed protection; (2) hardwood tree characteristics, qualities and uses vary as widely as there are species; (3) private ownership patterns (where private ownership exists) often do not reflect any discernible management objectives or goals. These factors pose serious inventory problems and consequently affect data availability on quantity, quality, and uses of

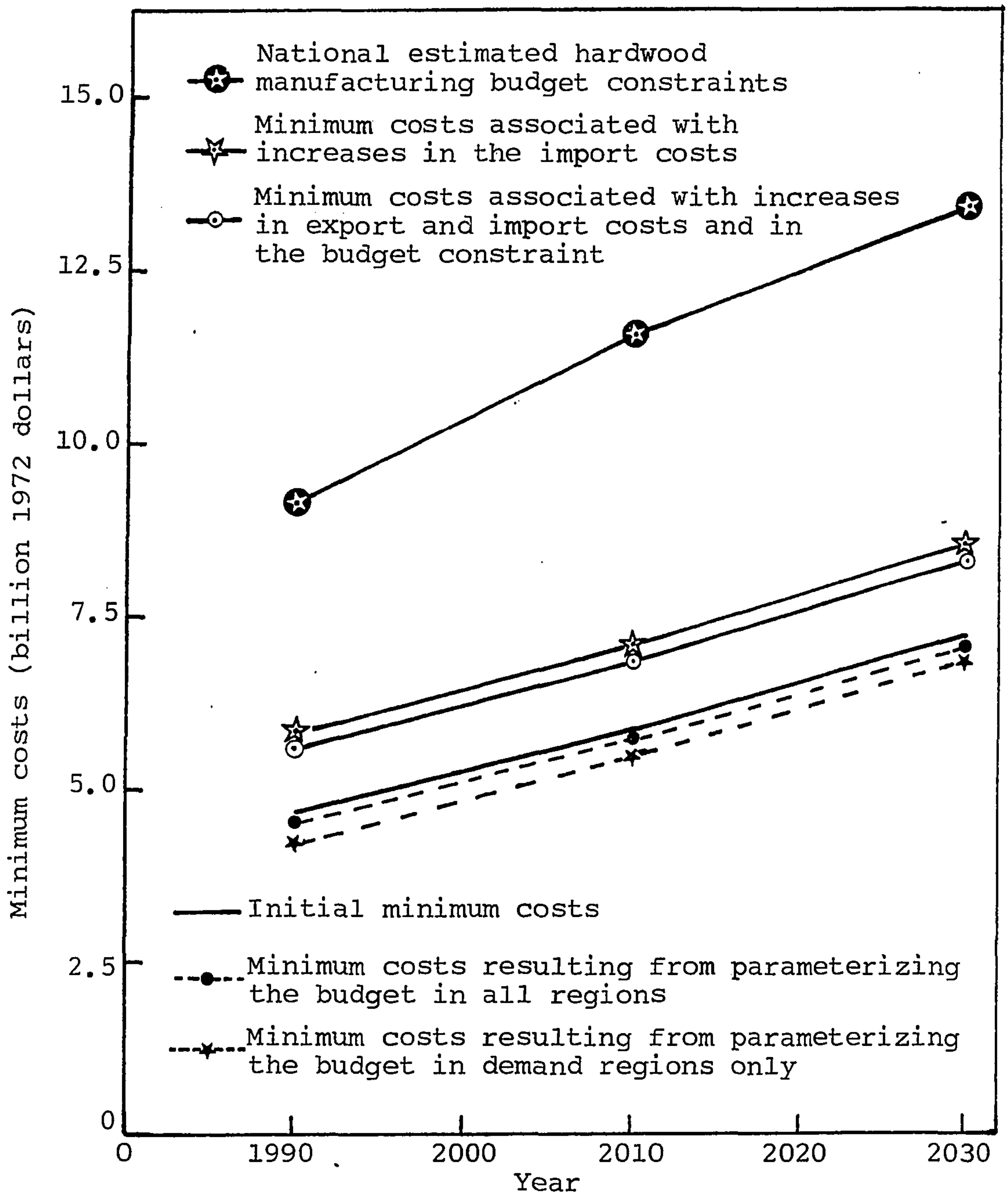

Figure 13. Minimum costs and estimated national budgets in the projection period

available hardwood growing stock in any economy.

Hardwoods are most widely distributed in the tropics where the greatest concentration of the developing economies abound. In addition to the problems mentioned above, the developing countries still harvest hardwood timber from the natural forest and have little experience and limited investments in forest plantations. Such countries often do not have any accurate inventory of the hardwood and softwood resources.

Given these problems facing hardwood production and the characteristics of the countries or the economies where hardwoods predominate, this model is considered useful for the following reasons. (1) It is comprehensive, it encompasses several activities or operations such as production, import, export and transportation, whereas some models may only deal with production or transportation. (2) The recognition of the existence of productive capacity in a demand region and its incorporation in this model makes it more flexible than other models which might have purely supply and purely demand regions. (3) Its ability to utilize data from past trends for future quantity determinations for decision making is useful. This last characteristic is expected to be of utmost use to developing countries where data are often not current. Since the model can utilize data generated by econometric models based on historical trends, a quantitative approach to long-term planning in developing countries may not constitute a bottleneck.

Within any country, this model could be used to determine what level of production of a set of products would meet the consumption and export requirements of the nation at minimum cost. The model also can indicate what regions would transport particular products to other regions and the annual quantities to transport. In the same vein, it can tell the least cost of quantities to import or accept (in the case of domestic transfers) from regions.

Besides domestic utility, this model could be used in international trade. With this model and a good knowledge of the factor endowments and comparative advantages for commodity productions, the annual flow of commodities between countries that would maintain a balance of trade and/or payment and minimize deficits could be determined.

SUMMARY AND CONCLUSIONS

Forest Service projections of the demand and supply for the period 1990 to 2030 based on assumptions of increased population, higher GNP and DPI, rising prices and improved technological development indicate that the quantity of timber products people would want to consume will be more than that which will be available for consumption.

Past and present trends show that the relative price of timber (especially softwood timber) and associated products have been rising steadily while those of hardwoods have been fairly constant. Prices of timber products substitutes such as steel, concrete and plastics have remained steady or in the case of steel declining. The price advantage enjoyed by substitutes over wood products has triggered off a gradual substitution for wood products by these materials. For example, concrete is beginning to displace hardwood lumber in flooring, plastics in furniture manufacturing and steel in construction.

Given the constant relative price of hardwood products and the improvement in technology which is increasing the utilization of hardwoods in pulping, the need to explore the chances of increasing hardwood production to help ameliorate the wood products supply situation was considered imminent. Such an increase in supply is expected to keep wood products prices within acceptable ranges to consumers and possibly prevent the substitution away from timber and its products.

Resources available for hardwood production have to be determined. The hardwood production potential of all regions in the United States given the resources needs to be known.

To help determine the resources and the potential, the United States was divided into twelve regions. Nine of these regions were designated hardwood supply regions as they produced more output than they consumed in 1977, which is the base year with which the regional productive capacities were determined. The other three were designated demand regions because they consumed more than they produced in the same year or that they have a high consumption potential, e.g., Pacific Southwest. A cost minimizing LP model was developed to determine the minimum cost of producing and transporting the demand quantities (domestic, import and export) of hardwood lumber veneer and plywood, pulpwood, and particleboard in the period 1990 to 2030, including the quantities and combination of resources that would be needed in achieving the goal. The objective is to be accomplished subject to regional resource (land, labor, and budget) constraints, and demand (domestic, export and import demand) constraints.

Land constraints for each region were estimated with the hardwood commercial timberland availability of a region based on hardwood forest types. Labor constraints were determined with the expected labor requirement for hardwood products manufacturing as estimated by the product of labor productivity (from

1977 census of manufactures data) and the quantity of products to be produced. The capital constraints were also determined with the expected capital requirement for the manufacture of products with the unit cost of product and the quantity to be produced. Regional domestic and import demands were estimated in proportion to their 1980 population figures by distributing the national demand for a product in the proportion of the population figures among regions. Production (supply) and export demands were determined for the regions by applying the regional productive capacity to total national production and export, respectively. Transportation of products to other regions and exports were limited to supply regions while production and import are allowed in all regions with the bulk of the imports going into the demand regions who have limited productive capacity.

The objective function is to minimize the cost of providing the future demands of four primary hardwood product groups, namely: lumber, veneer and plywood, pulpwood, and particleboard subject to the resource and demand constraints mentioned above. Three main cost items were considered in the objective function. They include production costs, import costs, and transportation costs. Export costs were considered not applicable except for the costs encountered in the local production and transportation of products intended for exports.

A preliminary test model was first developed with two of the twelve regions. Several test runs were made with this reduced model to test the model for validity. The model's sensitivity was also tested with the Range Analysis option to ensure its responsiveness to changes in the objective function coefficients and the constraint (RHS) values. Further sensitivity tests using parametric programming was later performed on the optimal solution of a full model where the full model represents the twelve regions (nine supply regions and three demand regions). The regional constraints were fed into the cost minimizing LP model and runs were made to determine the minimum cost of meeting the future demands of the selected hardwood products. Data for three time periods (years 1990, 2010, and 2030) over the projection years were used to reduce computation cost and effort. Interpolation for the intervening years 2000 and 2020 is made. The selected years (1990, 2010 and 2030) are referred to as Periods I, II and III, and their objective functions designated as Z1, Z2, and Z3, respectively.

Results obtained with the cost minimizing runs show that the minimum cost in 1972 dollars of meeting the demand for the four hardwood products in 1990 will be $4709 million. The quantities of these products in this period stand at 10.1 billion board feet domestic demand, 0.4 billion board feet import demand, and 0.1 billion board feet export demand for lumber. The figures for veneer and plywood stand at 5.8

billion square feet (3/8" basis) domestic demand, 8.6 billion square feet import demand, and 50 million square feet export demand. For pulpwood, the quantities are 36.7 million cords domestic demand, 1.3 million cords import demand, and 1.3 million cords export demand. Lastly, for particleboard, the quantities are 15.5 billion square (3/8" basis) domestic demand, 100 million square feet import demand and 200 million square feet export demand.

With respect to resources, land appears to be available in enough quantity in all twelve regions and is therefore not limiting. Labor and capital seem to be limiting as supply regions 1, 2 and 4, and all demand regions often exhausted their labor and capital constraints.

The activities occurred as specified in the model. Production, export and transportation activities were carried out as indicated. Transfer of commodities occurred between supply and demand regions but never between any two supply regions. This is understandable following the definition of supply regions as those that produce more products than they consume. Among the supply regions, region 2 (Middle Atlantic) appears to have the highest potential to transport products, especially lumber, to other regions. Region 4 (Central States) also shows special capability with veneer and plywood shipments. See Figure 6 and Table 19 for more details on the transportation of products between regions. It was observed that supply regions first fulfill their export demands completely before carrying out transportation of products to other regions. The import activity was partially fulfilled since only veneer and plywood and pulpwood entered the basis in the optimal solution while lumber and particleboard failed to enter the optimal solution. An attempt to force the two products into the optimal solution using the procedure BOUNDS resulted in infeasibility of the solution. The implication is that costs are better minimized if the two products are produced locally than if they are imported.

Results in 2010 and 2030 follow similar patterns as in 1990. Land again appears not limiting while labor and capital resources seem limiting as the allocations of these resources were often exhausted. Transfer of products from supply to demand regions took place as before with regions 2 and 4 transporting the most products among the supply regions. The minimum cost in 1972 dollars of meeting the demands for the products in the second period, 2010, is $5852 million. The demand quantities for the products in this period are: 13 billion board feet domestic demand, 0.8 billion board feet import demand, and 0.4 billion board feet export demand for lumber. For veneer and plywood, the quantities are: 6.6 billion square feel (3/8" basis) domestic demand, 4 billion square feet import demand and 0.05 billion square feet export demand. In the case of pulpwood, the demands are: 53.4

million cords domestic demand, 1.3 million cords import demand, and 1.3 million cords export demand. For particleboard, we have 21.7 billion square feet (3/8" basis) domestic demand, 0.10 billion square feet import demand and 0.2 billion square feet export demand.

The minimum cost in 1972 dollars of meeting the demands in this period is $7264 million. Also, by interpolation, it was found that the minimum costs of supplying the demand quantities of the four products in 2000 and 2020 are about $5200 and $6500, respectively (see Figure 13). The quantities of products demanded in this period stand at 16 billion board feet domestic demand, 1.0 billion board feet import demand and 0.5 billion board feet export demand for lumber. The quantities for veneer and plywood are: 7.2 billion square feet (3/8" basis) domestic demand, 4 billion square feet import demand and 0.05 billion square feet export demand. For pulpwood, we have 70.7 million cords domestic demand, 1.3 million import demand, and 1.3 million export demand. Finally, the particleboard demands are: 26 billion square feet (3/8" basis) domestic demand, 0.2 billion square feet import demand, and 0.03 billion square feet export demand.

It was also observed in Periods II and III as was the case in Period I that lumber and particleboard imports did not enter the basis. Again, an indication that it is cheaper to produce this domestically than import them.

Model sensitivity was tested by parametric programming applied to the optimal solutions. Several tests were performed and the results obtained are as follows. Incrementing the budget constraint for all regions by $1 billion each time up to a maximum of $8 billion in 1990 would cause a reduction in the total cost from $4709 million to $4657 million at a maximum value of $8 billion in additional budget, a reduction from $5852 million to $5800 million in 2010, and a reduction from $7264 to $7211 million in 2030. Supply regions initially increased the use of resources to produce enough to meet commodity transfer obligations to demand regions. But later, as demand regions increased their productive capacity, the supply regions' use of resources declined. The reduction in total cost with subsequent increases in budget was shown in Figure 8.

Increasing the budget constraint by $10 million in only the demand regions up to a maximum of $100 million caused a reduction in the total cost from the initial value of $4709 million to $4461 million. As total cost decreased with the addition to the budget, outputs in the demand regions increased. Figure 9 shows the minimum cost corresponding to specific additions to the budget in demand regions. Also, the supply regions cut back on their supply with subsequent increases in budget, thus allowing demand regions to increase their production levels.

Periods II and III results follow the same pattern as in Period I with the minimum cost reduced from $5852 million to $5599 million in Period II and a reduction from $7264 million to $7008 million in Period III. These results show that a region given a proper incentive (the appropriate factors, capital in this case) always explores its potentials and utilizes them to the fullest. With the injection of the right quantity of capital, the demand regions were able to produce some of the products they consume, thereby relying less on outside producers. The result is a clear proof that a budgetary policy that tends to inject more money for production into sectors with better natural resource endowments is unreasonable. Such a policy is not only discriminatory but demoralizing since we have seen that a sector can fully develop its potential when given the right resources.

The model showed no sensitivity (was irresponsive) to a possible introduction of export cost by way of an export tax. Introducing $10 million, $100 million and $500 million as export costs did not affect the quantity exported or imported and did not change the minimum total cost values of $4709 million, $5852 million and $7264 million in Periods I, II, and III, respectively. Adding to the budget as much as was introduced as export cost in the objective function did not cause any changes in the import and export quantities. Instead, it caused reduction in the total costs from $4709 million to

$4644 million in 1990. A similar pattern of behavior was observed for Periods II and III, with the Period II cost falling from $5852 million to $5786 million, while Period III cost fell from $7264 to $7199 million. Given the model's insensitivity to export cost alone, a reduction in total cost with increases in export cost and the budget makes me conclude that it is the introduction of more capital and not the export cost that caused the reduction in total cost. The addition of capital increases the productive capacity of demand regions, causes the supply regions to reduce production, saves resources and trnasportation costs for shipping products to demand regions. The net effect of all these is a reduction in total cost. Figure 10 showed the minimum costs resulting from introducing export costs and increasing the budget constraints.

Incrementing the import cost by $1 million up to a maximum of $10 million did not result in model response. It is possible that this range of import costs might not have been large enough to stimulate the model's response. Parameterizing both the objective function and the RHS through simultaneous increases in import costs and budget by $2 billion up to a maximum of $10 billion resulted in a rise in the minimum cost from the initial $4709 million to $5806 million in 1990; a rise from $5852 million to $7111 million in 2010; and a $7264 million to $8458 million in 2030. There appears to be an indication that model insensitivity was as a result of budget limitations since responses followed when the budget was increased simultaneously with increases in import cost. Model sensitivity was further displayed by all the regions reducing imports of all products and increasing domestic production of some products as import costs were incremented. Eventually, imports of all products in all regions stopped. Increased domestic production necessitated higher demands for production factors or resources with consequent increase in total costs. The minimum total costs associated with increases in import cost and budget constraint were shown in Figure 11.

Finally, model sensitivity to the simultaneous introduction of export cost, an increase in import cost and the budget constraint was explored. An export cost of $4 billion, import cost increase of $4 billion and budget increase of $8 billion were simultaneously introduced into the system. Total costs rose, domestic production increased, imports ceased, but exports remained unchanged, and more resources were used. The minimum total costs rose from $4709 million to $5669 million in 1990; from $5852 to $6961 million in 2010 and $7264 million to $8298 million in 2030. Figure 12 showed values of minimum costs associated with increases in export and import costs and in the budget constraint.

In summary, a cost minimizing LP model has been developed and applied to the forecast demand of four hardwood products: lumber, veneer and plywood, pulpwood and particleboard during the period 1990 to 2030. The minimum cost of meeting the demand quantities of these products including optimum resource combinations to achieve the objective was determined and was found to be sufficient and not limiting. Labor and capital are found to be limiting as comparatively high percentages or 100% of the two resources were used in some regions.

The model is found to be sensitive to certain changes such as (1) increases in import costs, (2) increases in budgets, especially for regions with capital limitations. In addition, the flexibility of the model makes it applicable to different economies with varying conditions and goals.

In conclusion, one could say that the model has been proven valid and useful for optimization. Many questions are left unanswered. They include hardwood and softwood production trade-offs among regions; product substitutions in multi-purpose managements, e.g., optimum recreation, timber, wildlife etc. combinations in a given region. Finally, this model could be used to solve the familiar problem of when and where agricultural lands would revert to forestry; what rate of substitution will be optimum for agricultural crops and forest crops, especially in the area of agri-silviculture.

It is hoped that the information provided would have provoked some thoughts and that, soon, researchers would venture into some of the unknowns expressed in this study.

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APPENDIX A

Range Analysis Output

Section 1: Rows at limit level (Table 33)

This section, as well as the other sections, has eleven columns. The first column is captioned NUMBER which is an internal identification showing the numeric name of the row. The second ROW is the user's or alphabetic row name. The third caption, AT, indicates the status of the vector in the solution: LL indicates nonbasic, activity at lower limit; UL indicates nonbasic, activity at upper limit; EQ implies nonbasic, fixed. It is worth noting that the MPSX assumes that the lower limit of a "less than" (L) constraint is zero.

The fourth column, ACTIVITY, is the value the row takes in the solution. It is the amount of resource used for a "less than" constraint, or the commodity requirement for a "greater than" constraint. For example, in the NUMBER 5, ROW R041, the value under ACTIVITY of 1.05 indicates that only 1.05 billion board feet of hardwood lumber is required from domestic demand since it is at the lower limit (LL) while a "greater than" was expressed for the row.

The fifth column, SLACK ACTIVITY, is the value of underuse or overuse activity associated with the requirement. An activity at its limit level as is the case here has a zero slack activity. The dots (periods) under SLACK ACTIVITY

Table 33. Section I - Rows at limit level

Number	Row	AT	Activity	Slack activity	Lower limit Upper limit	Lower act. Upper act.	Unit cost	Upper cost Lower cost	Limiting process	AT
5	R041	LL	1.05	0.0	1.05	0.0	.07600-		LUMBD1	LL
					None	162.956	.07600		R011	UL
6	R051	LL	0.609	0.0	0.609	0.208	.62800-		VEPLY1	LL
					None	8.506	.62800		R011	UL
7	R061	LL	3.853	0.0	3.853	0.0	17.60000-		PULPD1	LL
					None	142.658	17.60000		R021	UL
8	R071	LL	1.627	0.0	1.627	0.0	.03450-		PARTD1	LL
					None	66.385	.03450		R011	UL
10	R091	UL	0.372	0.0	None	0.0	.42900		VEPLYI1	LL
					0.372	0.773	.42900-		VEPLY1	LL
11	R101	UL	0.136	0.0	None	0.0	11.60000		PULPI1	LL
					0.136	6.458	11.60000-		PULP1	LL
13	R121	LL	0.022	0.0	0.022	0.0	.07600-		LUMBE1	LL
					None	161.918	.07600		R011	UL
14	R131	LL	0.004	0.0	0.004	0.0	.62800-		VEPLYE1	LL
					None	7.901	.62800		R011	UL
15	R141	LL	0.178	0.0	0.178	0.0	17.60000-		PULPE1	LL
					None	138.982	17.60000		R021	UL
16	R151	LL	0.023	0.0	0.023	0.0	.03450-		PARTE1	LL
					None	64.781	.03450		R011	UL
17	R161	EQ	0.0	0.0	0.0	1.083	.07600-		LUMB1	LL
					0.0	161.896	.07600		R011	UL
18	R171	EQ	0.0	0.0	0.0	.400	.62800-		VEPLY1	LL
					0.0	7.897	.62800		R011	UL
19	R181	EQ	0.0	0.0	0.0	6.321	17.60000-		PULP1	LL
					0.0	138.804	17.60000		R021	UL
20	R191	EQ	0.0	0.0	0.0	1.650	.03450-		PART1	LL
					0.0	64.758	.03450		R011	UL
23	R032	UL	1.274	0.0	None	.659	.17614		PULP2	LL
					1.274	43.981	.17614-		PULPT12	LL
24	R042	LL	0.676	0.0	0.676	0.0	.08939-		LUMBD2	LL
					None	8.779	.08939		PULP2	LL

represent zeros.

The sixth through the eleventh column each has two entries per row. Column six shows the LOWER LIMIT and UPPER LIMIT of the constraint for each row. Using the same example of NUMBER 5, for lumber domestic demand, there is a lower limit of 1.05 billion board feet in West Gulf and no upper limit as indicated with NONE.

In column seven, the LOWER ACTIVITY gives the lower limit to which the resource or requirement may be decreased in the right hand side (RHS) at a reduction in cost per unit shown in the corresponding UNIT COST indicated in column eight. Below this limit, the change in total cost per unit of commodity demanded (shadow price) will change. In the lumber example, the RHS restriction on the domestic demand of hardwood lumber can decrease to zero in West Gulf, without changing the shadow price of $.076 per board foot. The UPPER ACTIVITY showed the upper limit to which the resource or requirement level may be increased at the implicit cost shown in the corresponding UNIT COST of column eight. This implies that the domestic demand for hardwood lumber can increase to 162.956 billion board feet in West Gulf without changing the shadow price of $0.076. Above this demand level, the shadow price will change.

Column nine has UPPER COST and LOWER COST which is not defined in this section. The tenth column is the LIMITING PROCESS. It indicates the activity that would change when the limits under LOWER ACTIVITY and UPPER ACTIVITY shown in column seven are exceeded. In the lumber example, if the LOWER ACTIVITY of zero board foot in column seven is exceeded, lumber demand in region 1 would decrease to its lower limit which is zero. If, on the other hand, the UPPER ACTIVITY level of 163 billion board feet are exceeded, land will enter into the solution at its upper limit of 36328.5 thousand acres in region 1. The eleventh column, AT, indicates the status of the LIMITING PROCESS column or row if the LOWER ACTIVITY or UPPER ACTIVITY limits are exceeded.

Section 2: Columns at limit level (Table 34)

Like in other sections, there are eleven columns. The first four columns: NUMBER, COLUMN, AT, and ACTIVITY are identical. They perform the same functions as in Section 1. The fifth column, INPUT COST, is the cost per unit of the corresponding activity in the objective function. For example, the NUMBERS 44 and 64 indicate that the cost for hardwood lumber import in regions 1 and 2 is $.394 (1972 dollars) per board foot.

Columns six through eleven have two rows per activity. In column six, a LOWER LIMIT and an UPPER LIMIT are expressed. In this example, a lower limit of zero and an upper limit of infinity (represented with NONE) are indicated.

In column seven, LOWER ACTIVITY tells the activity level that would result from an increase in cost of the activity

Table 34. Section 2 - columns at limit level

Number	Column	AT	Activity	Input cost	Lower lt. Upper lt.	Lower Act. Upper act.	Unit cost Unit cost	Upper cost Lower cost	Limiting process	AT
44	LUMBI1	LL	0.0	0.39400	0.0	161.896-	.31800-	Infinity	R011	UL
					None	0.041	.31800	.07600	R081	UL
47	PARTI1	LL	0.0	0.08980	0.0	64.758	.05530-	Infinity	R011	UL
					None	0.010	.5530	.03450	R111	UL
52	LUMBT12	LL	0.0	0.07600	0.0	1.083	.06261-	Infinity	LUMB1	LL
					None	0.687	.06261	.01339	LUMB2	LL
55	PARTT12	LL	0.0	0.09670	0.0	1.650	.09062-	Infinity	PART1	LL
					None	1.070	.09062	.00608	PART2	LL
61	VEPLY2	LL	0.0	0.62800	0.0	7.911	.08301-	Infinity	R011	UL
					None	0.160	.08301	.54499	VEPLYT12	LL
64	LUMBI2	LL	0.0	0.39400	0.0	60.655	.37401-	Infinity	R012	UL
					None	0.026	.37401	.01999	R082	UL
67	PARTI2±	LL	0.0	0.08980	0.0	61.558	.06504-	Infinity	R012	UL
					None	0.0006	.06504	.02476	R112	UL
72	LUMBT21	LL	0.0	0.07600	0.0	0.687	.10277-	Infinity	LUMB2	LL
					None	1.083	.10277	.02677-	LUMB1	LL
73	VEPLYT21	LL	0.0	0.02760	0.0	0.160	.06006-	Infinity	VEPLYT12	LL
					None	22.311	.06006	.03246-	PULP2	LL
74	PULPT21	LL	0.0	3.10000	0.0	2.063	6.74602-	Infinity	PULPT12	LL
					None	0.198	6.74602	3.64602-	PULP2	LL
75	PARTT21	LL	0.0	0.09670	0.0	1.070	.11981-	Infinity	PART2	LL
					None	1.650	.11981	.02311-	PART1	LL

of the amount shown in column eight UNIT COST. In the example, and using the number 44, increasing the cost of lumber import by $.318 will result in a negative 161.896 billion board feet or zero lumber import. The UPPER ACTIVITY is the activity level that would result from a reduction by an amount shown under UNIT COST in column eight. Using the same example, a reduction of import cost for hardwood lumber by $.318 per board foot would result in .041 billion board feet of lumber import in region 1 which is higher than the quantity zero currently in the basis.

In column nine, UPPER COST, shows the highest cost for inputs that will permit the activity to be maintained at its current level and status in the optimal solution. The LOWER COST is the lowest cost that will allow the activity to be maintained at its present level or status in the optimal solution. In the example, with lumber import, the UPPER COST is infinity while the LOWER COST is $0.076 per board foot.

The tenth column LIMITING PROCESS, as well as the eleventh column AT, are interpreted in the same way as in Section 1. Using the previous example, lumber import and land will enter the solution at their upper levels of infinity and 36328.5 thousand acres, respectively, if the limits are exceeded in column seven.

Section 3: Rows at intermediate level (Table 35)

This section has exactly the same interpretation as Section 1. But in column three, the status of the vector is BS (in the basis and feasible) as against LL, UL and EQ in Section 1. Another area of difference is in column eight where the UNIT COST is not the shadow price like in Section 1 where resources are limited. For example, in the last row of Table 35, if the cost of importing particleboard is infinitely large, zero quantity of particleboard is imported in region 2 (East Gulf) and no activity enters the solution. If the cost declines to $.065, particleboard import in the same region rises to 1.070 billion square feet making particleboard importation in region 2 enjoy a higher demand.

Section 4: Columns at intermediate level (Table 36)

This section's interpretation is similar to that of Section 2. Columns one through six are self-explanatory and have been discussed in Section 2. Columns seven and eight show that a negative quantity of nearly 3.0 billion board feet (or zero quantity) of hardwood lumber will be produced in region 1 if the unit cost of producing hardwood lumber were $0.10277 per board foot. But 1.8 billion board feet per year will be produced in the same region if the unit cost of producing lumber were to be $.06261 per board foot. UPPER COST implies that $.17877 is the highest cost that can make lumber production in region 1 remain in the optimal solution at 1.08

Table 35. Section 3 - Rows at intermediate level

Number	Row	AT	Activity	Slack activity	Lower limit Upper limit	Lower act. Upper act.	Unit cost	Upper cost Lower cost	Limiting process	AT
2	R011	BS	3.949	32.379	None	3.293	.02038		VEPLY2	LL
					36.328	9026.239	.06900		R071	LL
3	R021	BS	0.753	16.240	None	0.750	5.24565		VEPLY2	LL
					16.993	0.755	17.91637		LUMBT12	LL
4	R031	BS	120.071	720.151	None	120.071	Infinity		None	
					840.222	120.795	.14976		R032	UL
9	R081	BS	0.0	0.041	None	0.0	Infinity		None	
					0.041	1.083	.31800		LUMBI1	LL
12	R111	BS	0.0	0.010	None	0.0	Infinity		None	
					0.010	1.650	.05530		PARTI1	LL
21	R012	BS	0.537	18.525	None	0.332	.20962		LUMBT12	LL
					19.063	0.696	.08391		VEPLY2	LL
22	R022	BS	0.007	26.284	None	0.005	17.91636		LUMBT12	LL
					26.293	0.010	5.24565		VEPLY2	LL
28	R082	BS	0.0	0.026	None	0.0	Infinity		None	
					0.026	0.687	.37401		LUMBI2	LL
31	R112	BS	0.0	0.006	None	0.0	Infinity		None	
					0.006	1.070	.06504		PARTI2	LL

Table 36. Section 4 - columns at intermediate level

Number	Column	AT	Activity	Input cost	Lower lt. Upper lt.	Lower act. Upper act.	Unit cost Unit cost	Upper cost Lower cost	Limiting process	AT
40	LUMBP1	BS	1.08	.07600	0.0	2.968-	.10277	.17877	LUMBT21	LL
					None	1.770	.06261	.01339	LUMBT12	LL
41	VEPLYP1	BS	0.400	.62800	0.0	0.240	.08301	.71101	VEPLY21	LL
					None	0.638	.42155	.20645	R092	UL
42	PULPP1	BS	6.321	17.60000	0.0	6.318	14.50000	32.10000	LUMBT12	LL
					None	6.327	2.32650	15.27351	VEPLY2	LL
43	PARTP1	BS	1.650	.03450	0.0	1.640	.05530	.08980	PARTIL	LL
					None	66.409	.03450	0.0	R071	LL
45	VEPLYI1	BS	0.372	0.19900	0.0	7.524	.42900	.62800	R091	UL
					None	0.372	Infinity	Infinity-	None	
46	PULPI1	BS	0.136	6.00000	0.0	138.668	11.60000	17.60000	R101	UL
					None	0.136	Infinity	Infinity-	None	
48	LUMBE1	BS	0.022	0.0	0.0	0.022	Infinity	Infinity	None	
					None	161.918	.07600	.07600-	R121	LL
49	VEPLYE1	BS	0.004	0.0	0.0	0.004	Infinity	Infinity	None	
					None	7.901	.62800	.62800-	R131	LL
50	PULPE1	BS	0.178	0.0	0.0	0.178	Infinity	Infinity	None	
					None	138.982	17.60000	17.60000-	R141	LL
51	PARTE1	BS	0.023	0.0	0.0	0.023	Infinity	Infinity	None	
					None	64.781	.03450	.03450-	R151	LL
53	VEPLYT12	BS	0.160	0.02760	0.0	0.240	.08301	.11061	VEPLY2	LL
					None	22.472	.06006	.03246-	VEPLYT21	LL
54	PULPT12	BS	2.426	3.10000	0.0	2.423	14.50000	17.60000	LUMBT12	LL
					None	2,432	2.32650	.77350	VEPLY2	LL
56	LUMBD1	BS	1.060	0.0	0.0	1.060	Infinity	Infinity	None	
					None	162.956	.07600	.07600-	R041	LL
57	VEPLYD1	BS	0.608	0.0	0.0	0.608	Infinity	Infinity	None	
					None	8.506	.62800	.62800	R051	LL
58	PULPD1	BS	3.853	0.0	0.0	3.843	Infinity	Infinity	None	
					None	142.657	17.60000	17.60000-	R061	LL
59	PARTD1	BS	1.627	0.0	0.0	1.627	Infinity	Infinity	None	
					None	66.585	.03450	.03450-	R071	LL

billion board feet per annum. LOWER COST indicates that $.01339 is the lowest cost that can make lumber production activity in region 1 remain in the optimal solution at the same 1.08 billion board feet per annum.

Column ten, LIMITING PROCESS shows that lumber transportation from region 2 to region 1 will enter the solution if the LOWER ACTIVITY as indicated in column seven is exceeded. If the UPPER ACTIVITY in column seven is exceeded, then lumber transportation from region 1 to region 2 enters the basis. Column eleven indicates that both activities in column ten will enter the solution at their lower limits.

These results proved that the model is valid and sensitive enough to be used for optimization and was used as such.

APPENDIX B

MPSX Procedures and Options

Table 37. Basic MPSX procedure

Card no.		Column (1 5 10 15 30 40 55)	Description
JOB1		//HARDWOOD JOB U4890, NWONWU	Tells the computer I am authorized to run on account number U4890
JCL1		//SI EXEC MPSX	Specified to computer which programs to use
JCL2		//MPSCOMP.SYSIN DD *	Signifies to computer that the MPSX program follows
P1		PROGRAM	Signifies beginning of program control deck
P2	0001	INITIALZ	System initialization macro
P3	0002	TITLE('THESIS')	Title to be printed on each page
P4	0096	MOVE(XDATA,'HARDWOOD')	Data set name
P5	0098	MOVE(XPBNAME,'MINCOST')	Problem name
P6	0099	MOVE(XRHS,'Z1')	RHS name for period 1 (1990) data
P7	0100	MOVE(XOBJ,'OBJ1')	Objective function name
P8	0101	CONVERT('SUMMARY')	Convert input data to binary problem format
P9	0102	SETUP('MIN')	Organize problem and prepare for minimization
P10	0103	BSDOUT	Printout of data in card-like format
P11	0104	PICTURE	Printout of data in pictorial form
P12	0105	OPTIMIZE	Optimization procedure
P13	0414	SOLUTION	Printout of current solution
P14	0415	EXIT	Return control to computer
P15	0416	PEND	Signifies end of program control deck
JCL3		//MPSEXEC.SYSIN DD *	Indicates to computer that data deck follows
D1		NAME HARDWOOD	Identifies data deck
D2		ROWS	Indicates that the row section follows
D3		COLUMNS	Indicates column section follows
D4		RHS	Indicates RHS section follows
D5		ENDATA	Signifies end of the data deck
JOB2		/*	Signifies end of job

Table 38. Post-optimality analysis: Range option

Card no.	Column (1 5 10 15 30 40 55)	Description
JOB1	//HARDWOOD JOB U4890, NWONWU	Tells the computer I am authorized to run on account number U4890
JCL1	//SI EXEC MPSX	Specifies to computer which programs to use
JCL2	//MPSCOMP.SYSIN DD	Signifies to computer that the MPSX program follows
P1	PROGRAM	Signifies beginning of program control deck
P2	0001 INITIALZ	System initialization macro
P3	0002 TITLE('THESIS')	Title to be printed on each page
P4	0096 MOVE(XDATA,'HARDWOOD')	Data set name
P5	0098 MOVE(XPBNAME,'MINCOST')	Problem name
P6	0099 MOVE(XRHS,'Z1')	RHS name for period 1 (1990) data
P7	0100 MOVE(XOBJ,'OBJ1')	Objective function name
P8	0101 CONVERT('SUMMARY')	Convert input data to binary problem format
P9	0102 SETUP('MIN')	Organize problem and prepare for minimization
P10	0103 BCDOUT	Printout of data in card-like format
P11	0104 PICTURE	Printout of data in pictorial form
P12	0105 OPTIMIZE	Optimization procedure
P13	0414 SOLUTION	Printout of current solution
Ran1	RANGE	Determines range of input cost for which the optimal basis remains unaltered
P14	0415 EXIT	Return control to computer
P15	0416 PEND	Signifies end of program control deck
JCL3	//MPSEXEC.SYSIN DD *	Indicates to computer that data deck follows
D1	NAME HARDWOOD	Identifies data deck
D2	ROWS	Indicates that the row section follows
D3	COLUMNS	Indicates column section follows
D4	RHS	Indicates RHS section follows
D5	ENDATA	Signifies end of the data deck
JOB2	/*	Signifies end of job

Table 39. MPSX procedure with data for three periods (1990, 2010 and 2030)

Card no.	Column 1 5 10 15 30 40 55	Description
JOB1	//HARDWOOD JOB U4890, NWONWU	Tells the computer I am authorized to run on account number U4890
JCL1	//SI EXEC MPSX	Species to computer which programs to use
JCL2	//MPSCOMP.SYSIN DD *	Signifies to computer that the MPSX program follows
P1	0001 PROGRAM	Signifies beginning of program control deck
P2	0002 INITIALZ	System initialization macro
P3	0096 TITLE('THESIS')	Title to be printed on each page
P4	0097 MOVE(XDATA,'HARDWOOD')	Data set name
P5	0098 MOVE(XPBNAME,'MINCOST')	Problem name
P6	0099 MOVE(XRHS,'Z1')	RHS name for period 1 (1990) data
P7	0100 MOVE(XOBJ,'OBJ1')	Objective function name
P8	0101 CONVERT ('SUMMARY')	Convert input data to binary problem format
P9	0102 SETUP('MIN')	Organize problem and prepare for minimization
P10	0103 OPTIMIZE	Optimization procedure
P11	0412 SOLUTION	Printout of current solution
P12	0413 MOVE(XRHS,'Z2')	RHS name for period II (2010) data
P13	0414 PICTURE	Printout of data in pictorial form
P14	0415 OPTIMIZE	Optimization procedure
P15	0416 SOLUTION	Printout of current solution
P16	0417 MOVE(XRHS,'Z3')	RHS name for period III (2030) data
P17	0418 PICTURE	Printout of data in pictorial form
P18	0419 OPTIMIZE	Optimization of procedure
P19	0420 SOLUTION	Printout of current solution
P20	0421 EXIT	Return control to computer
P21	0422 PEND	Signifies end of program control deck
JCL3	//MPSEXEC.SYSIN DD *	Indicates to computer that data deck follows
D1	NAME HARDWOOD	Identifies data deck
D2	ROWS	Indicates that the rows section follows
D3	COLUMNS	Indicates columns section follows

Table 39. (Continued)

Card no.	Column 1	5	10	15	30	40	55	Description
D4	RHS							Indicates RHS section follows
D5	ENDATA							Signifies end of the data deck
JOB2	/*							Signifies end of job

Table 40. Incrementing the budget constraint in all regions through parametric programming

Card no.	Column 1 5 10 15 30 40 50	Description
JOB1	//HARDWOOD JOB U4890, NWONWU	Tells the computer I am authorized to run on account number U4890
JCL1	//SI EXEC MPSX	Specifies to computer which programs to use
JCL2	//MPSCOMP.SYSIN DD *	Signifies to computer that the MPSX program follows
P1 0001	PROGRAM	Signifies beginning of program control deck
P2 0002	INITIALZ	System initialization macro
P3 0096	TITLE('THESIS')	Title to be printed on each page
P4 0097	MOVE(XDATA,'HARDWOOD')	Data set name
P5 0098	MOVE(XPBNAME,'MINCOST')	Problem name
P6 0099	MOVE(XRHS,'Z1')	RHS name for period 1 (1990) data
P7 0100	MOVE(XOBJ,'OBJ1')	Objective function name
P8 0101	MOVE(XCHCOL,'CHCOL1')	Indicates column 1 (RHS) values are to be changed
P9 0102	XPARDELT=1000.0	Specifies incremental values
P10 0103	XPARMAX=8000.0	Specifies the maximum value of the increment
P11 0104	XPARAM=0.0	Specifies the initial value of the parameter
P12 0105	CONVERT('SUMMARY')	Convert input data to binary problem format
P13 0106	SETUP('MIN')	Organize problem and prepare for minimization
P14 0107	OPTIMIZE	Optimization procedure
P15 0416	SOLUTION	Printout of current solution
P16 0417	PARARHS	Initiates parametric programming procedure on RHS
P17 0418	SOLUTION	Printout of current solution
P18 0419	MOVE(XRHS,'Z2')	RHS name for period II (2010) data
P19 0420	OPTIMIZE	Optimization procedure
P20 0421	SOLUTION	Printout of current solution
P21 0422	MOVE(XRHS,'Z3')	RHS name for period III (2030) data

Table 40. (Continued)

Card no.	Column (1, 5, 10, 15, 30, 40, 50)	Description
P22	0423 OPTIMIZE	Optimization procedure
P23	0424 SOLUTION	Printout of current solution
P24	0425 EXIT	Return control to computer
P25	0426 PEND	Signifies end of program control deck
JCL3	//MPSEXEC.SYSIN DD *	Indicates to computer that data deck follows
D1	NAME HARDWOOD	Indicates data deck
D2	ROWS	Indicates that the rows section follows
D3	COLUMNS	Indicates columns section follows
D4	RHS	Indicates RHS section follows
D4.1	CHCOL1 R031 0.45	
D4.12	CHCOL1 R0312 0.0003	
D5	ENDATA	Signifies end of the data deck
JOB2	/*	Signifies end of job

Table 41. Introduction of export cost through parametric programming on the objective function

Card no.	Column 1 5	10 15 30 40 55	Description
JOB1	//HARDWOOD JOB U4890, NWONWU		Tells the computer I am authorized to run on account number U4890
JCL1	//SI EXEC MPSX		Specifies to computer which programs to use
JC12	//MPSCOMP.SYSIN DD *		Signifies to computer that the MPSX program follows
P1	0001	PROGRAM	Signifies beginning of program control deck
P2	0002	INITIALZ	System initialization macro
P3	0096	TITLE('THESIS')	Title to be printed on each page
P4	0097	MOVE(XDATA,'HARDWOOD')	Data set name
P5	0098	MOVE(XPBNAME,'MINCOST')	Problem name
P6	0099	MOVE(XRHS,'Z1')	RHS name for period I (1990) data
P7	0100	MOVE(XOBJ,'OBJ1')	Objective function name
P8	0101	MOVE(XCHROW,'CHROW1')	Indicates that row 1 (objective fun tion) values are to be changed
P9	0102	XPARDELT=1.0	Specifies incremental values
P10	0103	XPARMAX=10.0	Specifies the maximum value of the increment
P11	0104	XPARAM=0.0	Specifies the initial value of the parameter
P12	0105	CONVERT('SUMMARY')	Convert input data to binary problem format
P13	0106	SETUP('MIN')	Organize problem and prepare for minimization
P14	0107	OPTIMIZE	Optimization procedure
P15	0416	SOLUTION	Printout of current solution
P16	0417	PARAOBJ	Indicates parametric programming procedure on the objective function
P17	0418	SOLUTION	Printout of current solution
P18	0419	MOVE(XRHS,'Z2')	RHS name for period II (2010) data
P19	0420	OPTIMIZE	Optimization procedure
P20	0421	SOLUTION	Printout of current solution
P21	0422	MOVE(XRHS,'Z3')	RHS name for period III (2030) data

Table 41. (Continued)

Card no.	Column 1	5	10	15	30	40	55	Description
P22 0423			OPTIMIZE					Optimization procedure
P23 0424			SOLUTION					Printout of current solution
P24 0425			EXIT					Return control to computer
P25 0426			PEND					Signifies end of program control deck
JCL3	//MPSEXEC.SYSIN DD *							Indicates to computer that data deck follows
D1	NAME			HARDWOOD				Indicates data deck
D2	ROWS							Indicates that the rows section follows
D2.1	N	CHROW1						
D3	COLUMNS							Indicates columns section follows
D3.1		LUMBE1		CHROW1	0.004			Species the column and unit cost in the
D3.1		VPLYE1		CHROW1	0.034			change row associated with an activity where
D3.1		PULPE1		CHROW1	0.96			LUMBE1 represents lumber export activity
D3.1		PARTE1		CHROW1	0.001			column in region 1
.								
.								
.								
D3.12		LUMBE12		CHROW1	0.004			
D3.12		VPLYE12		CHROW1	0.034			
D3.12		PULPE12		CHROW1	0.96			
D3.12		PARTE12		CHROW1	0.001			
D4		RHS						Indicates RHS section follows
D5		ENDATA						Signifies end of the data deck
JOB2		/*						Signifies end of job

Table 42. Incrementing the import cost of all four products through parametric programming on the objective function

Card no.	Column (1 5 10 15 30 40 55)	Description
JOB1	//HARDWOOD JOB U4890, NWONWU	Tells the computer I am authorized to run on account number U4890
JCL1	//SI EXEC MPSX	Specifies to computer which programs to run
JCL2	//MPSCOMP.SYSIN DD *	Signifies to computer that the MPSX program follows
P1	0001 PROGRAM	Signifies beginning of program control deck
P2	0002 INITIALZ	System initialization macro
P3	0096 TITLE('THESIS')	Title to be printed on each page
P4	0097 MOVE(XDATA,'HARDWOOD')	Data set name
P5	0098 MOVE(XPBNAME,'MINCOST')	Problem name
P6	0099 MOVE(XRHS,'Z1')	RHS name for period 1 (1990) data
P7	0100 MOVE(XOBJ,'OBJ1')	Objective function name
P8	0101 MOVE(XCHROW,'CHROW1')	Indicates that row 1 (objective function) values are to be changed
P9	0102 XPARDELT=2.0	Specifies incremental values
P10	0103 XPARMAX=10.0	Specifies the maximum value of the increment
P11	0104 XPARAM=0.0	Specifies the initial value of the parameter
P12	0105 CONVERT('SUMMARY')	Convert input data to binary problem format
P13	0106 SETUP('MIN')	Organize problem and prepare for minimization
P14	0107 OPTIMIZE	Optimization procedure
P15	0416 SOLUTION	Printout of current solution
P16	0417 PARAOBJ	Indicates parametric programming procedure on the objective function
P17	0418 SOLUTION	Printout of current solution
P18	0419 MOVE(XRHS,'Z2')	RHS name for period II (2010) data
P19	0420 OPTIMIZE	Optimization procedure
P20	0421 SOLUTION	Printout of current solution
P21	0422 MOVE(XRHS,'Z3')	RHS name for period III (2030) data

Table 42. (Continued)

Card no.	Column 1	10	15	30	Description
P22	0423	OPTIMIZE			Optimization procedure
P23	0424	SOLUTION			Printout of current solution
P24	0425	EXIT			Return control to computer
P25	0426	PEND			Signifies end of program control deck
JCL3	//MPSEXEC.SYSIN DD *				Indicates to computer that data deck follows
D1	NAME		HARDWOOD		Indicates data deck
D2	ROWS				Indicates that the rows section follows
D3	COLUMNS				Indicates columns section follows
D3.1	LUMBI1		CHROW1	0.004	Specifies the column and unit cost in the
D3.1	VPLYI1		CHROW1	0.034	change row associated with an activity where
D3.1	PULPI1		CHROW1	0.96	LUMBI1 represents lumber import activity
D3.1	PARTI1		CHROW1	0.001	column in region 1
.					
.					
.					
D3.12	LUMBI12		CHROW1	0.004	
D3.12	VPLYI12		CHROW1	0.034	
D3.12	PULPI12		CHROW1	0.96	
D3.12	PARTI12		CHROW1	0.001	
D4	RHS				Indicates RHS section follows
D5	ENDATA				Signifies end of the data deck
JOB2	/*				Signifies end of job

Table 43. Parameterizing the import and export costs and the budget constraint (RHS) using the option PARARIM

Card no.	Column (1 5 10 15 30 40 55)	Description
JOB1	//HARDWOOD JOB U4890, NWONWU	Tells the computer I am authorized to run on account number U4890
JCL1	//SI EXEC MPSX	Specifies to computer which programs to run
JCL2	//MPSCOMP.SYSIN DD *	Signifies to computer that the MPSX program follows
P1	0001 PROGRAM	Signifies beginning of program control deck
P2	0002 INITIALZ	System initialization macro
P3	0096 TITLE('THESIS')	Title to be printed on each page
P4	0097 MOVE(XDATA,'HARDWOOD')	Data set name
P5	0098 MOVE(XPBNAME,'MINCOST')	Problem name
P6	0099 MOVE(XRHS,'Z1')	RHS name for period 1 (1990) data
P7	0100 MOVE(XOBJ,'OBJ1')	Objective function name
P8	0101 MOVE(XCHROW,'CHROW1')	Indicates that row 1 (objective function) values are to be changed
P9	0102 MOVE(XCHCOL,'CHCOL1')	Indicates that column 1 (RHS) values are to be changed
P10	0103 XPARDELT=8000.0	Specifies incremental values
P11	0104 XPARMAX=64000.0	Specifies the maximum value of the increment
P12	0105 XPARAM=0.0	Specifies the initial value of the parameter
P13	0106 CONVERT('SUMMARY')	Convert input data to binary problem format
P14	0107 SETUP('MIN')	Organize problem and prepare for minimization
P15	0108 OPTIMIZE	Optimization procedure
P16	0417 SOLUTION	Printout of current solution
P17	0418 PARARIM	Indicates parametric programming simultaneously on the import costs, export costs and the budget constraints
P18	0419 SOLUTION	Printout of current solution
P19	0420 MOVE(XRHS,'Z2')	RHS name for period II (2010) data

Table 43. (Continued)

Card no.	Column 1 5 10 15 30 40 55	Description
P20	0421 OPTIMIZE	Optimization procedure
P21	0422 SOLUTION	Printout of current solution
P22	0423 MOVE(XRHS,'Z3')	RHS name for period III (2030) data
P23	0424 OPTIMIZE	Optimization procedure
P24	0425 SOLUTION	Printout of current solution
P25	0426 EXIT	Return control to computer
P26	0427 PEND	Signifies end of program control deck
JCL3	//MPSEXEC.SYSIN DD *	Indicates to computer that data deck follows
D1	NAME HARDWOOD	Indicates data deck
D2	ROWS	Indicates that the rows section follows
D2.1	N CHROW1	
D3	COLUMNS	Indicates columns section follows
D3.1	LUMBE1 CHROW1 0.004	Specifies the column and unit cost in the change row associated with an activity where LUMBE1 and LUMBI1 represent lumber export and import activity columns in region 1
D3.1	LUMBI1 CHROW1 0.004	
.		
.		
.		
D3.12	PARTE1 CHROW1 0.001	
D3.12	PARTI1 CHROW1 0.001	
D4	RHS	Indicates RHS section follows
D4.1	CHCOL1 R031 0.045	Specifies the row of the change column and the value of the row in the change column
.		
.		
D4.12	CHCOL1 R0312 0.0003	
D5	ENDATA	Signifies end of the data deck
JOB2	/*	Signifies end of job

APPENDIX C

National Resources and Products Demand Constraints

Table 44. National hardwood resources and products demand constraints

Resource/product	Year 1990	2000	2010	2020	2030
Land (million acres)	300	300	300	300	300
Labor (thousand persons)	175	191	209	224	240
Capital (million dollars)	9157	9312	11580	12534	13440
Lumber (billion bd ft)					
Domestic demand	10.1	11.3	12.9	14.6	16.0
Import	0.4	0.6	0.8	0.9	1.0
Export	0.2	0.3	0.4	0.5	0.5
Veneer and Plywood (billion sq ft 3/8" basis)					
Domestic demand	5.8	6.2	6.6	6.8	7.2
Import	3.55	3.75	4.05	4.05	3.85
Export	0.05	0.05	0.05	0.05	0.05
Pulpwood (million cords)					
Domestic demand	36.7	44.6	53.4	62.2	70.7
Import	1.3	1.3	1.3	1.3	1.3
Export	1.3	1.3	1.3	1.3	1.3
Particleboard (billion sq ft 3/8" basis)					
Domestic demand	15.5	18.3	21.7	24.0	26.1
Import	0.1	0.1	0.2	0.2	0.2
Export	0.2	0.2	0.3	0.3	0.3

APPENDIX D

Base Year and Projection Years Costs and Resource Uses

Table 45. Regional hardwood commercial timberland availability and use in the base year, 1977

Region number	Region	Expected land available	Actual land used
		-----(1000 acres)----	
1	New England	17205	1814
2	Middle Atlantic	42533	10438
3	Lake States	35183	1970
4	Central States	41973	2243
5	South Atlantic	31964	1581
6	East Gulf	19063	940
7	Central Gulf	36329	1826
8	West Gulf	36761	2356
9	Pacific Northwest	27419	1254
10	Pacific Southwest	4608	287
11	Northern Rocky Mountain	1557	645
12	Southern Rocky Mountain	6094	1278

Table 46. Regional hardwood labor availability and use in the base year, 1977

Region number	Region	Estimated labor available	Actual labor used
		----(1000	persons)--
1	New England	37.07	9.6
2	Middle Atlantic	82.15	7.5
3	Lake States	65.41	5.3
4	Central States	80.35	5.9
5	South Atlantic	113.74	10.6
6	East Gulf	75.9	8.1
7	Central Gulf	83.9	6.4
8	West Gulf	65.2	8.6
9	Pacific Northwest	20.0	1.8
10	Pacific Southwest	1.5	0.2
11	Northern Rocky Mountain	0.1	0.003
12	Southern Rocky Mountain	0.4	0.03

Table 47. Regional hardwood manufacturing estimated capital availability and use in the base year, 1977

Region number	Region	Estimated capital available --(million	Actual capital used dollars)--
1	New England	617	617
2	Middle Atlantic	558	558
3	Lake States	413	413
4	Central States	567	467
5	South Atlantic	742	742
6	East Gulf	542	542
7	Central Gulf	568	465
8	West Gulf	5442	608
9	Pacific Northwest	126	126
10	Pacific Southwest	17	17
11	Northern Rocky Mountain	0.2	0.2
12	Southern Rocky Mountain	2.1	2.1

Table 49. National resource use in the base year 1977 and in the projection years 1990, 2010, and 2030

Resource	1977 Actual resource used	1977 Calculated resource used	1990	2010	2030
			--Calculated resource used---		
Land (1000 acres)	NA[a]	26632	43932	57010	70602
Labor (1000 persons)	66[b]	64	95.3	117.4	144.7
Capital (million 1972 dollars)	4000[b]	4557	4709	5852	7264

[a]NA stands for not applicable.

[b]Indicates that the transportation activity and its corresponding resource use is not included.