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Evaluation of the IIASA Model of the Global Forest Sector

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1. INTRODUCTION

This monograph provides an extensive evaluation of the IIASA Global Forest Sector Trade Model (GTM). The central issue concerns the behavior and performance of the model. The purpose of this work is to deepen our understanding of the GTM (both its current state and its potential) so to determine its usefulness in forest economics research, forest industry applications, and forest policy analysis.

1.1 Background

Between 1980 and 1985, the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria conducted an extensive study of the world's forest sector. The Forest Sector Project (FSP) focused on modeling the economic behavior of forest products markets and the economic system that links the forest resources of the world. In addition to the core team of scientists assembled at IIASA to work full time on the FSP, the research included a collaborative network of approximately 300 forest scientists from all parts of the world. While a wealth of research papers and articles were generated from the project, the two primary products of the effort were: 1) a computer model, widely known as the Global Trade Model (GTM), designed to simulate the long-run economic behavior of the global forest sector; and 2) a book entitled The Global Forest Sector: An Analytical Perspective (Kallio, Dykstra, and Binkley (1987)), which provides an overview of the global forest sector, a comprehensive review of analytical techniques used in forest sector modeling, and a description of the structure of the GTM and several alternative scenarios. The model itself has been acquired by organizations in several countries which now are in the process of tailoring the structure to suit their own analytical needs.

Shortly after the FSP was formally completed in mid-1985, the Center for International Trade in Forest Products (CINTRAFOR) at the University of Washington in Seattle acquired the GTM and conducted an in-depth analysis of the model's usefulness as a tool for forest industry research, prediction, and policy analysis. This paper presents a detailed description of our analysis, findings, and conclusions.

Our work on the GTM has significantly benefited from the contributions of several individuals. Michael Pederson's expert programming assistance was a critical element of this research. Other individuals who assisted us in implementing and understanding the model were: Clark Binkley, Dave Brooks, Donn Cave, Dennis Dykstra, Markku Kallio, Jonna Kincaid, Gabor Kornai, Carol Weeks, and Jack Weeks.

1.2 Procedures for Model Evaluation

There are numerous ways to assess the performance of a large-scale simulation model. Relevant methods are:

1) Evaluation of the specification of equations (individually or by groups) and their overall role in the model structure
2) Evaluation of the statistical fit and validity of individual equations
3) Ex post (historical) simulation -- how well does the model predict the historical data from the estimation period?
4) Ex post forecast -- how well does the model predict historical data that were not used in the estimation? For example, if the model is estimated over the period 1960-1980, but historical data are available until 1985, a comparison is made between the predicted and actual data for 1981-1985.
5) Ex ante forecast -- does the base case produce reasonable, consistent projections that conform with expert intuition?
6) Sensitivity analysis

We utilize each of these methods, but rely most heavily on the first and last approaches. Consideration of structural properties of the model and sensitivity analysis provide the most comprehensive view of model behavior, along with the most penetrating insights. However, it is difficult to evaluate the structural properties of the model on the basis of available documentation, primarily as a result of the size and complexity of the model. Thus, our understanding of structure and interactions within the model result from careful dissection of the entire computer code. Once the structure of the model is fully understood, sensitivity analysis is used to reveal additional features of the model. Repeated simulation uncovers properties of model behavior that cannot be deduced from the model structure alone.

It should be emphasized at the outset that the evaluation of a model of this scale is a subjective process. It is not possible to develop reasonable statistical criteria to accept or reject the model, or to make precise statements regarding model validity. With regard to individual equations, their statistical properties indicate little about how the entire system of equations will perform. On a broader scale, what guidelines should one use for evaluating the ex post and ex ante simulations? Is it reasonable to expect all prices to fall within 5% of their historical levels? or 95% of prices to fall within 5% ? Should all endogenous variables be subject to the same ranges? More importantly, the model was designed to assess long-term trends and structural developments in the forest sector -- not to conduct short-run experiments. There are some features of the model, particularly investment behavior, that almost insure that the model will not reproduce the activities of specific years.

Ultimately, the final assessment of the model must be a qualitative judgment of its strengths and weaknesses. One must rely on expert opinion and intuition to judge the usefulness of the model. Part of the assessment must, of course, determine the potential of the model as the basis for future work and extensions. Models evolve, and we hope we can present the evaluation of this model in such an evolutionary context.

1.2.1 Sensitivity Analysis: Background and Methodology

Sensitivity analysis allows one to ascertain how model results depend on model inputs: one measures the response of an endogenous variable to a change in model input. There are two principal methods for conducting such an analysis. First, one could compute total derivatives that describe these effects. However, one must be able to develop an analytical solution to the model, which is extremely difficult (if not impossible) with a model as large as the GTM. Second, one can simply change a model input, solve the model, and compare the simulation results with the original solution. This is the approach used in the present evaluation.

One potentially-useful distinction in this analysis contrasts standard multiplier analysis with parameter-perturbation analysis (Kuh, Neese, and Hollinger, 1985). In conventional multiplier analysis, one changes an exogenous variable, simulates the model and calibrates the change in the endogenous variables. In parameter-perturbation analysis, one changes the parameters (equation coefficients) of the model, and proceeds to examine output sensitivity. We might add a third distinction: endogenous variable response to a change in equation specification or model structure.

There are basically two ways to proceed with sensitivity analysis by simulation. One is to follow classical experimental design and conduct a carefully-structured systematic analysis of the model. However, this method is only practical for small-scale experiments. If one wishes to test four parameters at two settings, one must generate 2^4 or 16 simulations. Though fractional factorial experiments typically assume variables may take on two different values, we are working with variables (and parameters) with continuous distributions and thus many more settings. Of course, we are interested in many more variables as well. Five parameters and five settings require 3125 simulations, and the infeasibility of such an approach is readily apparent. Thus, while classical experimental design is instructive in its approach and its emphasis on variable interactions, it is extremely unwieldy for large models.

Sensitivity analysis of the GTM requires a much less systematic and less rigorous approach. One must make three choices for this analysis: what inputs to test, what range over which to test them, and how to evaluate the response (given the large number of endogenous variables). Due to the large number of choices, the analysis must be performed on a rather ad hoc basis. We rely on our detailed knowledge of the GTM, and our knowledge of forest sector modeling in general, to make these choices. The model components that are tested are discussed in detail within each section.

1.2.2 Sensitivity Analysis: Summary Statistics

Since it is not possible to discuss changes in all of the endogenous variables in a simulation, it is necessary to construct summary statistics. Here we briefly review some of the concepts that are used throughout this manuscript.

Summary statistics for activity levels are constructed as a linear combination of variables judged to be most important. The most general of these is an index associated with industrial wood, aggregated over regions and products (sawlogs and pulpwood). The second is an index of solid wood products, and the third, an index of pulp and paper products. More detailed measures aggregate over regions to compute world totals, but retain the identity of individual commodities. Measures of aggregate quantities -- production, consumption, and trade -- are straightforward and require only simple summations: product groups have been selected so that all units are comparable. Aggregate price indexes require some weighting scheme. We have chosen to weight our price variables by producing regions' shares.

We rely principally on two measures of change to compare differences between two simulations. The first concept is the mean percent difference, which indicates the net response (or net change) resulting from an input change. The mean percent difference is calculated as:

$$[\,(Y^A - Y^B) \,/\, Y^B\,]\,100$$

where:

Y^A = Grand quantity total for alternative scenario

Y^B = Grand quantity total for BASE CASE (or control) scenario

Note that this is equivalent to a weighted average (weighted by BASE CASE quantities in the current period) of regional percentage differences.* In this manuscript, we often refer to the mean percent difference in production (trade) across regions simply as the percentage change in world output (trade).

Since the mean percent difference may incorporate the effects of offsetting positive and negative changes, we utilize a second statistic -- the absolute mean percent difference -- to identify the presence and extent of opposing forces. The absolute mean percent difference is computed as:

$$[\ ABS(Y_1{}^A - Y_1{}^B)\ 100\ +\ ABS(Y_2{}^A - Y_2{}^B)\ 100\ +\ \ldots\ ]\ /\ Y^B$$

where:

ABS = absolute value

$Y_1{}^A$ = quantity for region 1 in alternative scenario

$Y_1{}^B$ = quantity for region 1 in BASE CASE (or control) scenario

Again, note that this equivalent to a weighted average (weighted by BASE CASE quantities in the current period) of regional absolute mean percentage differences.

The same approach is used to compute mean percent differences and absolute mean percent differences associated with price variables. However, the actual formulas are complicated by the fact that the quantity weights do not cancel. Again, in this manuscript, we refer to the volume-weighted mean percent difference in price across regions as simply the percentage change in world price.

The combined usefulness of these two statistics can be easily demonstrated in the following example. Assume we have a two-region model and that the two regions produce equal volumes of a product in a particular period. Say we change some parameters in the model and find that in the new solution region 1 increases output by 50%, while production falls by 50% in region 2. In this example, the mean percent

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* This calculation of mean percent difference should not be confused with a simple average of percentage changes across regions in which each region (observation) is treated identically.

difference in output is 0%, and the mean absolute percent difference is 50%. The change in parameters has no effect on total production activity, but there are radical differences at the regional level.

We have developed and experimented with several additional statistics to assist in the sensitivity analysis. These were primarily directed at measuring the distributional impacts associated with alternative scenarios. For example, dividing the mean percent difference by the absolute mean percent difference yields a measure of the uniformity of directional changes: if all changes are positive, the index equals 1.0; if all changes are negative, the index equals -1.0; and if the changes are approximately offsetting, the index will be near 0. While such statistics were often helpful as diagnostic tools, we believe they have limitations as summary statistics and they are not reported in this manuscript.

For the most part, we report our comparisons between the BASE CASE and alternative simulations for the year 2000 only. For simulations in which the paths of the endogenous variables and the between-period dynamics are important to the analysis, we have tried to address these. However, the analysis of changes in 2000 often captures the essence of the sensitivity analysis, and, in the interests of brevity, we have focused our attention on that year.

1.3 Overview of the Global Trade Model

The GTM divides the globe into eighteen producing/consuming regions. In each of these regions, sixteen forest products are modeled. These include: nine final products (two types of sawnwood, two types of panels, four types of paper and paperboard, and fuelwood), three intermediate products (recycled paper and two types of pulp), and four primary products (two types of sawlogs and two types of pulpwood).

The GTM is a spatial equilibrium market model, and a solution is obtained within each period by maximizing the sum of global consumer and producer surplus. The centrally-planned economies are an exception to this rule -- behavior in these regions is determined by other factors such as maximizing foreign exchange earnings. Regions may trade all products except fuelwood. Transportation costs, tariff rates, and nontariff barriers are recognized on each trading arc. Within each period the model generates an optimal solution that specifies regional production, consumption, exports, imports, and prices.

Intertemporal behavior is modeled by updating all relevant parameters and model variables. For example, demand curves are shifted to reflect population and income growth. As another example, timber inventories are modified by means of an endogenous timber supply model that harvests timber according to the model solution and grows the remaining timber stock. The model then advances to the next period (intervals are five years) and computes the new solution. There are no optimal control features in the model, that is, the model does not seek intertemporally-optimal trade, production, and consumption patterns. Operationally, this implies that although the solution in period T influences the solution in period T+1, the reverse is not true.

1.3.1 Regional Definitions

The GTM includes eighteen regions: together these encompass the entire globe and no regions are exogenous to the model. The regions are listed in Table 1.1, along with three-letter abbreviations that are frequently used in this manuscript.

Table 1.1 The Eighteen GTM Regions and Corresponding Abbreviations

Western Canada	WCA	Rest of Western Europe	WEU
Eastern Canada	ECA	U.S.S.R	SUN
Western U.S.	WUS	Eastern Europe	EEU
Eastern U.S.	EUS	Africa	AFR
Brazil	BRA	China	KIN
Chile	CHI	Japan	JAP
Rest of Latin America	RLA	Southeast Asia	SEA
Finland	FIN	Australia-New Zealand	ANZ
Sweden	SWE	Rest of World	RWO

The region called the "Rest of World" includes any area which is not accounted for by the previous seventeen regions. The Indian subcontinent and the Middle East comprise the core of this region; however, we have found the model documentation is not adequate to determine whether certain countries belong to Southeast Asia or Rest of World.

1.3.2 Product (and Unit) Definitions

There are sixteen products modeled in the GTM. These are listed in Table 1.2 by product category. Again, abbreviations that are used frequently in this manuscript accompany the product names. All units in the model are reported on a metric basis. The units that correspond to each product, either cubic meters or metric tons, are also presented in the table.

Table 1.2 The Sixteen GTM Products, Corresponding Abbreviations, and Relevant Units

Product	Abbreviation	Units
Final Products:		
Coniferous sawnwood	CSAW	cubic meters
Nonconiferous sawnwood	NSAW	cubic meters
Veneer and plywood	VEPY	cubic meters
Composition panels	BOAR	cubic meters
Newsprint	NEWS	metric tons
Printing and writing papers	PRNT	metric tons
Household and sanitary papers	HHSP	metric tons
Packaging paper and board	PACK	metric tons
Fuelwood	FUEL	cubic meters
Intermediate Products:		
Recycled paper	RCYC	metric tons
Coniferous white pulp	CWIP	metric tons
Nonconiferous white pulp	NWIP	metric tons
Primary Products:		
Coniferous logs	CLOG	cubic meters
Nonconiferous logs	NLOG	cubic meters
Coniferous pulpwood and chips	CPWD	cubic meters
Nonconiferous pulpwood and chips	NPWD	cubic meters

Three items should be noted concerning product definitions. First, only "white" pulps or bleached chemical pulps are directly included in the model based on the rationale that international pulp trade is essentially limited to this product. Other types of pulp are indirectly accounted for by incorporating their wood use as pulpwood used in manufacturing paper and paperboard. The cost associated with wood is thus included directly; the costs associated with converting the wood to pulp are included in the manufacturing cost estimates for the respective products. Second, composition panels includes all panel products that are not made from veneer; thus, this category includes all types of particleboard and fiberboard products. The names "composition panels" and "reconstituted panels" are used interchangeably in this document. Third, the term primary product must be interpreted with caution. Although sawlogs and pulplogs are clearly primary products, pulpwood chips are byproducts. A significant fraction of fuelwood is produced directly from trees and thus may be considered a primary product; however, here we list fuelwood as a final product.

1.3.3 BASE CASE Definition

We employ a BASE CASE scenario as a control to conduct the sensitivity analysis. The endogenous variables in the BASE CASE scenario are very similar to those developed in the IIASA study; however, they are not identical due to changes in the model structure and parameters that were implemented between completion of the FSP and distribution of model. Given the multitude of minor changes, we feel that we were reasonably successful in replicating the FSP results.

Although it is tempting to consider the BASE CASE to be the most likely future path of forest sector markets, it was not constructed as such -- Dykstra and Kallio (1987a) specifically provide a disclaimer stating that the BASE CASE is not a forecast. Rather, the BASE CASE is simply a reasonable benchmark against which to compare scenario changes. Nevertheless, we should note that due to the structure of the model, and particularly due to nonlinear features, changes from our BASE CASE will not necessarily convey the same information as changes that could be measured from some other arbitrarily-defined base case.

1.4 Some General Comments on Model Structure

Because the GTM is a spatial equilibrium model, it has some inherent structural features that almost guarantee it will not predict bilateral trade flows with much accuracy. One set of characteristics pertains to its broad scope (or high level of aggregation) in both geographical and product dimensions. The second set of attributes relates to the economic assumptions that drive the model behavior.

Many of the regions in the GTM cover substantial physical territory -- the U.S.S.R. and Africa are good examples. Large regional sizes increase the probability that one area of a region could actually import a commodity, while another part of the region exports the identical item. The regions, in effect, are not homogeneous, but are comprised of many smaller entities.

The same argument may be made concerning product aggregation. Products are often defined in such broad terms that they encompass many quite distinct commodities. For example, coniferous sawnwood may include both high-grade specialty items and low-grade utility items. Even if the geographical boundaries of a region were quite narrowly defined, the region may import and export the "same" product. Needless to say, the violation of homogeneity assumptions at both the region and product level significantly compounds the problem of modeling bilateral trade flows.

There are some questionable assumptions concerning the portrayal of economic behavior in the model. These would make it difficult to model bilateral trade flows even in the absence of region/product aggregation problems. The objective function used in the GTM assumes that producers seek to maximize profits, while consumers seek to minimize expenditures. While these appear to be eminently reasonable assumptions, there are clearly many other factors at work that influence trading patterns. These include traditional marketing arrangements, long-term trading agreements, perceived differences among buyers, delivery performance, expectations with regard to future markets, etc. The GTM has attempted to account for some of the effects that may be attributed to "trade inertia"; however, these constraints are essentially arbitrary since it is not possible to determine these effects statistically.

Given these problems, spatial equilibrium models will have difficulty predicting bilateral trade flows. However, one must be careful not to judge the entire GTM on this basis: bilateral trade flows are only one item of interest generated in the GTM solution. Even though the predictions for bilateral trade flows may be poor, it does not follow that predictions of total trade, production, consumption, and prices will also be poor. The evaluation of the GTM must consider the wide array of potential uses and applications.

1.5 Some General Comments on the Supporting Data Base

In any economic model with worldwide scope, the supporting data base will be weak due to poor (or nonexistent) data in many regions. Although IIASA had the advantage of access to an extensive network of forest scientists throughout the world, it was not possible to meet adequately many of the model's data requirements. Problems with the data base are complicated by poor documentation of unpublished data sources: in many cases it is extremely difficult to replicate or update these data. Data on parameters such as technological coefficients for individual manufacturing technologies are essentially unobtainable.

We have encountered several instances of inconsistencies in the data that have proven difficult to resolve. In some cases this is due to problems in obtaining the appropriate data. We offer two pertinent examples: 1) fuelwood production in Brazil in 1980 is 152 mm m^3, but the maximum potential production is 44 mm m^3, 20 directly from tree harvest, and 24 from manufacturing residues; and 2) the harvest of nonconiferous trees in the U.S. is quite low compared to published U.S. sources, apparently due to the omission of fuelwood and other removals (cultural operations, land clearing, and land use changes) from the harvest figures -- this problem may have occurred for all developed countries. In other cases, data may be available but the difficulty lies in the sheer magnitude of the data modification task: in many cases, changes to the data require rebalancing (hence further modifications) of the entire data base. For example, the model shows a huge shipment of coniferous pulpwood from Australia-New Zealand to Japan in 1980 -- this was actually a flow of nonconiferous pulpwood (eucalyptus chips).

Data problems obviously create significant problems for potential users of the model. It seems fair to say that anyone who chooses to analyze the global forest sector using the GTM will need to construct their own data base. This is particularly true given that the base year data is for 1980, and is thus quite old by any standards.

1.6 Monograph Outline

The next section of this monograph provides an evaluation of the BASE CASE as a means of identifying some of the salient features of the GTM. Sections 3 through 7 discuss the key modules of the GTM and are organized as follows: Section 3, Final Product Demand; Section 4, Product Supply; Section 5, Timber Supply; Section 6, Trade and Transportation; and Section 7, Miscellaneous Features: Exchange Rates and the Centrally-planned Economies. We begin each section by briefly reviewing the methodology used in the model. Next we provide a summary of some of the strengths and weaknesses of the methodology from a theoretical standpoint. We also point out possible oversights and/or errors in the model, and consider questionable features. Third, we present the results of sensitivity analysis that has been conducted to test key features of each module. Section 8 summarizes our analysis, presents our conclusions, and provides recommendations for modifying and improving the GTM.

2. EVALUATION OF THE BASE CASE

Our evaluation of the BASE CASE consists of directly comparing the simulation results for 1980 with actual historical data, and analyzing the projection results (this exercise thus incorporates ex post simulation, ex post forecasting, and ex ante forecasting). As mentioned in Section 1, we are not concerned with whether the BASE CASE provides the most reasonable projection of future activities; rather, we are concerned with the character of the results and what these results suggest about model structure and performance.

2.1 Results for 1980

The 1980 production predictions match the actual historical data extremely well. As shown in Table 2.1, the mean percent error for world production of individual products is always less than 2%, and generally less than 1%. The mean absolute percent errors also are small, indicating the predictions are fairly accurate for individual regions. This is to be expected given the initial conditions in the model (specifically the methodology for locating the demand curve and the establishment of base year capacity).

Production capacity constraints are binding for a large share of production, and are thus responsible for much of the success in predicting production. Table 2.2 shows the number of regions which operate at full capacity in 1980, along with some figures on the importance of these regions in world production. Without these constraints, production would increase, and prices would fall to the variable-cost level reflected by the current technology. However, while some critics may point to the important role of these constraints in the predictions, it is also true that capacity critically determines production in the real world as well: the inclusion of capacity constraints is essential to represent actual behavior.

Table 2.1 Historical Production Data and Prediction Errors for 1980

	Historical Value (mm units)	Mean Percent Error	Mean Absolute Percent Error
Individual Products:			
RCYC	47.9	-0.4	4.6
CLOG	608.5	-0.7	1.8
NLOG	292.9	-0.5	4.4
CPWD	383.1	-1.1	4.3
NPWD	147.1	-0.3	2.3
CWIP	30.7	-1.3	7.6
NWIP	20.8	-0.5	0.6
CSAW	313.8	-0.6	0.8
NSAW	117.8	-0.7	0.7
VEPY	44.9	0.8	1.3
BOAR	57.7	-0.1	0.2
NEWS	26.2	-1.9	1.9
PRNT	45.7	-0.5	0.6
HHSP	8.9	-1.1	1.1
PACK	85.3	-0.5	0.8
FUEL	1361.1	0.3	0.7
Industrial roundwood:			
Total	1252.1	-1.8	3.7
Coniferous	849.7	-2.6	4.0
Nonconiferous	402.5	0.1	4.9
Solid wood products:	534.1	-0.5	0.6
Paper and paperboard:	166.2	-0.8	0.9

Notes:
1) Production and consumption are identical at the world level; thus, the first two columns are identical for world consumption. However, mean absolute percent errors will differ between the production and consumption figures.
2) Solid wood products includes CSAW, NSAW, VEPY, and BOAR.
3) Paper and paperboard includes NEWS, PRNT, HHSP, and PACK.

The 1980 predictions for total trade flows are not nearly as accurate as the production results. Table 2.3 shows total historical flows, total predicted flows, and statistics comparing these figures. The last column of Table 2.3 indicates the percentage (by volume) of predicted bilateral flows that are operating on export constraints. We also observe that the predicted volume of trade for 1980 is often significantly less than the actual volume of trade for all commodities. We further explore these trade patterns and the role of trade inertia constraints in Section 6.

Table 2.2 Importance of Capacity Constraints in Determining the Production of Final and Intermediate Goods in 1980

Product	Number of Regions Constrained	Production Volume Constrained (mm units)	Percent of World Production
CWIP	13	23.07	76
NWIP	15	18.40	89
CSAW	14	281.40	90
NSAW	15	106.14	91
VEPY	15	41.60	92
BOAR	14	54.71	95
NEWS	16	23.14	90
PRNT	17	44.71	98
HHSP	12	7.42	84
PACK	14	77.38	91

Table 2.3 Comparison of Historical and Predicted Values of World Exports for 1980

Product	Historical Value (USD/unit)	Predicted Value (USD/unit)	Mean Percent Error	Mean Absolute Percent Error	Percent Constrained by Volume
RCYC	5.4	3.7	-31.5	40.0	47
CLOG	28.4	24.8	-12.6	21.3	22
NLOG	42.4	34.5	-18.6	19.3	22
CPWD	39.1	28.6	-26.9	27.7	49
NPWD	3.9	2.5	-37.3	37.3	59
CWIP	11.6	11.4	-1.8	18.2	22
NWIP	5.8	5.2	-10.1	14.9	22
CSAW	92.3	80.3	-13.0	13.6	24
NSAW	15.2	12.8	-15.5	21.1	45
VEPY	13.1	11.4	-13.5	19.6	23
BOAR	5.8	4.6	-20.1	20.1	28
NEWS	11.7	10.7	-7.6	7.6	8
PRNT	5.7	4.7	-17.8	21.4	28
HHSP	0.6	0.4	-36.4	36.4	52
PACK	11.3	9.6	-14.8	17.2	25

In Table 2.4, we focus on the most heavily-traded item (coniferous sawnwood). This table shows that the errors in predicting bilateral trade flows are extremely large and often at trade inertia bounds. This result is inevitable since spatial equilibrium models fail to reproduce actual trade flows accurately by virtue of their construction and underlying assumptions.

Why are trade flow predictions poor while production predictions are significantly more accurate? In general this is due to the fact that commodities are significantly aggregated and thus may be quite heterogeneous; however, the model treats these products as homogeneous and thus they act as perfect substitutes. With this assumption, it is difficult to explain transhipments and impossible to explain cross-hauls.* It should also be noted that since flows will move uni-directionally in the model solution, prices must deviate by transportation costs. This will create errors in the consumption volumes and thus contribute to errors in the estimation of flows.

Table 2.4 Comparison of Historical and Predicted Values of Major Coniferous Sawnwood Flows for 1980 (mm m^3)

Arc	Historical Value	Predicted Value	Percent Error
WCA to ECA	13.54	8.68	-36.0
to WUS	4.86	4.12	-15.2
to JAP	2.58	5.16	100.0
ECA to EUS	11.00	5.50	-50.0
to WEU	3.42	4.31	26
WUS to EUS	25.27	25.32	0.2
to JAP	1.53	0.77	-50.0
FIN to WEU	6.91	7.78	12.6
SWE to WEU	5.26	5.14	-2.3
SUN to WEU	3.25	2.98	-8.3
to EEU	2.24	2.24	0
EEU to WEU	1.77	1.85	4.5
Sum of Above Flows	81.63	73.85	
Percent (by volume) of Total CSAW Flows	88.5	92.0	

The 1980 price results are mixed. The higher-value products tend to be reasonably close in percentage terms, whereas the intermediate and primary products

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* It appears that some predictions are poor due to errors in the original data base. For example, the original data show significant volumes of lumber moving from WCA to ECA and ECA to EUS. The model attempts to eliminate this transhipment and ship directly from WCA to EUS, which is likely a better representation of actual market behavior. However, it never succeeds because of high transport costs.

exhibit much greater errors, primarily reflecting the magnitude of differences in base prices. These results are shown in Table 2.5.

Table 2.5 Comparison of Historical and Predicted Values of Prices for 1980

Product	Historical Value (USD/unit)	Predicted Value (USD/unit)	Mean Percent Error	Mean Absolute Percent Error
RCYC	161.7	170.6	5.2	6.6
CLOG	49.4	49.9	0	12.0
NLOG	42.2	46.3	6.4	19.4
CPWD	24.6	26.2	21.8	43.3
NPWD	22.9	22.7	2.9	26.4
CWIP	452.7	405.5	-9.9	10.0
NWIP	413.6	390.7	-5.4	6.0
CSAW	184.2	176.6	-4.1	7.3
NSAW	189.5	189.3	0.1	5.3
VEPY	450.4	423.9	-5.6	8.8
BOAR	206.4	203.3	-1.7	6.1
NEWS	443.2	445.1	0.5	4.4
PRNT	765.6	742.0	-2.8	6.3
HHSP	804.3	854.0	6.0	7.5
PACK	484.7	482.8	0.4	5.5
FUEL	9.8	9.7	-0.7	0.9

Note: Prices are weighted by regional production.

There are two essential elements to understanding the accuracy of the price predictions. The first concerns the construction of the demand and supply curves. The demand curve incorporates the price at the point of consumption. The supply curve represents the marginal cost curve for the industry at an "average" mill site. Because intra-regional transportation costs are omitted from the GTM, historical prices will lie above costs by at least the cost of delivering a product within a region. Thus predictive errors for prices may result from the failure of the model to link producers and consumers spatially, that is, the misspecification of transportation costs. Prices (in exporting regions) may fall to the level of mill costs as a result of this omission. Table 2.6 presents historical and predicted values of coniferous sawnwood prices and costs along with the price/cost ratio for each region (note that these margins may also be due to high levels of demand and thus cover some portion of capital costs).

Table 2.6 Historical and Predicted Values of Coniferous Sawnwood Prices and Costs in 1980 (USD/m^3)

		Historical			Predicted	
Region	Price	Cost	Price/Cost	Price	Cost	Price/Cost
WCA	165.0	146.4	1.13	126.8	126.8	1.00
ECA	165.0	133.6	1.24	164.6	123.0	1.34
WUS	160.0	121.7	1.31	146.2	119.6	1.22
EUS	160.0	111.3	1.44	190.7	96.7	1.97
BRA	200.0	162.0	1.23	223.9	223.9	1.00
CHI	110.0	126.6	0.87	122.6	122.6	1.00
LAR	200.0	150.2	1.33	187.1	152.4	1.23
FIN	195.0	152.2	1.28	180.2	158.6	1.14
SWE	210.0	148.3	1.42	180.6	168.9	1.07
WEU	220.0	149.0	1.48	203.1	160.4	1.27
SUN	180.0	nr		177.5	nr	
EEU	180.0	nr		180.6	nr	
AFR	190.0	140.6	1.35	225.1	147.2	1.53
KIN	190.0	nr		190.0	nr	
JAP	210.0	155.9	1.35	194.6	152.6	1.28
SEA	210.0	171.5	1.22	154.2	154.2	1.00
ANZ	200.0	172.5	1.16	186.6	172.1	1.08
RWO	200.0	193.4	1.03	213.4	212.0	1.01

Note: nr = not relevant

The second element relates to the aggregation of regions and products (and the assumption that each product is homogeneous). For those regions that trade freely (not operating on a trade boundary), prices must differ by the cost of transportation between regions: this fundamental identity must hold whether regions are operating on the horizontal portion of their supply curves or on their production bounds. However, we often do not observe such price differences historically. This may be due to heterogeneous products, large regions competing such that cross-hauls are evident, etc. For example, 1980 coniferous sawnwood prices are USD 165/m^3 in Western and Eastern Canada and USD 160/m^3 in the Western and Eastern U.S. Yet the Canadian regions export large volumes of lumber to the U.S. Solving the model for 1980 yields the price results shown in Table 2.7; transfer costs are also presented.

Table 2.7 Predicted Values of Prices and Transfer Costs for North American Regions in 1980 (USD/m^3)

Origin	Price	Destination	Price	Transfer Cost
WCA	126.8	ECA	164.4	37.8
WCA	126.8	WUS	146.2	19.4
ECA	164.4	EUS	190.7	26.6 (on bound)
WUS	146.2	EUS	190.7	44.5

2.2 The Projection Results

The BASE CASE projection paths for some key items are depicted in Figures 2.1-2.6. Figures 2.1 and 2.2 present world production volumes for industrial roundwood and solid wood products. Figure 2.3 shows the total world volume of trade for several major products.* Price patterns are plotted in Figures 2.4 (raw materials), 2.5 (solid wood products), and 2.6 (pulp, paper, and paperboard). Some of the salient features of these figures are discussed below.

2.2.1 The Accuracy of 1985 Predictions

One very useful exercise in model validation is to examine how well the model predicts historical data which lie beyond the range of the model estimation period (ex ante simulation). Thus, it is very tempting to compare predicted values for 1985 with actual data. However, such a comparison is not valid. The discussion below explains why and provides some insight into the nature of the model projections.

The investment sector in the GTM operates on the principle that additional capacity is created only if price levels justify an adequate return to capital. This "capital cost" is included in the formulation of prices in the current time step of each model solution (except the base period). As a result, most of the prices predicted by the model in each projection period are "long-run" prices. The actual prices we observe in 1985 (or in any historical year) could, of course, range from variable-cost levels to prices which include "excess" profits, depending on the period of the business cycle. Thus, the structure of the model suggests that predicted and actual prices should not be the same (except coincidently). For a valid comparison at a single point in time, one

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* Traded volumes do not necessarily refer to international trade because of shipments between the West U.S. and East U.S. and between West Canada and East Canada.

Figure 2.1 World Industrial Roundwood Production by Species in the BASE CASE

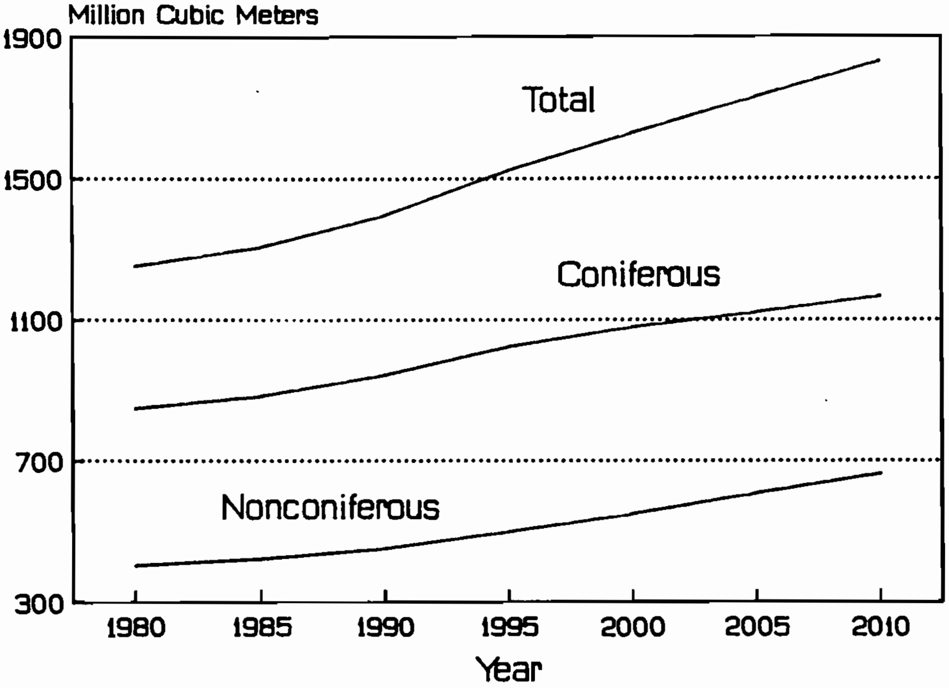


Figure 2.2 World Solid Wood Products Production in the BASE CASE

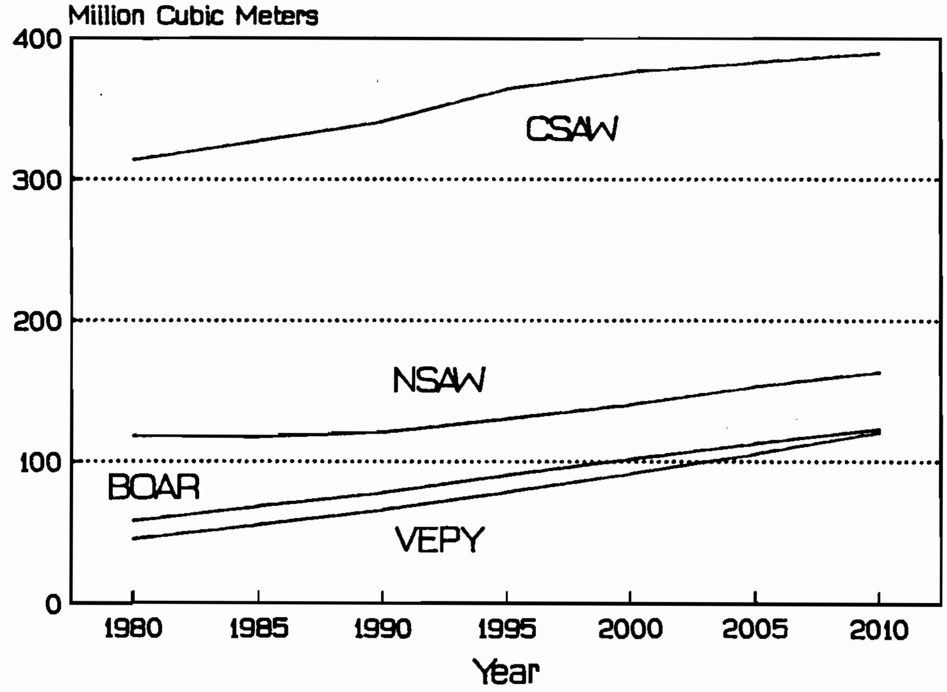


Figure 2.3 World Trade of Major Forest Products in the BASE CASE

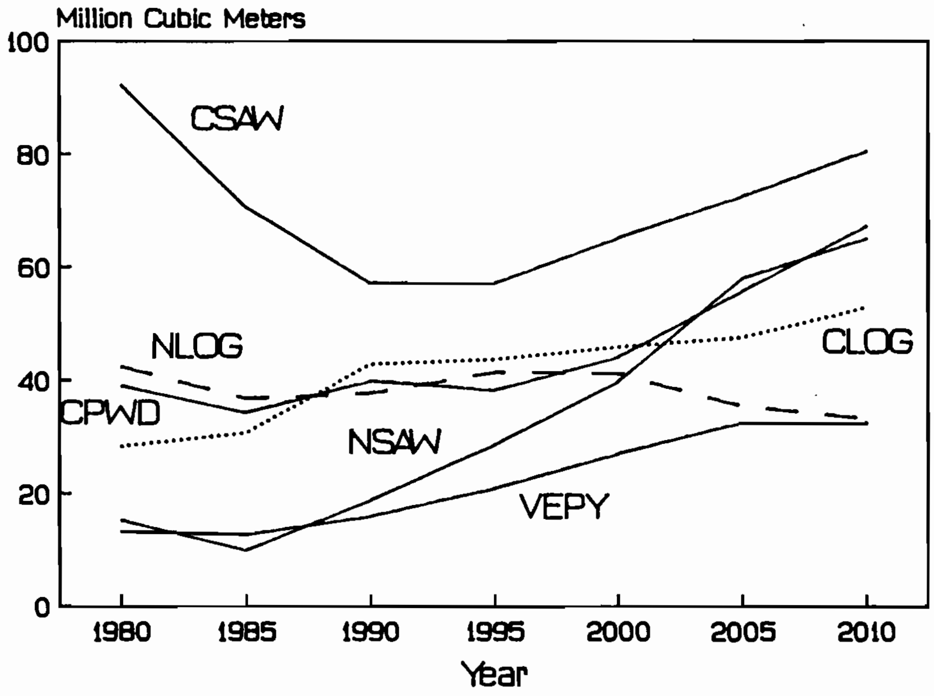


Figure 2.4 World Prices for Primary Products in the BASE CASE

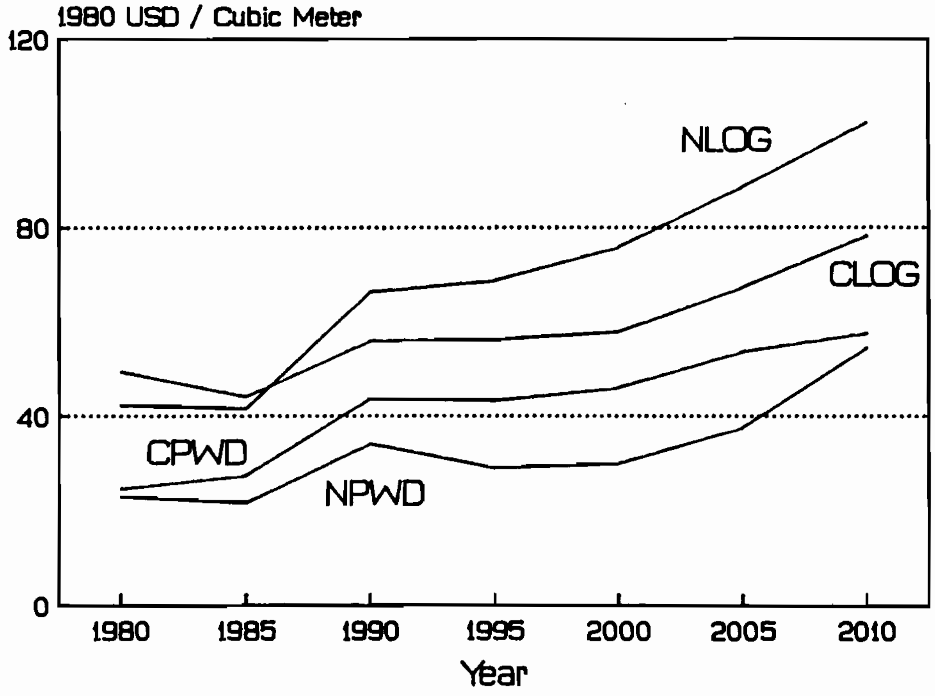


Figure 2.5 World Prices for Solid Wood Products in the BASE CASE

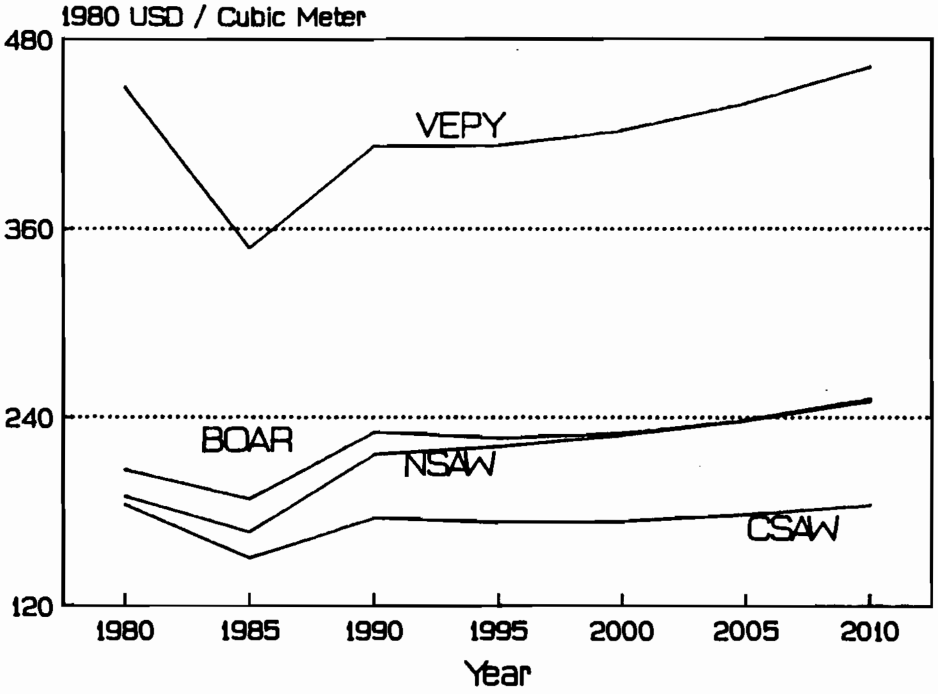
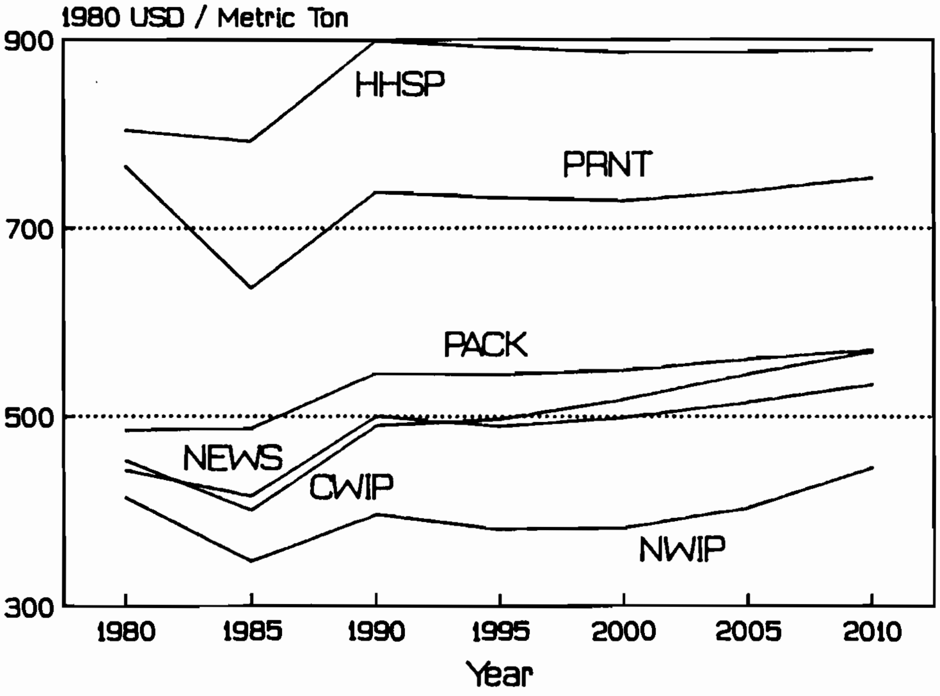


Figure 2.6 World Prices for Pulp, Paper, and Paperboard in the BASE CASE



would need to compare the model predictions with a long-run moving average of historical values.

The GTM price formulation must be understood in using the model to assess price inflation trends. The change from the initial year (1980) to the first projection period (1985) can be very misleading since we move from a "short-run" to a "long-run" price. Price inflation will be overstated (understated) if the initial year exhibits poor (excess) profitability. The step-function approach to supply modeling leads to other questionable behavior which we explore in more depth in Section 4.

One conceptual flaw in the model is evident from examining the behavior of prices in 1985. Though not billed as a forecasting model, the model incorporates several features designed to enhance its ability as a forecasting tool: one of these is the flexibility to incorporate known information about future capacity and investment in new technology. However, in the current version of the GTM this leads to two problems.

First, the lower limit on investment is implemented as a lower bound on production for the newest technology. This may result in a region partially using their modern, old, and new capacity. Clearly we would expect the new capacity to used first because it is the most efficient; however, it enters the model with an associated capital cost and is thus the highest-cost technology. This makes the interpretation of product prices extremely difficult for such regions.

The second problem is with the mechanism for handling announced capacity.* In the GTM, only the portion of potential new capacity which is actually used is constructed and made available in the subsequent period. Thus, announced capacity which is available in the current time step, but unutilized, will be retired immediately in the model.

2.2.2 The 1985 Price Decline

Perhaps the most significant feature of the BASE CASE projection is the significant drop in prices in 1985 for most products in most regions. Table 2.8 presents the average world prices for 1980, 1985, and 1990 along with period-to-period percentage changes. This pattern occurs in the face of demand curve shifts which are

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* Announced capacity must be distinguished from known investment. Announced capacity is a measure of the existing stock of capacity in a given year, whereas investment relates to the amount of capacity added in that year. Investment in the third technology could be (say) 0.2 units, but a larger amount of capacity could exist due to prior investment (or data inconsistencies). If only 0.2 units are utilized, the extra amount will be retired immediately.

fairly similar over time within each region/product combination (for example, the demand for newsprint in Western Europe shifts out at about the same rate over time).

Table 2.8 BASE CASE Price Projections for 1980, 1985, and 1990 (USD/unit)

	1980			Percent Change		Percent Change
	Historical	Predicted	1985	1980-1985	1990	1985-1990
RCYC	161.7	170.6	175.5	2.8	176.1	0.3
CLOG	49.4	49.9	44.0	-11.8	55.9	27.0
NLOG	42.2	46.3	41.4	-10.6	66.4	60.4
CPWD	24.6	26.2	27.4	4.6	43.7	59.5
NPWD	22.9	22.7	21.5	-5.3	34.1	58.6
CWIP	452.7	405.5	400.3	-1.3	489.8	22.4
NWIP	413.6	390.7	346.3	-11.4	396.2	14.4
CSAW	184.2	176.6	150.1	-15.0	175.9	17.2
NSAW	189.5	189.3	166.6	-12.0	216.5	30.0
VEPY	450.4	423.9	347.5	-18.0	412.5	18.7
BOAR	206.4	203.3	187.5	-7.8	230.7	23.0
NEWS	443.2	445.1	415.8	-6.6	500.0	20.3
PRNT	765.6	742.0	636.0	-14.3	737.8	16.0
HHSP	804.3	854.0	792.4	-7.2	898.6	13.4
PACK	484.7	482.8	487.0	0.9	545.5	12.0
FUEL	9.8	9.7	8.4	-13.4	11.5	36.9

Note: Percent change represents change from the 1980 predicted values to 1985, and 1985 to 1990.

The 1985 decline in prices can be explained by exchange rates. The U.S. dollar appreciated significantly relative to all currencies between 1980 and 1985. The appreciation of exchange rates shifts both the demand and supply curves. However, the demand curve will shift downward by a greater percentage than the supply curve, because capital and transportation costs are not affected by exchange rates in the GTM. Thus, the price-quantity equilibria will shift downward and to the left: prices and quantities will both fall.

Model simulation with the exchange rates at 1980 levels produces results which differ dramatically from the BASE CASE. These results show the importance of exchange rates in the 1985 price decline (see Table 2.9). With exchange rates held at 1980 levels, prices rise significantly between 1980 and 1985 -- this compares with large price declines in the BASE CASE for nearly all commodities. The reversal in price trends is particularly dramatic for raw materials.

The rate of price increase in the constant exchange rate scenario slows dramatically after 1985. As discussed earlier, this is due to the design of the model: prices for 1985 and beyond are long-run prices incorporating an adequate return to capital, whereas 1980 prices are "short-run." This contrasts with rapid price inflation due to the exchange rate shock in the BASE CASE between 1985 and 1990.

Table 2.9 Percentage Changes in World Prices from 1980 to 1985 and 1985 to 1990: BASE CASE versus Constant Exchange Rate Case

	BASE CASE		1980 Exchange Rates	
	1980-1985	1985-1990	1980-1985	1985-1990
RCYC	2.8	0.3	2.2	- 1.1
CLOG	-11.8	27.0	7.6	- 1.1
NLOG	-10.6	60.4	22.5	9.0
CPWD	4.6	59.5	40.5	8.7
NPWD	-5.3	58.6	23.3	1.1
CWIP	-1.3	22.4	15.3	5.7
NWIP	-11.4	14.4	0.1	- 1.2
CSAW	-15.0	17.2	- 0.8	0.8
NSAW	-12.0	30.0	13.8	2.7
VEPY	-18.0	18.7	- 2.6	3.1
BOAR	-7.8	23.0	10.3	3.3
NEWS	-6.6	20.3	5.1	5.5
PRNT	-14.3	16.0	0.3	2.2
HHSP	-7.2	13.4	6.2	1.4
PACK	0.9	12.0	14.5	- 1.3
FUEL	-13.4	36.9	18.6	0

Note: Percentage changes represent changes from the 1980 predicted values to 1985, and 1985 to 1990.

2.2.3 Price Separation Among Regions

An obvious feature of the BASE CASE results is that prices separate significantly between trading partners. This trend has been explained as a function of the model structure and assumptions. Relative price inflation among regions may be an artifact of this separation.

First, consider the example of solid wood products in the U.S. In Table 2.10 we show prices for coniferous sawnwood, veneer and plywood, and coniferous logs. The Western U.S. has a surplus of wood relative to demand within that region, while the Eastern U.S. has a deficit. In the periods shown, the Eastern U.S. imports both lumber and plywood from the Western U.S. As a result, prices diverge by the cost of transporting these products from the West to the East; hence, the relative price inflation in the two regions between 1980 (actual prices) and 1985 is strictly artificial.*

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* Relative price inflation between the predicted 1980 values and the 1985 values is more meaningful because much of the transfer cost adjustment is imbedded in the 1980 solution.

This separation of product prices results in the divergence of prices of raw materials in the two regions. The structure of the model is such that profits will generate new investment in plant capacity, and eventually the profit will accrue to the raw material. As a result, we see that log prices in the Eastern U.S. rise rapidly, but are stable to declining in the Western U.S.

Table 2.10 Regional Price Trends in the U.S. for Some Key Products (USD/m^3)

	1980			
	Actual	Predicted	1985	1990
Coniferous sawnwood:				
WUS	160.0	146.2	126.0	133.2
EUS	160.0	190.7	170.5	177.6
Veneer and plywood:				
WUS	430.0	387.5	340.4	350.2
EUS	410.0	427.3	380.2	389.6
Coniferous sawlogs:				
WUS	44.0	40.9	32.7	37.3
EUS	35.0	31.6	47.8	62.3

Another example of this separation may be found with newsprint in Western Europe. Finland and Sweden export newsprint to the remainder of Western Europe. Since the costs of transporting newsprint from Finland and Sweden to "Other" Western Europe are essentially the same, predicted newsprint prices in Finland and Sweden also are nearly the same, but both lie significantly below the price in Western Europe. Again, the difference is much greater than we observe historically in 1980. (See Table 2.11.)

Table 2.11 Newsprint Price Trends in Finland, Sweden, and "Other" Western Europe (USD/metric ton)

	1980			
	Actual	Predicted	1985	1990
Finland	450.0	434.2	372.9	548.3
Sweden	480.0	433.2	372.0	548.7
WEU	500.0	515.5	454.2	604.3

2.2.4 Increased Total Trade

A key aspect of the BASE CASE projections is that we observe a significant increase in the total volume of trade over time. The economic fundamentals of the BASE CASE suggest that demand increases necessitate greater exports of forest products from resource-rich to resource-poor countries. Total trade increases are shown in Table 2.12.

Table 2.12 World Trade in Forest Products (mm units) -- Selected Years

	1980 (Actual)	1995	2010	Percent Change 1980-2010
RCYC	5.40	1.31	3.74	-30.7
CLOG	28.35	43.88	52.96	86.8
NLOG	42.40	41.60	33.26	-21.6
CPWD	39.10	38.29	67.34	72.2
NPWD	3.91	5.75	22.33	471.1
CWIP	11.59	11.55	16.10	38.9
NWIP	5.84	7.82	19.23	229.3
CSAW	92.25	57.19	80.57	-12.7
NSAW	15.18	28.65	65.18	329.4
VEPY	13.14	20.95	32.50	147.3
BOAR	5.82	3.61	4.70	-19.2
NEWS	11.67	15.24	16.43	40.8
PRNT	5.66	11.02	25.68	353.7
HHSP	0.55	0.23	0.23	-58.2
PACK	11.25	12.66	18.43	63.8

2.2.5 Increasing Product Specialization

Another critical feature of the GTM is that although total trade rises over time, there is an increasing orientation to specific items. The trade inertia constraints play an obvious role in holding trade levels near historical levels in the early part of the simulation. Over time, the role of these constraints diminishes rapidly because they are formulated as exponential functions (in four periods, the lower constraint is only 6% of the historical level (0.5^4), while the upper constraint is 16 times as large (2.0^4)). In the longer run, the formulation of product supply dominates behavior and regions tend to specialize in exporting certain commodities. We investigate the importance of the inertia constraints and the formulation of product supply in later sections. We show some results of product specialization for paper and paperboard in Table 2.13.

Table 2.13 Paper and Paperboard Exports From Major Regions in 1980 (Actual) and 2010 (mm metric tons)

	NEWS	PRNT	HHSP	PACK
Eastern Canada:				
1980	6.93	0.50	0.04	0.59
2010	13.44	0.01	0	0.01
Western U.S.:				
1980	0.21	0.01	0.06	0.52
2010	0	0	0	8.08
Eastern U.S.:				
1980	0.09	1.30	0.05	3.66
2010	0	0.03	0	9.47
Finland:				
1980	1.34	1.83	0.10	1.57
2010	0.34	21.84	0.01	0.11
Sweden:				
1980	1.30	0.54	0.11	2.79
2010	0.14	1.66	0	0.25

3. FINAL PRODUCT DEMAND

There are nine final products modeled in the GTM (see Table 1.2 or 3.1). Demand curves are incorporated for each of these products in the base year, and these demand curves are shifted over time in five-year steps. Final product demand methodology is identical for all regions, except the Soviet Union and Eastern Europe.

3.1 IIASA Demand Curve Methodology

3.1.1 The Static Formulation for the Market Economies and China

The demand curves are estimated in constant-elasticity form:

$$Q = a\,P^b \qquad 3.1$$

To position these demand curves, this equation is divided by base year values:

$$Q / Q_0 = (P / P_0)^b \qquad 3.2$$

where:

Q_0 = base year consumption
P_0 = base year price
b = price elasticity of demand (Table 3.1)

The demand curves are then linearized for use in the GTM. The linearization is:

$$Q / Q_0 = (1 - b) + b\,(P / P_0) \qquad 3.3$$

Rearranging equation 3.3 yields the inverse demand curve for the base year:

$$P = [1 - (1/b)]\,P_0 + (1/b)\,(P_0 / Q_0)\,Q \qquad 3.4$$

Using GTM program notation we may rewrite equation 3.4 as:

$$P = MU + PHI\ Q \qquad 3.5$$

This formulation is modified with constraints. First, demand is assumed to be vertical at a fixed percentage of base year consumption (it appears this was 50% in the Forest Sector Project).* Second, fuelwood demand is assumed to be infinite at its lower price limit (this is USD 5/m^3 in the current version of the model).

3.1.2 Shifting the Demand Curve Over Time

The demand curve is shifted over time by multiplying the base year consumption level by:

$$e^{uT} \quad ; \; u = (g\, y + n + d) \quad \text{and} \quad T = (5t)$$

where:

u = annual growth rate in demand
T = number of years from base year
g = annual growth rate of income/capita (computed as a declining function of income/capita, $e^{(a - k\, r)}$, with $k = -0.06$ and r = income/capita)
y = income elasticity of demand for a given product (Table 3.1)
n = annual population growth rate
d = technological trend (0 for all products except CSAW; for CSAW, $d = -0.03$ in the developed regions)
t = time period of solution ($0 = 1980$, $1 = 1985$, etc.)

and multiplying the base year price by the real exchange rate, X. Thus, the demand curve in any period is:

$$Q \,/\, (Q_0\, e^{uT}) = (1 - b) + b\, [P \,/\, (P_0\, X)] \qquad 3.6$$

Alternatively, the inverse demand curve in any period is:

$$P = [1 - (1/b)]\, (P_0\, X) + (1/b)\, (P_0 \,/\, Q_0)\, (X \,/\, e^{uT})\, Q \qquad 3.7$$

---

* These constraints were actually introduced for computational reasons in the case of nonlinear demand curves. However, they were maintained in all "versions" of the model.

The inverse demand curve in the base year (equation 3.4) can be obtained simply by setting $X = e^{uT} = 1$ in equation 3.7.

It is clear that income-, population-, and technology-related shifts affect only the slope in equation 3.7: demand increases cause the demand curve to shift outward, pivoting about the price intercept. Exchange rate changes, however, alter both the slope <u>and</u> intercept of the demand curve.

Table 3.1 Income and Demand Elasticities Used in the GTM

	GDP/capita (1980 USD)			
	< 750	750-1500	1500-3000	> 3000
	Income Elasticity			
CSAW	1.2	1.2	1.9	1.5
NSAW	1.0	1.0	0.7	0.7
VEPY	1.3	1.3	1.3	1.3
BOAR	1.3	1.3	1.3	1.3
NEWS	1.3	1.0	0.8	0.6
PRNT	1.3	1.3	1.3	1.2
HHSP	1.3	1.3	1.2	0.6
PACK	1.3	1.2	1.2	0.6
FUEL	-0.2	-0.2	-0.2	-0.2
	Demand Elasticity			
CSAW	-1.5	-1.5	-0.7	-0.5
NSAW	-0.5	-0.5	-0.9	-1.2
VEPY	-0.4	-0.4	-0.4	-0.4
BOAR	-0.4	-0.4	-0.4	-0.4
NEWS	-0.8	-0.5	-0.4	-0.3
PRNT	-1.2	-0.3	-0.2	-0.2
HHSP	-0.7	-0.3	-0.1	-0.1
PACK	-0.7	-0.3	-0.1	-0.1
FUEL	-0.7	-0.7	-0.7	-0.7

3.1.3 Eastern Europe

Base year consumption is set equal to apparent consumption in 1980. For forecast periods, a lower bound (target level) is set for consumption.* This target level is shifted over time by multiplying by (e^{uT}). The income elasticity is assumed to be zero.

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* Although this formulation implies that consumption may deviate from the target level, it is actually fixed at this volume. For this region, it is a mathematical fact that consumption will always be on the lower bound at the equilibrium solution.

3.1.4 Soviet Union

Consumption levels are specified exogenously by target levels and by a penalty for deviating from these levels. The target levels are specified exogenously by incrementing the target level by the same amount as the change in production. (Production is linked to exogenously-stated timber harvest levels.) The penalty function is mathematically derived so that it is actually implemented as a demand curve.

3.2 Theoretical Evaluation of the Demand Curve Specification

3.2.1 Comparison of Demand Curve Methodology with Use-factor Approach

The IIASA methodology is similar to the use-factor approach to modeling forest products demand. Due primarily to statistical problems associated with traditional demand estimation, the use-factor approach is considered to be state-of-the-art modeling technique in forest products sector modeling (Cardellichio and Veltkamp, 1981; Cardellichio and Binkley, 1984; Spelter, 1985). To compare these approaches, let:

Q = total lumber consumption in housing
H = housing starts
UF = use factor, consumption divided by starts

so, by definition, Q is simply the product of UF and H.

We may write the demand curve as a function of price as follows:

$$Q = (a + b P) H \quad , \quad b < 0$$

so the elasticity of lumber consumption with respect to housing is 1.0.

Now solve for the inverse demand curve:

$$P = - (a/b) + (1/b)(1/H) Q \qquad 3.8$$

which is in precisely the same form as equations 3.4 and 3.7. The intercept of the inverse demand curve is fixed on the price axis, and a shift in housing alters the slope of the demand curve. Housing in any period can be defined as ($H_0\ e^{uT}$) so that the comparability between demand curve shifts is clear.

3.2.2 Omission of Cross-price Elasticities

The only price term included in the GTM demand functions is the own price of the commodity in question. Cross-price elasticities were intentionally omitted by the Forest Sector Project team, "primarily due to lack of data and time." Thus, the elasticity of substitution between GTM products is assumed to be zero. There are compelling reasons to believe that this formulation significantly weakens the power of the GTM as a long-run simulation tool.

For discussion purposes, it is useful to distinguish between two types of cross-price elasticities: exogenous and endogenous. An exogenous cross-price elasticity is one in which the price of the competing/complementary good is exogenous to the entire model. In the GTM, including the price of brick in the softwood lumber demand equation would be one example of an exogenous cross-price elasticity. An endogenous cross-price elasticity would require that demand curve shifts be simultaneously determined during the model solution. For example, the price of reconstituted panels might influence the demand for veneer and plywood, and vice versa. It is a relatively simple task to incorporate exogenous cross-price elasticities in the GTM, but extremely difficult to include endogenous cross-price elasticities. One possible shortcut to enrich the demand specification would be to utilize the relationship between lagged endogenous variables; thus, these predetermined prices would effectively act as exogenous variables.

We should note that defining several commodities as a single homogeneous group implies that the individual commodities are perfect substitutes. Veneer and plywood constitutes an important example in the GTM. Because <u>softwood</u> and <u>hardwood</u> plywood are lumped together, the elasticity of substitution between these goods is assumed to be infinite.

3.2.3 Selection of End-Use Indicators

There appear to be two serious problems with the selection of end-use indicators for final products. First, demand is estimated as a function of real income only (population and real income/capita). The demand specification does not adequately represent the varied array of end uses for which wood products are used. This is likely to lead to biased and inconsistent estimates of model parameters.

The second, related problem is that the methodology used to model forest products demand is identical for all final products. In many regions of the world, end-use markets for solid wood are quite different than end-use markets for pulp and paper. Solid wood markets tend to be more closely tied to housing construction and industrial production, while pulp and paper markets are more commonly linked to overall economic activity. Modeling demand growth for solid wood will likely be overstated if tied to overall population growth, rather than say population growth for those in the prime household-forming age groups. These trends are confounded by the interpretation of the technological trend variable in the demand formulation: it is quite high (minus 3%/year) for coniferous sawnwood demand in the developed regions of the world.

3.2.3.1 The Interaction of Population and Income

The conventional use factor for paper consumption is real GDP, real GNP, or some other suitable proxy for national income. However, demand curves in the IIASA model are shifted by the sum of growth in population and income/capita. It is easy to show that these are not equivalent representations and that the IIASA formulation omits the interaction between population and income. That is, the current GTM excludes the income growth of the additional population.

This may be demonstrated by defining the shift factor (growth rate) for national income as follows:

$$(Y_{+1} - Y) / Y = [(Z\ N)_{+1} - (Z\ N)] / (Z\ N) =$$

$$(1 + z)(1 + n) - 1 = z + n + z\,n \qquad 3.9$$

where:

Y = National income

Z = Per capita income

N = Population

z = Growth rate in per capita income

n = Growth rate in population

The first two terms to the right of the last equality in equation 3.9 are included in the GTM formulation, but the third term is omitted.

3.2.4 Demand Curve Linearization

GTM demand curves are estimated in nonlinear (constant-elasticity) form, but incorporated in the model as linear approximations. As long as price projections are very similar to base year levels, this linearization will have minimal effect on simulation results. However, as one moves away from the base year price-quantity equilibria, this approximation will increasingly distort the "correct" solution.

To see the magnitude of this distortion, consider the following example. Rewrite equation 3.3 as:

$$Q = Q_0 (1-b) + b Q_0 (P / P_0) \qquad 3.10$$

The derivative of consumption with respect to price is:

$$dQ / dP = b (Q_0 / P_0)$$

so the demand elasticity is:

$$e = (dQ / dP)(P / Q) = b (Q_0 / P_0)(P / Q) \qquad 3.11$$

Substituting equation 3.10 into 3.11 and solving yields the following expression for the elasticity:

$$e = b P / [(1-b) P_0 + b P] \qquad 3.12$$

It is easy to show that the derivative of this elasticity with respect to price is negative, which is a simple proof that a linear demand curve becomes more elastic as price rises. The implications of this fact are shown in Table 3.2. As the demand curve becomes increasingly elastic at base price-quantity points, demand is choked off at a much faster rate. If the demand elasticity is initially -1.0, demand goes to zero when prices double. It is clear that linear demand curves may significantly understate consumption and price inflation for simulations with rising prices.

Table 3.2 Point Elasticities at Five Prices Along Three Differently-sloped Linear Demand Curves

Price Relative to 1980	Elasticity at Base Price-Quantity for: Curve 1 - 0.5	Curve 2 - 1.0	Curve 3 -2.0
25% Higher	- 0.7	- 1.7	-5.0
50% Higher	- 1.0	- 3.0	approaches minus infinity
75% Higher	- 1.4	- 7.0	
100% Higher	- 2.0	approaches minus infinity	
200% Higher	approaches minus infinity		

3.3 Sensitivity Analysis

Many of the key first-order effects of sensitivity analysis to demand parameters can be deduced from partial derivatives. Consider the change in final product consumption at 1980 prices, or, in effect, the shift in the demand curve. The demand curve is shifted by:

$$\text{shift} = e^{(g\ y + n + d)\ 5t}$$

so we may differentiate this expression to determine the following annual elasticities:

$E(\text{shift},g) = g\ y$

$E(\text{shift},y) = g\ y$

$E(\text{shift},n) = n$

We arrive at the following straightforward conclusions. First, a percentage change in population (or, a 1% error in the projected population growth rate) shifts the demand curve by n percent. Thus, a 20% difference on 5% growth is 1%, whereas a 20% difference on 1% growth is only 0.2%. Second, a percentage change in income growth or income elasticity shifts the demand curve by (g y). Thus, an error in income growth has the most significant impact for high-income growth and high-income elasticity. Third, since the above changes are stated in terms of percentage changes, it should be clear that the absolute value of consumption in the base year is critical in determining the absolute impact. Thus, while errors in projecting income growth will have a more significant percentage impact on plywood consumption in China than in the U.S., the absolute value of the change will be much more significant in the U.S. and thus on world output trends.

Now we perturb some of the key model variables/parameters to determine the full effects (total derivatives) of these variables on the model solution. With respect to demand curve shifts, our focus is on the effect of total shifts, not specifically on population or income per se, so we can manipulate either of these to examine model sensitivity to these shifts. Since the levels of income elasticities appear to be the most controversial, this is the variable/parameter which we choose, but the effects may be generalized to the other demand shifters.

The question of what constitutes reasonable changes in the demand parameters naturally arises. One standard method for arriving at the appropriate range for testing involves direct use of the standard errors used in the original estimation of the parameters. However, these statistical estimates are not readily available. More importantly, such errors are naturally conditional on the premise that the demand model is correctly specified -- an assumption that we may not wish to accept. As a result, we choose our ranges on a fairly ad hoc basis, but make them sufficiently large to encompass a wide range of behavior. We also must beware of nonlinearities in the test procedure, so we make the test at several levels to isolate such effects. It is also important to consider whether to implement these changes as percentage differences, or absolute changes. We choose percentage differences since these are more consistent with the possibilities of errors in the econometric estimates. Finally, there are several decisions to make concerning how to implement these changes over regions and products. We will address this issue in more detail below.

3.3.1 Income Elasticity Simulation Results

We begin by changing the income elasticities used in the GTM. As discussed above, the magnitude of the resulting shifts in the demand curves will vary significantly across products and regions due to differences in initial income elasticities and differences in income/capita growth. Using printing papers as an example, Table 3.3 shows the regional variation in annual demand curve shifts in the BASE CASE (in 1980), highlighting the effects of the different components. Excluding Eastern Europe (where consumption is independent of income), we observe annual total shifts ranging from 2.3% in Canada to 7.5% in Southeast Asia.

Table 3.3 Regional Annual Percentage Demand Curve Shifts by Component for Printing Papers in 1980

GDP/Capita 1980 USD	Region	Population Growth	Income/Cap Growth	Income Elasticity	Total Shift
> 3000	WCA	1.2	0.90	1.2	2.3
	ECA	1.2	0.90	1.2	2.3
	WUS	1.0	1.65	1.2	3.0
	EUS	1.0	1.65	1.2	3.0
	FIN	0.2	2.99	1.2	3.8
	SWE	0.2	2.48	1.2	3.2
	WEU	0.4	2.20	1.2	3.0
	SUN	0.8	3.08	1.2	4.5
	JAP	0.8	3.73	1.2	5.3
	ANZ	1.6	1.88	1.2	3.9
1500-3000	BRA	2.2	2.77	1.3	5.8
	CHI	2.5	1.67	1.3	4.7
	RLA	2.4	1.67	1.3	4.6
	EEU	0.8	3.20	1.3	0.8
750-1500	SEA	2.5	3.82	1.3	7.5
< 750	AFR	2.9	0.73	1.3	3.9
	KIN	1.2	4.35	1.3	4.0
	RWO	2.3	3.38	1.3	4.5

We have simulated the GTM with income elasticities for all final products (except Fuelwood) set 50% and 100% lower than in the BASE CASE, and increased by the same percentages. Obviously, the largest (smallest) shifts in demand curves will occur in the regions where the income effect (income elasticity multiplied by income/capita growth) is largest (smallest). Table 3.4 presents the printing paper demand curve shifts for 100% changes (both decreased and increased) in the income elasticities. As in Table 3.3, the largest demand shift is in Southeast Asia; however, the smallest shift is in Africa, not Canada, because the demand curve shift in Africa is dominated by population growth, rather than the income effect (again ignoring Eastern Europe). The demand curve shifts also give rise to two important observations concerning the importance of exponential growth. First, we observe the sheer magnitude of the changes when annual percentages are compounded over time. For example, the demand curve for Southeast Asia shifts out 265% from the BASE CASE position in only four periods. Second, we observe that a 100% increase in the income elasticity causes a much larger shift in the demand curve than a 100% decrease as a result of compounding; furthermore, the imbalance is exaggerated in regions with more rapid growth.

Now consider changes in printing paper consumption that result from these demand curve shifts. The most obvious result is that, in general, the percentage changes in consumption are very similar to the percentage changes in demand. There are two key reasons for this result. First, printing paper demand curves are very inelastic (see Table 3.1). Second, most of the cost of producing printing paper is fixed over the different scenarios. Only the wood portion of production costs is variable in the model. In the BASE CASE in 2000, wood costs account for only 15% of total printing paper cost for the newest technology in the Western U.S. Contrast these figures with those for coniferous sawnwood: the demand elasticity is -0.5 for the 10 wealthiest regions (2.5 times more elastic than printing papers) and wood costs account for 43% of total costs for the newest technology in the Western U.S. in 2000. The shift in Western U.S. coniferous sawnwood demand is reduced 20% when the income elasticity is reduced 100%, but consumption falls only 11%. Western U.S. demand increases 57% when the income elasticity is doubled, but consumption rises only 11%. Returning to the printing papers case, Africa provides one example of a dramatic income response. In Africa the demand elasticity is -1.2. The combination of this high elasticity with tight wood supplies results in significantly reduced printing paper consumption.

The results for the centrally-planned economies stand out as anomalies so the economic behavior of these regions deserves special attention. First, Soviet consumption responds to demand curves shifts in the opposite manner as in other regions. In the GTM, Soviet production is fixed by the level of timber removals. Consumption levels depend on price, and when prices rise around the world, the Soviets alter their trading patterns to obtain a more favorable balance of trade. As a result, imports, and hence consumption, decline. Second, income has no effect on the level of consumption in Eastern Europe. Finally, in China, the increase in printing paper consumption almost exactly equals the increase in demand. Chinese capacity increases by the same amount as demand. Product prices are not cost-determined for the centrally-planned economies; rather, they depend on the value of products produced by their trading partners. When trade is not viable (as in this case), prices remain essentially unchanged.

Table 3.4 Percentage Changes in Printing Paper Demand, Consumption, and Prices Relative to the BASE CASE in 2000 Due to Income Elasticity Changes

	100% Reduction in Income Elasticities			100% Increase in Income Elasticities		
Region	Demand	Consumption	Price	Demand	Consumption	Price
WCA	-19	-18	-5	23	18	20
ECA	-19	-17	-7	23	18	17
WUS	-30	-29	-7	43	38	19
EUS	-30	-29	-6	43	39	15
BRA	-49	-48	-4	96	88	16
CHI	-34	-33	-8	52	48	10
RLA	-35	-33	-8	53	48	13
FIN	-46	-45	-7	85	79	17
SWE	-40	-39	-7	66	61	15
WEU	-38	-37	-6	62	56	16
SUN	-50	1	-7	98	-3	18
EEU	0	0	-6	0	0	13
AFR	-17	-2	-8	21	-16	13
KIN	-43	-43	0	76	75	0
JAP	-53	-52	-5	111	104	16
SEA	-62	-62	-2	265	140	26
ANZ	-34	-32	-10	50	43	21
RWO	-35	-32	-3	54	4	15

All of the price changes associated with these demand curve shifts are in a fairly similar range, due to the opportunity to trade. Trade between regions insures that prices do not deviate by more than transportation costs between those regions (unless there are binding production and/or trade constraints). The most striking individual effect is that Chinese prices do not change as a result of the demand increases. As discussed above, this results from the special price formulation used for the centrally-planned economies.

We should also mention that production changes exhibit wide variation among regions. In spite of the price increases, some regions even reduce production from BASE CASE levels. This results from upward shifts in supply curves, due to raw and intermediate material price increases that are caused by the increased production of other, more profitable commodities.

Next, we move from the specific case of printing paper to more general considerations of the effects of these income elasticity changes. For each commodity we compute the percentage changes in world output (consumption and production are equivalent at the global level, thus we use the term output), prices (weighted-average price changes, weighted by BASE CASE production), and trade (again, exports and imports are equivalent at the global level). These results are reported for 100% changes in income elasticities in Table 3.5.

The output results differ radically across commodities within the solid wood products group. For example, when the income elasticity for all final products is increased 100%, world output of veneer and plywood increases 60%, world output of coniferous sawnwood increases only 13%, and world output of nonconiferous sawnwood falls 2%. The competing derived demand for sawlogs is the crucial factor behind these divergent trends. As the demand for these three products increases, the increased demand for sawlogs drives up sawlog prices. Note that the increase in coniferous sawlog and nonconiferous sawlog output is about the same, but coniferous log prices rise at a much faster rate. The resulting higher costs of production reduce the quantity of each commodity demanded.

There are two principal reasons we observe the large differences in solid wood products output. First, the demand curves for veneer and plywood shift out most rapidly because the initial income elasticities start from a higher base. The additional shift in the aggregate demand curve (weighted by 1980 consumption in each region) is 172% for veneer and plywood, 129% for coniferous sawnwood, and 75% for nonconiferous sawnwood. Second, the aggregate demand curve for nonconiferous sawnwood is most elastic, followed by coniferous sawnwood, and veneer and plywood. The differences in the 1980 elasticities at base price-quantities are accentuated by the BASE CASE price trajectories. Between 1980 and 2000, world nonconiferous sawnwood prices rise 21%, while coniferous sawnwood and veneer and plywood prices fall 6%. As discussed earlier, the linearization of the demand curves results in sharply higher elasticities for nonconiferous sawnwood than those initially stated in the model.*

Finally, note that the price increase for veneer and plywood is less than for either coniferous sawnwood or nonconiferous sawnwood. The net wood cost for a cubic meter of veneer and plywood is a much smaller share of total cost than the net wood cost for a cubic meter of sawnwood (20-25% compared to 40-50%). As a result, wood cost increases drive up sawnwood prices (and hence reduce demand) more rapidly than for panel products.

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* We have demonstrated how the demand elasticities contribute to this phenomenon by setting the nonconiferous sawnwood demand curve elasticities to -0.5 for all regions. In this scenario, we observe simultaneous increases in world production of coniferous sawnwood, veneer and plywood, and nonconiferous sawnwood.

The interpretation of regional consumption and production trends is significantly complicated by the fact that coniferous and nonconiferous veneer and plywood are aggregated in the GTM. As a result of this aggregation, increased demand for veneer and plywood increases both nonconiferous and coniferous sawlog demand; however, because the mix of species differs across regions the price effects will differ as well. Thus, while world consumption of coniferous sawnwood and veneer and plywood increase, some regions decrease their consumption of coniferous sawnwood. At the same time, production of both coniferous sawnwood and veneer and plywood falls in some regions.

Trade generally tends to show significant increases due to higher levels of world demand. This is consistent with BASE CASE results in which we observe increased trade over time. The only exception is veneer and plywood. Veneer and plywood imports in the Eastern U.S. (which account for 65% of world veneer and plywood trade in 2000 in the BASE CASE) decrease substantially, as wood shortages are filled by coniferous sawnwood imports from Eastern Canada. The Western U.S., the previous supply source for Eastern U.S. veneer and plywood, ships greater volumes of coniferous logs to Japan due to rapid price increases in that region.

Commodities within the paper and paperboard products group behave reasonably consistently. The 100% increase (decrease) in income elasticities causes the largest increase (decrease) in printing paper output: income elasticities for printing paper in the developed countries are much higher than for other paper products. As shown in the previous discussion of printing paper, consumption increases generally keep pace with demand due to the inelastic demand curves and low share of wood costs in final product prices. Low wood cost share explains why the increases in paper and paperboard prices are small relative to the rapid inflation in pulpwood costs. The explosion in household and sanitary paper trade is due to a modest increase in Japanese and Chinese imports coupled with minimal trade in this paper grade in the BASE CASE solution.

Raw material prices rise and fall dramatically due to changes in consumption and harvest levels. Coniferous log prices rise 144% due to a 15% production increase, while nonconiferous log prices rise 52% with a 17% production gain. The increase in solid wood products production significantly increases the production of mill residues (19% for coniferous residues and 32% for nonconiferous), but the additional demands for standing pulpwood timber are still substantial. The increase in coniferous roundwood pulpwood consumption is 27%, resulting in a 179% increase in prices. The increase in nonconiferous roundwood pulpwood consumption is 34%, causing a 161% price rise.

In part, these relationships reflect both the steepness of the wood supply curves and the cumulative effects of pasts harvests. (The rationale underlying the slope of these wood supply curves will be discussed in Section 5.) However, there also are important harvest constraints (particularly in the case of coniferous sawlogs) that contribute to this price surge. Approximately one-third of worldwide coniferous sawlog production operates on a perfectly inelastic supply curve in 2000. The regions involved include Brazil, Chile, the Soviet Union, Eastern Europe, and Australia-New Zealand. A second factor, though much less important, is that some sawlogs are harvested for pulpwood: thus, they affect price inflation, but are not included in the sawlog production figures.

Table 3.5 Percentage Changes in World Product Output, Prices, and Trade Relative to the BASE CASE in 2000 Due to Income Elasticity Changes

	100% Reduction in Income Elasticities			100% Increase in Income Elasticities		
	Output	Price	Trade	Output	Price	Trade
Solid Wood Products:						
CSAW	-23	-20	-40	13	48	64
NSAW	- 4	-17	-12	- 2	23	9
VEPY	-36	-15	-20	60	20	-49
BOAR	-24	-14	-48	28	30	43
Paper and Paperboard:						
NEWS	-17	-12	-17	13	24	28
PRNT	-33	- 5	-37	50	15	20
HHSP	-21	- 7	- 5	27	16	265
PACK	-20	- 9	- 5	24	21	1
Intermediate Products:						
RCYC	-25	- 6	30	32	4	141
CWIP	-22	-23	-34	29	54	40
NWIP	-32	- 6	-45	51	29	97
Raw Materials:						
CLOG	-24	-61	-84	15	144	67
NLOG	-12	-31	-58	17	52	92
CPWD	-20	-58	-14	24	179	66
NPWD	-27	-20	-61	33	161	61

The model dynamics associated with income elasticity changes are very complex due to the extensive interaction of commodities. To isolate these effects, we now change the income elasticities for only a subset of commodities. The first exercise is to double the income elasticities for solid wood products only. As a further refinement of this test, we double the income elasticity for sawnwood only: this removes the confounding effect of reconstituted panels and paper products competing for the same raw material, and veneer and plywood competing for sawlogs.

Increasing the income elasticities for solid wood increases world consumption/production of all solid wood products in 1985, and drives up sawlog prices. This increased production results in a significant increase in manufacturing residues. The increase in reconstituted panel demand for residues is not sufficient to absorb the increased chip production, so pulpwood prices initially fall. Paper and paperboard consumption increases as a result, as does the consumption of intermediate products and raw materials.

In the longer term (by 2000), all raw material prices rise higher than the BASE CASE. (See Table 3.6.) Two factors cause the increase in pulpwood prices. One is that in the BASE CASE there is direct competition for sawlog and pulpwood in some regions (most importantly Western Canada), and the increased sawlog price reduces the production of pulpwood from large trees. The second factor is that the increased harvest of large trees reduces the inventory of standing timber, thus shifting in the supply curves for all timber. The increase in pulpwood prices reduces world output of paper and paperboard and their use of intermediate products. However, in spite of the increased sawlog prices, the outward shifts in demand cause higher world output of coniferous sawnwood, veneer and plywood, and reconstituted panels. (Note that the gain in reconstituted panel products is significantly higher than that shown in Table 3.5, 44% versus 28%, since paper and paperboard production is much lower than in the previous scenario.) As before, nonconiferous sawnwood output is the exception and still does not increase with higher levels of demand. The increased price of nonconiferous sawlogs (due to panel production), and the high elasticity of nonconiferous sawnwood demand curves force this reduction.

The case in which we double the income elasticities for sawnwood only demonstrates two important differences with the above scenario. First, since reconstituted panel demand does not increase, the increased surplus of mill residues drives pulpwood prices down to a much greater degree, so that by 2000 paper and paperboard costs (and prices) are still lower than in the BASE CASE and world output has increased. (Note that reconstituted panel production behaves in the same manner as paper, but the impacts are larger due to the higher share of wood costs in total production costs.) Second, since the demand for sawlogs for veneer and plywood does not increase, we observe increased output of both coniferous and nonconiferous sawnwood. Now the resulting sawlog price increases reduce world output of veneer and plywood.

Table 3.6 Percentage Changes in World Product Output and Prices Relative to the BASE CASE in 2000 Due to Increasing Solid Wood and Sawnwood Income Elasticities 100%

	Solid Wood Only		Sawnwood Only	
	Output	Price	Output	Price
Solid Wood Products:				
CSAW	16.6	43.7	20.7	39.6
NSAW	- 5.8	26.1	9.8	15.9
VEPY	58.4	22.4	- 6.1	15.9
BOAR	44.0	7.6	0.9	- 2.4
Paper and Paperboard:				
NEWS	- 1.8	3.9	0.3	- 0.7
PRNT	- 0.2	0.9	0.2	- 0.5
HHSP	- 0.3	2.0	0.1	- 0.4
PACK	- 0.5	2.6	0.1	- 0.6
Intermediate:				
RCYC	- 0.9	- 0.6	- 0.1	- 0.4
CWIP	- 0.2	8.5	0.6	- 0.3
NWIP	- 0.5	0.8	0	- 1.6
Raw Materials:				
CLOG	17.0	108.3	14.4	91.9
NLOG	14.7	45.9	8.3	24.7
CPWD	5.2	30.9	0	- 3.7
NPWD	13.8	12.0	0.4	-10.9

We observe much the opposite in terms of model dynamics when we increase only the income elasticities for paper and paperboard. (See Table 3.7.) Whereas increases in solid wood production have a tendency to cause increases in paper and paperboard consumption in the near term (by depressing chip prices), increases in paper and paperboard production tend to cause increases in solid wood products consumption (excluding reconstituted panels) by boosting the value of mill residues, thus lowering lumber and plywood prices. These cost reductions offset the increased cost of sawlogs resulting from higher production levels.

In the longer term (by 2000), we observe the effects of the highly inelastic supply of coniferous pulpwood logs. The rapid increases in pulpwood log prices make coniferous pulpwood log and coniferous sawlog prices the same in most regions of the world. Thus, pulp mills effectively bid away coniferous sawlogs from lumber and plywood mills, and lumber and plywood production decrease. A less important effect is that timber supply curves also are shifting in due to the increase in overall harvest levels. Pulpwood scarcity is not as important on the nonconiferous side, so nonconiferous sawnwood output stays above BASE CASE levels even by 2000. One should also note the sharp reduction in reconstituted panel production as a result of the rising cost of pulpwood.

The impact of increasing only printing paper demand is generally quite similar as in the previous case, but the effects are significantly moderated. However, the one additional effect worth noting is that world output of other paper and paperboard products decrease as a result of the higher cost of wood fiber.

Table 3.7 Percentage Changes in World Product Output and Prices Relative to the BASE CASE in 2000 Due to Increasing Paper and Paperboard and Printing Paper Income Elasticities 100%

	Paper and Paperboard Only		Printing Paper Only	
	Output	Price	Output	Price
Solid Wood Products:				
CSAW	- 4.7	9.0	- 1.1	2.2
NSAW	1.9	- 1.1	1.7	- 1.1
VEPY	- 0.1	0.8	0.4	- 0.8
BOAR	- 7.9	16.9	- 4.1	8.4
Paper and Paperboard:				
NEWS	19.6	13.4	- 2.6	5.5
PRNT	52.0	10.8	53.6	7.0
HHSP	28.2	10.3	- 0.7	4.1
PACK	26.2	13.3	- 1.2	5.7
Intermediate:				
RCYC	33.2	6.2	6.9	- 2.1
CWIP	31.7	26.9	20.7	12.3
NWIP	53.1	27.6	47.5	21.1
Raw Materials:				
CLOG	- 4.7	41.7	- 1.0	14.7
NLOG	1.9	8.4	1.1	4.9
CPWD	22.9	92.6	9.0	27.1
NPWD	27.7	147.4	20.6	107.5

Our discussion of demand curve shifts would not be complete without explicit consideration of the technological trend variable associated with coniferous sawnwood. In the GTM, coniferous sawnwood demand shifts in 3% per year due to the technological trend variable in regions where GDP/capita exceeds USD 3000 in 1980. Obviously, this suppresses coniferous sawnwood demand dramatically. In 20 years, demand curves shift inward 81%, and in 30 years the technology factor causes a 143% shift.

There are three primary effects of removing this technological trend variable. The first shock to the model is that world output and prices of coniferous sawnwood and coniferous logs rise dramatically. There also is a substantial increase in trade for two reasons. First, producers in the less wealthy nations of the world reduce their coniferous sawnwood consumption and take advantage of more lucrative export opportunities. Second, and more importantly, there is a significant realignment of trade among the developed regions. The Western U.S. reduces production of coniferous sawnwood (and veneer and plywood) and increases coniferous sawlog shipments to Japan. Western Canada loses share of the Japanese coniferous sawnwood market, but ships the lost volume plus a good deal more to the Eastern U.S.* By 2000, world coniferous sawnwood output increases 21%, prices increase 30%, and trade increases 65% over BASE CASE levels. Coniferous log output increases 16%, prices rise 75%, and trade increases 98% compared with the BASE CASE.

The next most significant impacts are on the veneer and plywood sector. The increased cost of coniferous logs increases the cost of veneer and plywood production in regions which are heavily dependent on coniferous sawlogs. Higher-cost sawlogs in the Western U.S. reduce veneer and plywood production (as mentioned above) and cause loss of market share in the Eastern U.S. (Since the Eastern U.S. is able to import much of their expanded coniferous sawnwood requirements from Western Canada, their own production of veneer and plywood increases substantially.) Regions which are heavily dependent on nonconiferous logs for veneer and plywood (particularly Japan and Southeast Asia) expand production and replace more expensive imports or ship these panels to the "higher-cost" regions. Thus, veneer and plywood prices rise in all regions, and veneer and plywood consumption falls. Total trade decreases because of the new pattern of shipments in North America. It should be emphasized that these changes are due to the assumption that coniferous and nonconiferous veneer and plywood are perfect substitutes.

The next set of effects are somewhat minor and mixed across regions. Increased "nonconiferous" panel production raises the cost of manufacturing nonconiferous sawnwood; thus, nonconiferous sawnwood consumption declines in some regions (especially China, Japan, and Southeast Asia). These effects are small, but noticeable. Softwood pulpwood prices fall in most regions (though some rise where competition

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* Actually, Western Canada ships a large volume of coniferous sawnwood to the Western U.S., where it is then transhipped to the Eastern U.S. The transportation cost, including the tariff, from Western Canada to the Western U.S. is USD 42.5/m^3 and the cost from the Western U.S. to the Eastern U.S. is USD 44.5/m^3 for a total cost from Western Canada to the Eastern U.S. of USD 87.0/m^3. The cost of direct shipment is USD 112.4/m^3.

with sawlogs is tight) due to the increase in coniferous sawnwood production. Hardwood pulpwood prices are basically unchanged: increased "nonconiferous" veneer and plywood production offsets reduced nonconiferous sawnwood production sufficiently to increase nonconiferous residual output; however, this increase is just absorbed by the expansion in paper and paperboard output. As a result of these offsetting influences, the impacts on paper and paperboard output and prices are relatively small. Needless to say, some larger effects may be observed at the individual region level.

Because of the importance of the technological trend "assumption" on the BASE CASE results, we provide two figures contrasting this scenario with the BASE CASE. Figure 3.1 depicts world production of coniferous sawnwood in the BASE CASE and with the technological trend removed. Figure 3.2 shows coniferous sawnwood and coniferous sawlog prices in the two scenarios.

3.3.2 Demand Elasticity Simulation Results

As with the tests concerning the sensitivity of the GTM to the level of income elasticities, we test the demand elasticities by reducing them 50% and 100%, and increasing them by the same amounts.* The most critical determinant of the type of effects one can expect is the price path in the BASE CASE (hence, the effects depend on the underlying supply and demand curve shifts). Obviously, if prices are flat over the forecast horizon, then rotating the demand curve about the equilibrium price will have no impact on the model solution. Generally, if prices are rising, then reducing the elasticity of the demand curve (at the BASE price level) will increase consumption and prices. Conversely, if prices are falling, then a more inelastic demand curve (at the BASE price level) will result in lower consumption and lower prices.

As time horizon increases, the conclusions regarding output results may change depending on adjustments in the timber inventory. Assume prices are rising. If the demand curve is made more inelastic, the timber harvest will increase. If the timber inventory is cut more heavily in the early periods, it is possible that wood costs, and hence product prices, will rise rapidly enough to reduce consumption below BASE CASE levels in the longer term.

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* Adjustments are made to demand curves expressed in USD since this is much easier to implement than adjustments in local currencies. Since the demand curves are established in USD, shifted by demand shifters, and then adjusted by exchange rate changes, the net adjustments will not be exactly 50% or 100%.

Figure 3.1 World Coniferous Sawnwood Production: BASE CASE Compared with the "No Technological Trend" Scenario

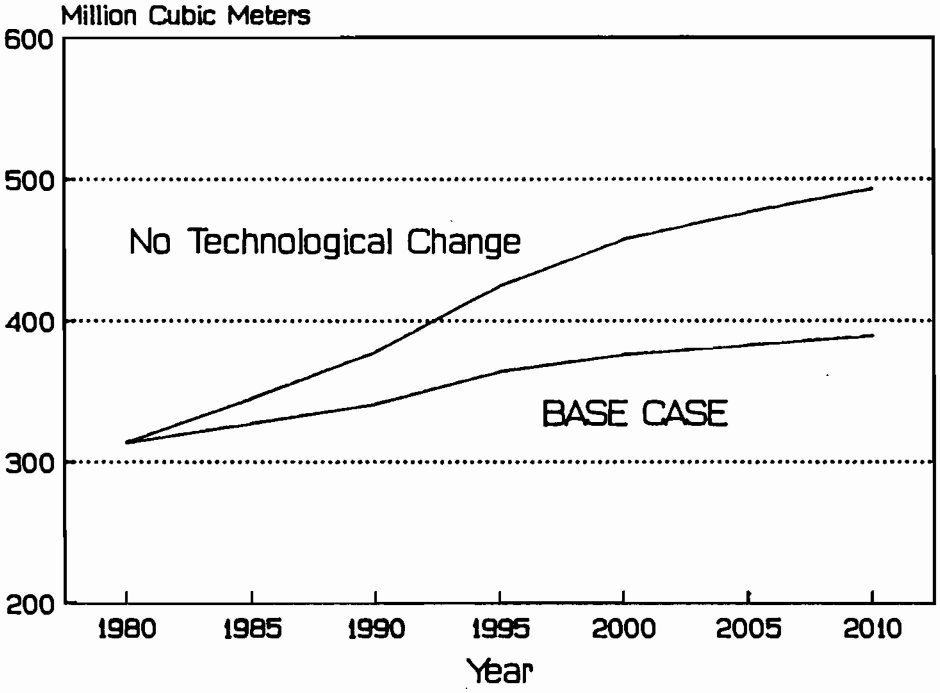
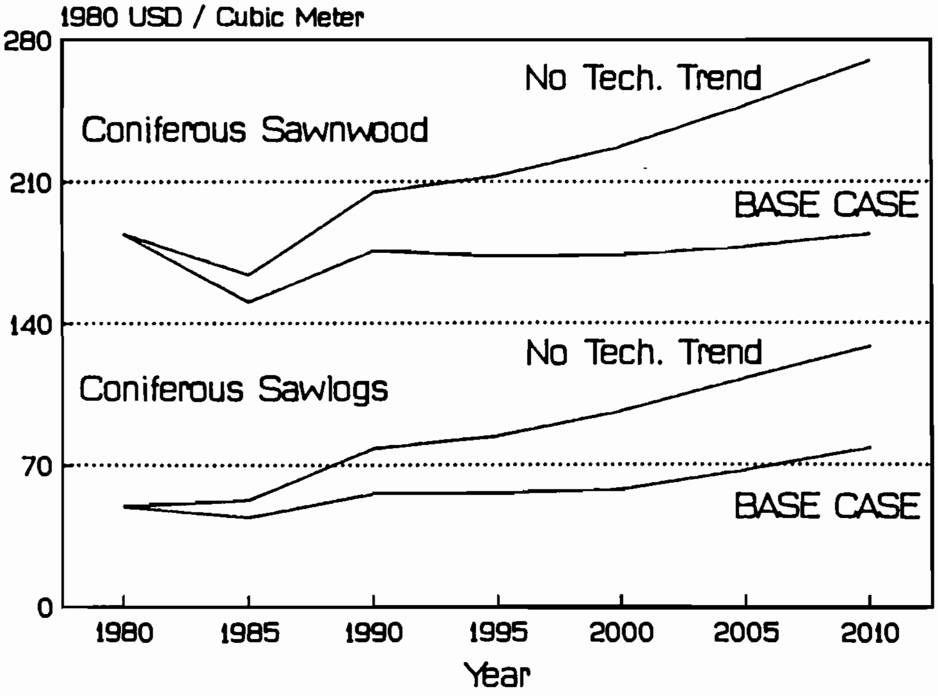


Figure 3.2 World Prices for Coniferous Sawnwood and Coniferous Sawlogs: BASE CASE Compared with the "No Technological Trend" Scenario



In Table 3.8 we present some of the key results of altering the BASE CASE demand elasticities. These are summarized as world impacts. Although they mask many of the adjustments occurring at the regional level, they provide a broad picture of the importance of the demand elasticities and their role in the GTM.

The first column of Table 3.8 shows the percentage change in prices between 1980 and 2000 in the BASE CASE. Comparing this column with column 2, we observe the general result that when prices are rising, making demand less elastic will result in increased consumption. This result is most dramatic for nonconiferous sawnwood, which also has far more elastic BASE CASE demand curves than other final products (for the ten most developed regions of the world). For some commodities, output increases even though prices are falling in the BASE CASE scenario. This apparent contradiction can be explained by the aggregation of regions exhibiting very different price paths and demand elasticities. For example, in the case of coniferous sawnwood, BASE CASE prices rise in five regions between 1980 and 2000. As we might expect, it is these five regions that show consumption increases in the less elastic demand scenario. Three of these regions (Africa, Southeast Asia, and Rest of World) have very high demand elasticities (-1.5). Thus, consumption increases in these regions are substantial and offset the smaller declines in other regions.

Although average world prices for reconstituted panels, newsprint, household and sanitary papers, and packaging papers increase at a fairly similar rate between 1980 and 2000 in the BASE CASE, output increases for household and sanitary papers and packaging papers are relatively modest. The demand curves for these two commodities are very inelastic in the BASE CASE, so a 100% reduction in the elasticity causes a comparatively minor change.

Increases in world output significantly increase the consumption of raw materials. The large jump in nonconiferous sawnwood production greatly increases the availability of mill residues. As a result, these residues, combined with the residues from higher plywood production, depress the price of hardwood pulpwood. The lower cost of hardwood fiber offsets much of the increased cost of softwood fiber, thus dampening price increases for paper and paperboard.

For much the same reasons presented above, increasing the demand elasticities by 100% causes a significant reduction in final product demand. This reduced demand decreases the consumption of intermediate products and raw materials, thus shifting the product supply curve downward. However, the downward shift is not sufficient to offset the consumption reduction, and consumption and prices fall from BASE CASE levels. (See Table 3.8.)

Table 3.8 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to Changing Final Product Demand Elasticities 100%

		100% Reduction in Demand Elasticities		100% Increase in Demand Elasticities	
	BASE CASE Price Change: 1980-2000	Output	Price	Output	Price
		Percent Change from BASE CASE			
Solid Wood Products:					
CSAW	- 5.6	3.4	7.6	- 2.1	- 1.6
NSAW	20.7	44.4	61.0	- 8.1	-10.3
VEPY	- 6.3	1.6	19.9	0.1	- 2.2
BOAR	11.4	8.1	1.8	- 6.4	- 2.4
Paper and Paperboard:					
NEWS	12.6	10.7	5.2	- 8.8	- 2.5
PRNT	- 4.9	3.0	2.8	- 2.6	- 1.0
HHSP	10.2	2.6	1.7	- 2.3	- 1.4
PACK	13.2	4.5	2.6	- 4.2	- 1.5
Intermediate:					
RCYC	8.0	4.6	2.5	- 4.9	- 0.4
CWIP	14.5	3.0	8.2	- 2.2	- 5.5
NWIP	- 7.5	3.3	- 6.5	- 3.5	- 1.7
Raw Materials:					
CLOG	17.0	6.1	27.2	- 2.1	- 5.1
NLOG	79.6	26.8	94.5	- 5.3	-13.9
CPWD	87.0	4.9	20.8	- 3.9	-12.5
NPWD	30.6	5.4	-28.1	- 4.6	-10.2

The effect of changing the demand elasticity for a single commodity or single region is relatively straightforward. For example, the results from making the demand curve for nonconiferous sawnwood less elastic are shown in Table 3.9. Nonconiferous sawnwood consumption rises in all regions, driving up the consumption and prices of nonconiferous sawlogs, and depressing the price of nonconiferous pulpwood. The cost of producing veneer and plywood in regions that are heavily dependent on nonconiferous sawlogs climbs substantially, due to the combined effect of higher sawlog prices and lower residue values. The largest reductions in veneer and plywood production occur in Western Europe, Japan, and Southeast Asia. Veneer and plywood production in the coniferous-dependent regions increases as these regions take advantage of improved market opportunities in the nonconiferous regions of the world (nonconiferous and coniferous veneer and plywood are assumed to be perfect substitutes). The largest gains are observed in the Western U.S., Eastern U.S., and

Finland. Total veneer and plywood trade also increases as the Eastern U.S. and Finland export to Western Europe, and the Western U.S. exports to Japan, partially offsetting a reduction in imports from Southeast Asia.

Coniferous sawlog prices rise in regions that produce "coniferous" veneer and plywood, but fall modestly in some regions that use only small amounts of coniferous wood in otherwise nonconiferous veneer and plywood. On average, coniferous sawnwood prices rise causing a small reduction in world consumption of coniferous sawnwood. There is little change in coniferous pulpwood prices, but the sharp reductions in nonconiferous pulpwood prices reduce paper and paperboard prices modestly and lead to higher consumption levels.

Table 3.9 Percentage Changes in World Output and Prices Relative to BASE CASE in 2000 Due to Reducing Nonconiferous Sawnwood Demand Elasticities 100%

	Output	Price
Solid Wood Products:		
CSAW	- 0.6	0.7
NSAW	44.5	55.8
VEPY	- 5.9	14.0
BOAR	1.1	- 3.0
Paper and Paperboard:		
NEWS	0.2	- 0.3
PRNT	0.4	- 1.0
HHSP	0.1	- 0.5
PACK	0.1	- 0.6
Intermediate:		
RCYC	0.3	- 0.3
CWIP	0.2	- 0.1
NWIP	0.4	- 5.9
Raw Materials:		
CLOG	1.5	5.1
NLOG	24.7	85.8
CPWD	0.1	0.1
NPWD	0.6	-32.4

3.3.3 Some Comments on the Evaluation of the GTM Demand Module

The exercise of increasing/decreasing income and price elasticities provides a great deal of information about the performance of the GTM. Generally, the model is quite sophisticated in its ability to capture many of the complex interactions among forest products. Product competition for raw materials (between sawnwood versus veneer and plywood, and among various grades of paper and paperboard and reconstituted panel products) reflects the detailed, but important characteristics of these markets. Additionally, the impacts of residue values on solid wood products production are incorporated.

The model results are, as one would expect, very sensitive to the parameter settings in the model. When the demand curves for several products are shifted out simultaneously (say, if population projections are revised), the elaborate interdependence of products/regions makes all parameter estimates very important. For example, the change in the plywood sector depends on the parameter estimates for sawnwood. Another example is that coniferous sawnwood demand in Japan will affect coniferous sawnwood exports from Eastern Canada to Western Europe. Thus, parameters of the model which are very uncertain will directly affect the results associated with the parameters for which one has more confidence. The complex structure of error relationships suggests that the demand parameters (and, indeed, all model parameters) must be fully understood by the user to appreciate fully the implications of a specific scenario. The importance of demand parameters also suggests that more sophisticated models of demand (using improved data, and improved methodology) would be a fairly critical development.

While the size and complexity of the GTM provides a researcher with a great deal of analytical power, its size has some important costs. In the above exercises, these costs may be identified as costs of user interpretation. Because of the numerous interactions in the model, it can be extremely difficult to trace and explain all of the impacts of a demand change. This is particularly true due to the number of constraints in the model. An expected result may not occur due to a constraint (for example, a ban on the flow of a commodity between two regions), and this may take a significant amount of time to uncover. However, if one commits the time to digest the information necessary to understand a specific simulation, the results are usually logical and intuitive.

4. PRODUCT SUPPLY

For the market economies, there are three technologies available for producing each product:

old (inefficient) technology
modern (efficient) technology
new technology

Each technology is characterized by a set of conversion coefficients, a capacity constraint, and associated production costs (variable and fixed).

4.1 IIASA Product Supply Curve Methodology

Because of the complexity of the product supply curve formulation, this section merely provides a broad overview of relevant methodology. More detailed comments are provided in the sections on theoretical evaluation and sensitivity analysis.

4.1.1 The Static Formulation

There is an upper bound on production for each technology. The capacity levels for old and modern technologies (and the potential for new capacity) are set prior to the current time step. In contrast, new capacity is "constructed" during the current time step. (No new capacity is permitted in the base year.) The upper bound on new capacity is designed to prevent excess investments in a single product line. Lower bounds are sometimes employed to meet production targets or to incorporate known investments.

Marginal production costs include nonwood costs only. The marginal production costs for <u>new</u> technologies include investment costs since expansion is undertaken only if it is profitable. New technology costs (on a per unit basis) equal:

marginal costs for modern capacity + (0.15 *x* investment cost per unit)

There is an investment budget that constrains the amount of new capacity that may be added in a given period. Maintenance costs are included as a fixed cost and these are deducted from the investment budget. Maintenance costs are proportional to the cost of new capacity using the following percentages:

old capacity, 18.7%
modern capacity, 8.3%

No capacity expansion is allowed in 1980 and the investment budget is set to zero.

Recycled paper production is represented by a single activity. The cost incorporates both the recovery cost and processing cost. The upper bound on production (capacity) is determined by paper consumption in a region and a recovery (recycling) rate. A region may exceed this bound by paying the slack price which is 10% higher than the BASE price. An absolute production limit is set by a slack production bound which is 20% greater than the initial production bound.

4.1.2 Production Dynamics

4.1.2.1 Investments in Productive Capacity

A bound is set for capacity expansion so that new capacity in a single product line cannot be increased by more than a given percentage of existing capacity. This increase is assumed to be 15% annually. Actual increments of new capacity depend on the price level (it must cover variable plus fixed costs) and the strength of demand. Total investment expenditures for all technologies in a region must not exceed the budget constraint.

The budget constraint is established as a percentage of the total value of forest products production in the preceding time step. The percentages -- referred to as capital turnover -- vary by region.

4.1.2.2 Aging of Productive Capacity

Capacity is moved across technologies according to a Markov process. At the beginning of each period, B of old capacity is retired, A of modern capacity becomes old, and all of new capacity becomes modern. Thus, the capacity which remains in each category is:

old capacity = (1-B) x old + A x modern
modern capacity = (1-A) x modern + new

B is assumed to be 1/3 and A equals 1/2 in the current version of the model.

4.1.2.3 Technological Development

Since old and modern technologies in the current period are a mixture of technologies available in the previous step, marginal production costs and conversion factors are computed as weighted averages based on capacity shares.

New technologies are assumed to evolve over time so that technologies (for final and intermediate products) in all regions become equally efficient by 2030. Furthermore, the loss or waste factor for logs will vanish by 2030. Both trends are determined by linear interpolation between 1980 and 2030.

Shares of coniferous and nonconiferous wood used in plywood are assumed to remain constant over time. However, softwood and hardwood (both pulpwood and pulp) shares of reconstituted panel products, paper, and paperboard products do change. Pulpwood (which includes raw materials for composition panels) and pulp coefficients are first computed by linear interpolation between 1980 and 2030. The resultant shares are then modified to shift coniferous input to nonconiferous input -- this factor increases linearly from 0 to 30%.

4.1.2.4 Recycled Paper

By 2030, all regions are assumed to recycle 50% of the paper and paperboard they consume. The trend from 1980 to 2030 is linear.

4.1.2.5 Exchange Rates

All variable production costs are scaled by the real exchange rate. However, the investment costs remain unchanged.

4.2 Theoretical Evaluation of the Product Supply Methodology

4.2.1 Critique of the Step-function Approach

One of our major criticisms of the IIASA methodology is with the step-function approach. Both theoretically and empirically, one would not expect marginal costs to move in discrete jumps, particularly given the length of the steps used in the GTM. The key advantage of such an approach is that one may incorporate a significant amount of a priori information on the production technologies. However, this strength is also a major weakness. The detailed data required for this approach are available only for pulp and paper products. More importantly, since these data were obtained from private sources, it does not appear possible to verify or update these data.

The step-function approach makes it extremely difficult to replicate market behavior because the marginal profit from an additional unit of production is always higher for the product on a lower step. This phenomenon leads to increasing specialization of output within a region. We demonstrate the consequences of the step-function approach in Section 4.3.1.

4.2.2 The Inclusion of Investment Costs for "New" Technologies

The IIASA model is billed as a long-run model, and thus it is critical that prices are sufficiently high to allow producers (or investors) an adequate return on their investment. To accommodate this behavior, the IIASA approach was to include investment costs in the production costs of the newest technology. The newest technology is only implemented when prices cover these total costs.

While this appears to be a sound approach for ensuring that "long-run" prices reflect "long-run" industry equilibrium, there are some problems with this approach. First, the approach is not consistent with base year behavior. Prices and costs in the base year are strictly short-run concepts. Thus, we move from a short-run snapshot, where the industry may be earning excess profits, or losing money, to a long-run solution in 1985. As a result, the 1980 to 1985 price changes are likely to be inconsistent and provide misleading information on price inflation.

Second, this approach is not satisfactory to project price trends through economic cycles. Thus, if demand rises sharply, prices will not respond since capacity constraints will not be binding. On the other hand, if demand declines, prices may fall quickly, as production shifts from the third to second step. Predicted prices depend critically on the model structure and it is unlikely that they will reflect realistic behavior.

Finally, there is an important theoretical question that remains to be addressed. "Short-run" prices are always formed by the intersection of demand and marginal cost. In market model construction, it is the least efficient producer that effectively determines the price faced by all producers. In the current formulation of the GTM, it is the most efficient producer that sets the price, which is governed by total production costs. The current formulation conceals the fact that we understand very little about the cost distribution of producers in many regions of the world. Further analysis of price formulation in the GTM should be conducted and alternatives should be carefully considered.

4.2.3 Known Investments Should be Treated as Sunk Costs

There is a deficiency in the model with respect to its treatment of known investments (also see Section 2.2.1). There are several model entries to accommodate the fact that new mill expansions that would be operational by 1985 were already known or announced by 1983 (particularly for large-scale, high-cost mills with long construction lead times that characterize the pulp and paper sector). Because this additional capacity is treated as new capacity, the industry is required to pay the capital costs associated with its construction. As a result, it is the highest-cost segment of the market, when it should be treated as the lowest cost, since the cost of construction is already sunk. This leads to perverse behavior in the model. In the 1985 solution, we find regions forced to produce with the "high-cost" third technology, while the lower-cost old capacity (which has already been paid for and thus excludes capital cost) may be underutilized.

4.2.4 Capacity Aging is Arbitrary

While it is necessary to retire capacity over time, the Markov process imbedded in the IIASA model is rather arbitrary. A more realistic representation would account for the fact that a great deal of capacity is maintained and modernized, and not actually "retired." This has important implications for pricing behavior. It would also help to rectify the problem of product specialization, which could be partially resolved by slowing the process of retirement of unprofitable capacity.

4.2.5 Technology Transfer and Adoption

There is probably no "best" way to include technological change in a long-run market model. The IIASA model, however, includes some key assumptions that make the operation of the model fairly rigid, as well as unrealistic. These assumptions pertain to technological uniformity and the attainment of long-run equilibrium.

The first of these assumptions is that the technology for an individual product will adjust to a single uniform target in all regions. This assumption implies rapid technological change in some regions, but very moderate technological improvement (and even technological regress) in other regions.

Second, the model incorporates the unlikely assumption that log loss or waste (wood not consumed as product or usable residues) in the manufacture of sawnwood and veneer and plywood will reach zero by 2030.

Third, there is a significant shift from softwoods to hardwoods in the pulpwood and pulp furnish in all regions. This shift should depend on the relative scarcity of these resources in individual regions. One must consider the availability of both mill byproducts and roundwood in determining these shares.

Fourth, it is assumed that all regions will reach 50% paper and paperboard recovery by 2030. Some regions are already approaching this level, while others recycle less than 20% of their paper and paperboard consumption.

4.2.6 Recycled Paper

The treatment of recycled paper in the GTM is naive, and relies heavily on the use of slack resources. A detailed review of this sector is provided in Section 4.3.2.4.

4.3 Sensitivity Analysis

There are a variety of possibilities for conducting sensitivity analysis of the production supply module because of the large number of structural elements that characterize the supply formulation. A fair amount of programming was required to conduct several of these tests, for example, to introduce variation in the long-term technology targets.

The sensitivity analysis proceeds as follows. Section 4.3.1 examines how the horizontal-step function approach influences the simulation results of the GTM. Section 4.3.2 considers the role of the assumption of identical long-run technology targets, and presents several simulations that focus on each of the major technological components. Section 4.3.3 addressed the procedure for adjusting capacity levels over time.

4.3.1 Horizontal-step Functions and Fixed Proportions in Resource Use

The horizontal-step function formulation for product supply combined with fixed proportions in resource use causes regions to specialize in the production (and export) of particular commodities. As a result, the product mix in different regions and the associated pattern of trade can differ substantially from historical patterns. The intuition for this phenomenon is as follows. Suppose a region produces two products from the same raw material, and the marginal cost curve for each is horizontal. An increase in the production of either product will drive up raw material costs and both curves will shift upward, the relative shift depending on their relative use of the raw material. Assume the region is a resource-abundant region and that it must export "wood" to deficit regions. It will produce the relatively low-cost item first. The relatively high-cost item will not be produced until the demand for the relative low-cost item is met, or other constraints (on production capacity or trade) are binding.

We can cite numerous simulation results that demonstrate this feature of the product supply specification. First we show how this behavior affects the BASE CASE results, utilizing an obvious example concerning sawnwood and plywood production in the U.S. From the historical period to 2000, coniferous sawnwood imports in the U.S. East fall from 36.6 to 3.6 mm m^3, while U.S. East production rises from 18.5 to 47.8 mm m^3. However, the U.S. East is unable to satisfy it huge "home" demand for both sawnwood <u>and</u> plywood: veneer and plywood production remains essentially stable, while imports increase from 6.3 to 17.7 mm m^3 (virtually all from the U.S. West). Over this same period, U.S. West coniferous sawnwood production falls from 32.7 to 12.9 mm m^3, while veneer and plywood production rises from 7.9 to 26.3 mm m^3. (Incidentally, this projection is inconsistent with all known projections, both public and private, of future production trends in this region.)

In a simulation in which we increase the volume of sawlogs needed to make one cubic meter of veneer and plywood in the U.S. West from 1.8 to 2.2 m^3, we observe the following changes between 1980 and 2000: 1) U.S. East coniferous sawnwood imports fall from 36.6 to 18.0 mm m^3, while U.S. East production increases from 18.5 to 31.6 mm m^3; 2) U.S. East veneer and plywood imports fall from 6.3 to 0.6 mm m^3, while production increases from 8.6 to 24.7 mm m^3; and, 3) U.S. West coniferous sawnwood production falls from 32.7 to 25.8 mm m^3, and veneer and plywood production declines from 7.9 to 7.4 mm m^3. It should be noted that we can produce similar results by altering any cost component of the product supply curve. For example, we obtain virtually identical results by increasing the nonwood cost of veneer and plywood production in the U.S. West by USD $20/m^3$, a figure well within our confidence limits of regional cost differences. As a result of the supply curve specification, the production projections for each commodity are very labile and can be easily reversed with minor changes in cost-related parameters.

4.3.2 The Role of Uniform Technology Targets

Section 4.3.2.1 provides a broad overview of the role of uniform technology targets by presenting a scenario in which all new technology targets are held at their 1980 levels. Sections 4.3.2.2 to 4.3.2.4 delve into some of the important components of technological evolution.

4.3.2.1 Technology Targets for Input-Output Coefficients

The GTM assumes that all input-output coefficients converge to a single target level in 2030. We have simulated the GTM assuming that new technology targets do not change over time. This modification introduces some key differences into this scenario when compared to the BASE CASE: 1) technology targets will vary by region according to their initial conditions; 2) wood (and pulp) use will not undergo the radical improvement observed in the BASE CASE; 3) wood residue generation and waste remain at BASE CASE levels; and, 4) coniferous-nonconiferous shares remain unchanged. Two special features of this simulation should be noted. First, only new technology targets are directly modified; thus, old and modern technologies will still improve as capacity in the new technology is "depreciated." Second, although this scenario generally implies that technologies will not improve as rapidly as in the BASE CASE, there are exceptions. For example, Japan produces coniferous sawnwood extremely efficiently in 1980 and it retains this high level of efficiency in this scenario, rather than regressing toward the industry average as in the BASE CASE.

The expected results of this scenario are straightforward, but as usual they are greatly complicated by the number of regions and products involved. In general, we would expect that prices for final products will be driven higher by less efficient resource use; however, this conclusion must be modified to account for reductions in nonconiferous pulpwood use (and associated reductions in nonconiferous pulpwood prices).

Impacts on output and prices at the world level in 2000 are summarized in Table 4.1. The increased utilization of coniferous sawlogs in sawnwood and plywood production drives up coniferous sawlog prices (and hence coniferous sawnwood and plywood prices) and reduces the consumption of coniferous sawnwood and plywood. The increased utilization of coniferous pulpwood in paper and reconstituted panel products drives up coniferous pulpwood prices. The increased demand for coniferous pulpwood is quite drastic because of the combined effect of: 1) retarding technological improvement in the manufacturing process; 2) failing to substitute nonconiferous pulpwood and recycled paper for coniferous inputs; and, 3) the reduction in the availability of residues due to lower sawlog harvest levels, and lower sawnwood and plywood manufacturing levels. Hence, by 2000, coniferous pulpwood production is 10.3% higher than in the BASE CASE, and coniferous pulpwood prices are 22% higher. One of the apparent anomalies of this scenario is that coniferous log production falls in spite of the fact that sawlogs are more poorly utilized in manufacturing sawnwood and plywood. The reason for this behavior is that demand and prices rise more rapidly for coniferous pulpwood than sawlogs. As a result, pulpwood and sawlog prices equilibrate in several regions and a significant volume of sawlogs (56.4 mm m^3) are downgraded to pulpwood -- the major reclassifications occur in Western Canada, Eastern Canada, China, and Australia-New Zealand.

Nonconiferous pulpwood production falls dramatically since it is not used as a substitute for coniferous pulpwood, and price decreases reflect this change. Nonconiferous sawlog output and prices also fall though the changes are fairly small. There are two primary reasons for these changes: 1) nonconiferous sawnwood production falls due to reduced profitability from the reduction in residue prices -- the fact that final demand is highly elastic means that only small price increases reduce consumption; and, 2) higher prices for coniferous sawlogs increase the cost of manufacturing plywood, reduce the demand for plywood, and reduce the demand for nonconiferous sawlogs used in plywood manufacture.

Some of the regional effects are particularly interesting. In the BASE CASE, some regions employ very inefficient technologies in 1980 and improve rapidly to reach the uniform world target by 2030. On the other hand, some regions are close to (or even beyond) the optimal level of efficiency in 1980, and thus these regions will improve very little (or even regress) over the forecast horizon. Thus, regional shifts will be based on relative changes in technological efficiency among producing regions.

For example, although Japan is an extremely efficient sawnwood producer and remains so in this scenario, it is also a fairly efficient plywood producer. At the same time, Southeast Asia (an important Japanese trading partner) is an inefficient producer of plywood. As a result, Japan increases its production of plywood, and reduces sawnwood production relative to the BASE CASE. Similar types of shifts can be observed among the North American regions, and Western European regions.

Table 4.1 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to Holding New Technology Coefficients Constant Over the Forecast Horizon

	Output	Price
Solid Wood Products:		
CSAW	- 2.3	3.8
NSAW	- 5.7	3.7
VEPY	- 0.9	2.8
BOAR	- 0.8	0.5
Paper and Paperboard:		
NEWS	- 1.4	2.2
PRNT	- 0.4	1.1
HHSP	- 7.1	7.4
PACK	- 0.7	3.6
Intermediate Products:		
RCYC	-13.3	- 7.4
CWIP	9.3	9.5
NWIP	- 7.9	- 4.4
Raw Materials:		
CLOG	- 0.6	13.0
NLOG	- 0.1	- 1.7
CPWD	10.3	22.0
NPWD	-12.0	-25.4

4.3.2.2 Wood Waste

For certain products described by the GTM, it is possible to determine the amount of wood loss in the manufacturing process because wood inputs and wood output are measured in comparable units. For example, if Y m^3 of sawlogs are required to yield 1 m^3 of sawnwood and X m^3 of residue, then wood waste (WW) equals Y - 1 - X. The calculation of a loss factor is possible for those products using sawlogs (rather than pulpwood) as a primary input, and include coniferous sawnwood, nonconiferous sawnwood, and veneer and plywood.

The GTM BASE CASE assumes that the loss factor goes to zero (no wood is wasted) by the target year. Here we present the results of two alternative scenarios, one in which we assume that the loss factor changes by only 50%, and one in which we assume that wood waste is unchanged (100% of base year levels).

We begin by describing our procedure for defining and determining the level of wood waste. Wood waste applies only to solid wood products so we measure total use as the sum of sawlog inputs. The total amount of material made consists of two components: 1) the product itself which is normalized to 1.0 unit; and, 2) the total amount of byproduct (residue) which is used as pulpwood or fuelwood. The volume which remains (total use less total make) is classified as wood waste.

We have implemented a procedure to alter wood waste over time. When we specify zero wood waste (WW = 0.00), all sawlog input is converted to product and usable residue. When WW is set to 1.00, then the same percentage of wood that is wasted in the base year will be wasted in the target year. The percentage is linked to the amount of wood not used directly in the product. For example, assume that 1.80 sawlogs are used to manufacture sawnwood in the base year, and that 0.50 units of pulpwood and 0.10 units of fuelwood are produced. In this case, 0.20 units of waste are generated, or waste is equivalent to 25% of "excess" input (0.20/0.80). If the target input is 1.50 and waste is set to 1.00, then we compute the following targets: 1.00 units of product, 0.375 units of byproduct, and 0.125 units of waste. Thus, the volume of sawlog not used directly as product is apportioned between usable byproduct and waste. This scheme is designed to ensure that enough material is available to produce a full unit of product in the target year. Calculation of the absolute volume of waste or linking the percentage waste to total sawlog input could lead to cases where, say, the target sawlog input is 1.50, but the waste "requirement" is 0.60.

By reducing the amount of usable residues produced in the manufacture of lumber and plywood, these scenarios have the effect of shifting product supply curves upward -- lumber and plywood curves shift upward due to reduced residue revenue and paper and paperboard curves shift upward due to higher pulpwood prices. The impacts of our two scenarios on world output and prices are summarized in Table 4.2. The effects are generally as expected. Most importantly, note the small magnitude of the changes involved. Waste is important conceptually, but makes little difference to the aggregate results because it is reflected primarily in the tradeoff with wood chips, and because the differences are fairly small.

Table 4.2 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to Higher Wood Waste

	50% Waste		100% Waste	
	Output	Price	Output	Price
Solid Wood Products:				
CSAW	- 0.1	-	- 0.3	0.2
NSAW	- 0.2	0.2	- 0.2	0.3
VEPY	- 0.2	0.7	- 0.2	0.8
BOAR	- 0.2	0.4	- 0.3	0.7
Paper and Paperboard:				
NEWS	- 0.1	0.1	- 0.2	0.4
PRNT	-	0.1	- 0.1	0.2
HHSP	-	0.1	-	0.3
PACK	-	0.1	- 0.1	0.4
Intermediate Products:				
RCYC	-	- 0.9	0.1	- 0.1
CWIP	- 0.1	- 0.4	- 0.1	0.6
NWIP	-	0.1	0.1	0.2
Raw Materials:				
CLOG	-	0.2	-	-
NLOG	-	0.4	-	0.1
CPWD	- 0.1	0.9	- 0.4	2.2
NPWD	- 0.1	1.0	- 0.1	0.3

There are some interesting changes at the regional level. For example, in Japan, 1980 total sawlog use in coniferous sawnwood production is 1.248 and byproduct output is 0.055, so waste production is 0.193. Though the absolute production of waste is similar to other regions, waste production on a percentage basis is 78% (that is, 0.193/0.248). Thus, in the unchanged waste scenario, by 2030 total use is 1.500 and waste is 0.389. As a result, in this scenario, Japan starts as the most efficient coniferous sawnwood producer and evolves to the least efficient producer of joint products (sawnwood and chips) by the end of the projection period.

4.3.2.3 Coniferous-to-Nonconiferous Transfer

The GTM assumes that there is a gradual transition from coniferous to nonconiferous input in the manufacture of reconstituted panel products and paper and paperboard products. For the BASE CASE, there is a 30% shift over the forecast horizon for both pulpwood and pulp inputs. The percentage change is assumed to be identical across the five final products that use these inputs (BOAR, NEWS, PRNT, HHSP, and PACK) and across all regions. Here we change this percentage to zero so that no species shift occurs. This simulation is a subset of the scenario presented in Section 4.3.2.1, and thus represents a more restricted version of the elimination of BASE CASE technological change. Hence, we are able to isolate the effects of coniferous-nonconiferous substitution.

At the aggregate level, the output of coniferous pulpwood and coniferous "white" pulp both increase by 5.8% (see Table 4.3). Obviously, the price increases are much smaller for pulp, which uses pulpwood as a raw material input. Note that the quantity and price changes are significantly smaller than in the more general technological change case shown in Table 4.1. By assumption, the increases in coniferous pulpwood and pulp use come at the expense of nonconiferous pulpwood and pulp use. The absolute values of percentage changes in nonconiferous pulpwood and pulp use are much larger than the percentage increases in coniferous pulpwood and pulp use, reflecting the fact that the quantity of nonconiferous material consumed is less in the base year.

As a result of raw material price changes, world paper and paperboard prices rise and output declines. However, this clearly need not be the case at the individual region level. Some regions show price decreases reflecting the initial technological mix and raw material costs.

The impacts on the solid wood sector differ significantly between species. On the coniferous side, sawlog prices rise due to the increased competition from pulpwood demands. In this scenario, 44.5 mm m^3 of coniferous sawlogs are downgraded to pulpwood in 2000, compared to only 31.1 mm m^3 in the BASE CASE. The increase in coniferous sawlog prices causes sawnwood prices to rise, and the increase outweighs the reduction that may be attributed to higher coniferous residue prices.

Nonconiferous sawlog prices fall. However, because of the dramatic reduction in nonconiferous pulpwood prices, nonconiferous sawnwood prices rise, and output falls.

World veneer and plywood production is more heavily oriented to coniferous input than to nonconiferous, the 1980 coniferous share being about 55%. Although the effects of coniferous/nonconiferous sawlog prices and residues are mixed, the effects from the coniferous side tend to dominate.

Finally, prices for reconstituted panel products fall and output shows a slight increase. Only "pulpwood" is consumed in reconstituted panels production and the 1980 nonconiferous share worldwide is 55%. Here the significant drop in nonconiferous pulpwood prices is the primary influence on reconstituted panel product markets.

Table 4.3 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to No Coniferous-Nonconiferous Substitution

	Output	Price
Solid Wood Products:		
CSAW	- 0.5	1.0
NSAW	- 1.0	0.6
VEPY	- 0.2	0.6
BOAR	0.2	- 1.3
Paper and Paperboard:		
NEWS	- 1.5	2.9
PRNT	- 0.2	1.0
HHSP	- 0.3	1.8
PACK	- 0.5	2.3
Intermediate Products:		
RCYC	- 0.3	1.5
CWIP	5.8	3.5
NWIP	- 9.0	- 3.9
Raw Materials:		
CLOG	- 0.3	5.5
NLOG	- 0.7	- 1.5
CPWD	5.8	10.2
NPWD	-13.0	-20.1

4.3.2.4 Paper and Paperboard Recovery Rates

The paper and paperboard recovery rate for a single region is defined as the amount of recycled paper produced divided by the amount of paper and paperboard consumed. In the current BASE CASE version of the GTM, recovery is assumed to improve linearly and reach 50% in all regions by 2030. Under this scenario, the region which shows the greatest improvement is Rest of World, which begins at 6.6% in 1980, and the region which shows the least improvement is Japan, which recovered 44.5% of the paper and paperboard it consumed in 1980.

For the market economies, there is a single cost associated with producing recycled paper, and it is exogenously set at the 1980 historical price. Thus, the marginal cost curve is horizontal, and there are no anticipated changes in manufacturing technology or production cost over time. The maximum amount of recycled paper which can be produced is set by the paper and paperboard recovery rate. At production levels below this capacity, only the amount of recycled paper that is used (produced) is assumed to be recovered; hence, the recovery rate refers to potential, rather than actual recovery. (Alternatively, this behavior may be interpreted as follows: the potential amount is always produced but we have the option of free disposal.) At the capacity bound, the model provides the option of drawing on "slack" resources. The slack price is 10% higher than the base year price, and the amount of slack resources available is 20% of current capacity. For example, if the 1980 price of recycled paper is USD 150/metric ton and current capacity is 5.0 million metric tons, then an additional 1.0 million metric tons are available at USD 165/metric ton. The marginal cost curve is vertical at 1.2 times the current capacity.

There are two differences between the centrally-planned economies and the market economies with regard to the treatment of recycled paper. First, there is no cost associated with producing recycled paper in the centrally-planned economies. However, as with the market economies, upper bounds (capacity) are set by the paper and paperboard recovery rates, and slack resources are available only at 1.1 times the base year price. Second, for the Soviet Union, slack resources are available for up to 200% of current capacity. As a result of this formulation, minimum production for the centrally-planned economies will always occur at their capacity bounds. If this level of production exceeds their domestic requirements, they will export and their prices will be determined accordingly.

Slack resources for recycled paper are used frequently and in large quantities in the BASE CASE. This is due to the large increases in recycled paper use assumed by the technological targets for paper and paperboard products. Of the potential 108 projected values of recycled paper production until 2010 (18 regions times 6 periods), slacks are used in 70 cases. In 27 of these cases, all potential slack material is used and slack constraints are binding.

We have run two simulations in which we change the projected paper and paperboard recovery rates, one in which these rates remain at 1980 levels and one in which the rates increase to 99%. When recovery rates are held at 1980 levels, regions immediately draw on slack resources for recycled paper, and recycled paper prices rise. As shown in Table 4.4, world prices are 32.9% higher than in the BASE CASE. The most direct impact of these price increases is to increase the cost of paper and paperboard production. The increases are smallest for printing papers, which use the least recycled paper as raw material furnish. The price increases cause output to decline for the four groups of paper as well as for the pulps. The second-order impacts are small and tend to be fairly complex due to the mix of region and product interactions. Because less paper and paperboard are produced, the demand for pulpwood declines, and hence pulpwood prices generally decrease. However, some regions will gain a comparative advantage in the production of paper and paperboard due to recycled paper availability (and pulpwood availability), and they may actually increase their production and export of recycled paper and/or paper and paperboard to recycled-paper poor regions. In these regions, pulpwood prices may rise. If sawlogs are in direct competition with pulpwood, sawlog prices may rise as well. As an example, we observe this phenomenon in Eastern Canada: newsprint prices rise, but Eastern Canada increases newsprint production and exports. This causes pulpwood demand to increase and pulpwood and sawlog prices rise. The net result is that coniferous sawnwood prices rise in Eastern Canada and production falls. The analysis of this scenario is further complicated by the change in residue availability.

When recovery rates are increased to 99%, so that effectively all paper and paperboard consumed is recycled, we observe some of the opposite effects, but the changes are of smaller magnitude. Recycled paper prices fall, and paper and paperboard prices decline, leading to increased output at the world level. Changes in nonconiferous pulpwood are straightforward, but coniferous pulpwood changes are complicated by the combined impacts of regional comparative advantage and the reclassification of sawlogs to pulpwood.

Table 4.4 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to Alternative Paper and Paperboard Recovery Rates

	1980 Recovery		99% Recovery	
	Output	Price	Output	Price
Solid Wood Products:				
CSAW	- 0.2	0.2	0.1	- 0.2
NSAW	-	-	0.1	-
VEPY	-	-	-	-
BOAR	-	- 0.8	-	-
Paper and Paperboard:				
NEWS	- 1.8	3.7	0.8	- 1.9
PRNT	- 0.4	0.9	0.1	- 0.3
HHSP	- 0.4	2.8	0.1	- 0.8
PACK	- 1.0	5.2	0.2	- 1.4
Intermediate Products:				
RCYC	- 2.6	32.9	0.9	-10.9
CWIP	- 0.2	-	- 0.1	- 0.5
NWIP	- 0.6	- 0.5	-	0.1
Raw Materials:				
CLOG	- 0.1	0.3	0.1	- 1.3
NLOG	- 0.1	- 0.2	-	0.1
CPWD	0.1	0.5	- 0.3	- 1.4
NPWD	- 0.6	- 2.6	0.2	2.4

These scenarios suggest one final test: how would the solution be affected if no slack material is available for recycled paper? Because final product production in the

Soviet Union and Eastern Europe is directly linked to timber harvest, the model fails to solve if no slacks are available in any region. Paper and paperboard production in these regions remains unchanged regardless of the recycled paper scenario, so recycled paper requirements cannot be met. It is this constraint that provides the rationale for the high upper bound on slack recycled paper production in the Soviet Union. When slack availability is removed in all regions except the Soviet Union, the model solves, and the Soviet Union exports recycled paper to several regions of the world (transhipments to other regions are common for those regions that do not have direct trading links with the Soviet Union).

4.3.3 Capacity Evolution

4.3.3.1 Capacity Depreciation (Retirement) Rates

Capacity depreciation is an important part of the pricing mechanism in the GTM. There are two important dimensions to be considered. First, timber consumption is conditional on the output level and the technology mix. For each of ten products (eight final products and two pulps) in each of the market economies, capacity is determined for each step of the supply function. Within each step, timber utilization is fixed. In almost all cases, the old (or least efficient) technology is most wood intensive, while the newest technology consumes the least wood. Thus, the more rapidly the existing capital is replaced by new technology, the more quickly the industry will reduce its average consumption of sawlogs and pulpwood. Conversely, slow capacity retirement implies higher wood consumption.

The second key aspect of this structure pertains to recovering the fixed cost of investment. When capacity retirement rates are rapid, new capacity is almost always being added and prices must be high enough to cover these fixed costs. However, when capacity is retired slowly, there may be sufficient capacity available to produce the needed amount of a commodity without investing in new capacity, and prices need only cover variable production costs in the GTM.

The combination of these two effects lead to some very interesting results with respect to capacity retirement rates. If capacity retirement rates are faster than in the BASE CASE, product prices will generally decline due to the downward shift in the supply curve. However, the results are not so predictable when capacity retirement rates are slowed from BASE CASE levels. Higher timber demand will lead to higher raw material costs and product supply curves shift upward. It is clear that if regions were to produce the same quantity of material as in the BASE CASE, then product prices would be significantly higher. But regions will generally cut back production (due either to relatively elastic consumer demand within the region or loss of market share to other regions). If the reduction in production is sufficiently large, then products prices will fall.

In the current version of the GTM, 33% of the old technology is retired each period, and 50% of the modern technology becomes old. Here we demonstrate the effects of reducing retirement rates such that only 10% of the old technology is retired, and 15% of the modern technology becomes old. World output and price changes relative to the BASE CASE in 2000 are shown in Table 4.5.

As we would expect, output rises for all categories of raw materials, and the corresponding prices show large increases as a result. Changes in intermediate materials also reflect the fact that technological improvements are retarded in this scenario: the average demand for coniferous and nonconiferous pulp is much higher, but there is a significant reduction in the demand for recycled paper.

The results for final products are mixed. Consider coniferous sawnwood. World prices for coniferous sawnwood rise and output decreases; however, at the regional level prices rise in 13 of the 18 regions, while production declines in only 8 regions. There are numerous changes that contribute to this set of results. For example, in the Western U.S., prices fall and output rises. In the BASE CASE, new technology is added in the U.S. West (in 2000) and prices are set to cover fixed costs. However, in this scenario, no new technology is added, and prices are established at the capacity bound for the modern technology. Nevertheless, production is much higher because of the higher levels of capacity remaining in the old and modern technologies. (Coniferous sawlog prices are significantly higher reflecting the increased production of coniferous sawnwood and plywood.) Prices also fall and production rises in Chile. In this case, prices are set to cover production costs for the newest technology; however, in the BASE CASE, production is bounded on the higher production bound and excess profits are earned in Chile. In contrast, in the Eastern U.S., prices rise and output falls. In this case, we observe (as with the Western U.S.) that there is no production with the third technology, yet prices still rise, due to the intersection of supply and demand. Thus, it is clear that the interaction of capital retirements and derived timber demand create a complex set of price/output responses that must be analyzed on a case-by-case basis.

The responses by the paper and paperboard sectors generally are smaller than for solid wood products. This may be attributed to the smaller share of wood costs in total production costs for these commodities.

Trade patterns are significantly affected by the shifting mix of capacities and production levels. However, since there are no clear patterns to changes at the regional/product level, there are also no clear patterns to changing trade flows. For example, total trade (in 2000) falls 39% for plywood and 23% for printing papers, but increases 29% for coniferous sawnwood and 20% for reconstituted panels.

Finally, we should note that there are significant changes with regard to product specialization. As one would expect, regions do not specialize as they do in the BASE CASE because their capacity mix tends to be much more similar to historical levels. The radical changes in U.S. lumber and plywood production that were evident in the BASE CASE do not appear in this scenario.

Table 4.5 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to Reduced Capacity-depreciation Rates

	Output	Price
Solid Wood Products:		
CSAW	- 0.5	1.2
NSAW	1.7	1.2
VEPY	- 0.4	1.4
BOAR	- 1.2	2.0
Paper and Paperboard:		
NEWS	- 0.5	0.3
PRNT	-	- 0.5
HHSP	-	- 0.1
PACK	- 0.1	0.1
Intermediate Products:		
RCYC	- 4.6	- 5.5
CWIP	3.6	2.7
NWIP	5.8	2.4
Raw Materials:		
CLOG	3.2	12.5
NLOG	2.3	6.4
CPWD	2.6	15.4
NPWD	1.0	21.8

4.3.3.2 Capacity Investment

Capacity is added in each period if prices are high enough to cover total production costs (variable plus fixed). However, capacity additions may be constrained by a physical and/or financial limitations.

Maximum allowable capacity expansion

The GTM contains a parameter that allows one to specify the maximum allowable annual capacity expansion for any product in any region. The current setting is 15% which means that capacity expansion for new technologies may reach 75% of existing capacity (existing capacity is for the year in question; thus, it is computed after the retirement of old capacity has occurred). In the BASE CASE scenario, these constraints are infrequently binding. For example, in 1990, of the 150 new technology capacity constraints (10 products and 15 regions -- the centrally-planned economies are excluded), 25 are binding. By 2000, only 12 new technology capacity constraints are binding. The importance of these constraints are, of course, tied to the capacity depreciation rates. When the rates of capacity retirement are slowed, these constraints play an even less important role.

To demonstrate the potential importance of these constraints, we have run two scenarios with alternative capacity expansion allowances. In the first case, we set the maximum annual capacity expansion to only 5%, while in the second case the value is set to 200% (to insure that it is never binding). Percentage changes in world output and prices relative to the BASE CASE in 2000 are shown in Table 4.6.*

With 5% expansion, we observe that production is heavily constrained by capacity (virtually all constraints are binding), and production falls substantially relative to the BASE CASE for all commodities. The decline in the demand for raw materials causes significant reductions in raw materials prices. However, final product prices rise dramatically due to the capacity constraints. The shadow prices associated with the capacity constraints are very large, and producers earn enormous profits. The one anomaly in these results is that coniferous pulp prices fall. The constraints on coniferous pulp capacity are slight due to the increased use of nonconiferous pulp;

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* We should note that due to an error in the GTM at the time these simulations were run, the alternative capacity expansion rates did not affect the last region -- Rest of World. Since the point of this exercise can be clearly made with these results, we did not rerun these scenarios.

thus, even though capacity is frequently binding for coniferous pulp, the effect of reduced costs dominates the impact of the constraint.

As expected, unlimited capacity expansion produces results that are not much different from the BASE CASE. This demonstrates that the physical constraints on capacity expansion are of limited importance in determining the BASE CASE results. The dramatic increase in coniferous pulpwood prices deserves comment, especially since there is no output change. This is primarily due to small production shifts among regions that cause Brazil to reach its resource constraint for large coniferous trees (the major source of pulpwood in this region). Because of the resource constraints in the emerging regions, raw material prices can behave erratically.

Table 4.6 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to Alternative Potential Capacity Expansion Rates

	5% Expansion		No Limit	
	Output	Price	Output	Price
Solid Wood Products:				
CSAW	- 9.5	14.6	0.3	- 0.6
NSAW	-12.1	12.6	1.3	- 0.8
VEPY	-26.6	70.0	0.2	- 0.5
BOAR	-24.4	53.2	- 0.6	1.2
Paper and Paperboard:				
NEWS	-12.6	28.5	0.1	- 0.1
PRNT	-21.2	90.5	0.1	-
HHSP	-15.2	107.8	-	- 0.1
PACK	-16.2	103.1	- 0.1	0.7
Intermediate Products:				
RCYC	-17.0	- 1.3	0.2	- 3.4
CWIP	-14.6	-15.0	0.8	0.2
NWIP	-19.3	298.4	- 0.2	- 0.9
Raw Materials:				
CLOG	- 9.9	-15.4	0.7	3.8
NLOG	-18.5	-38.7	0.1	1.1
CPWD	-16.7	-44.2	-	29.0
NPWD	-21.3	-14.3	- 0.3	1.5

Financial constraints

Capacity expansion may also be constrained by the availability of financial resources. There are two steps for determining the availability of funds in the GTM. First, the total amount of revenue generated in the previous period is calculated: prices are multiplied times domestic production for all manufactured products and summed. Second, total revenue is then multiplied by a capital turnover ratio. This factor indicates how much of this revenue may be recirculated in the forest products industry. The value of the capital turnover ratio ranges from 0.8 (Finland and Sweden) to 1.5 (for seven regions -- typically developing areas -- which indicates that external financing is available). The value is 1.0 for the remaining nine regions. It should also be noted that Western Canada and Eastern Canada are combined and treated as a single region for investment purposes, as are the Western and Eastern U.S.

These capital funds are used for two purposes in the model. First, they are used to cover maintenance costs. Maintenance costs are treated as a fixed cost in the GTM and do not enter the marginal cost functions. Second, capital funds are used to build new capacity, and the total investment cost is simply the investment cost per unit multiplied times the number of units.

It should be pointed out that it is curious that revenue is used in the investment calculation rather than profit. Obviously, revenue used to pay variable costs cannot be subsequently invested. However, profit (quasi-rent) would not be correct in this formulation either, since this would include only the quasi-rent earned by old and modern producers (assuming the third technology constraint is not binding). Since prices are formulated to cover the fixed costs of additional capacity, the most appropriate specification (within this general framework) would be to require that quasi-rent is adequate to cover maintenance costs. This suggests that the current budget constraint should probably be omitted.

The budget constraint is rarely binding in the BASE CASE. The constraint is never binding in 1985, binding in four regions in 1990, one region in 1995 and one region in 2000. We ran two simulations to test the sensitivity of the model results to this parameter. In the first, we changed the level of maintenance costs from 18.7% to 25% for old technologies and 8.3% to 15% for modern technologies. The financial constraints were still not binding in 1985, and binding in only one region in 2000. In the second scenario, we increased the capital turnover rate fivefold so that financial constraints were never binding. The results for both scenarios suggest that financial constraints have only minimal impacts on the BASE CASE solution (see Table 4.7).

Table 4.7 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to Alternative Financial Constraints

	Higher Maintenance Costs		Unlimited Budget	
	Output	Price	Output	Price
Solid Wood Products:				
CSAW	-	- 0.1	- 0.1	0.2
NSAW	0.2	- 0.1	0.2	- 0.1
VEPY	0.1	- 0.1	-	-
BOAR	- 0.1	- 0.4	- 0.2	0.4
Paper and Paperboard:				
NEWS	- 0.1	0.2	- 0.2	0.4
PRNT	- 0.1	0.8	0.2	- 0.9
HHSP	-	0.2	-	- 0.3
PACK	- 0.1	0.3	-	-
Intermediate Products:				
RCYC	0.6	0.3	- 1.6	- 1.4
CWIP	- 0.3	- 0.2	0.3	0.3
NWIP	0.8	0.1	- 0.1	- 0.3
Raw Materials:				
CLOG	0.1	- 1.3	0.2	3.0
NLOG	-	- 0.3	0.1	0.4
CPWD	- 0.6	- 1.5	0.8	3.9
NPWD	0.3	- 0.8	0.1	1.0

This analysis demonstrates that in the BASE CASE results, capacity additions are rarely discouraged due to physical or financial constraints. However, this need not be true for alternative policy or economic scenarios, particularly those that incorporate rapidly increasing final products demand. Thus, one must be wary of the role of capacity constraints in long-run scenario analysis. If one wishes to impose long-run capacity constraints, the GTM incorporates a good deal of flexibility for implementing these.

5. TIMBER SUPPLY

The GTM is designed to model four growing stock classes in each region:

large coniferous trees
large nonconiferous trees
small coniferous trees
small nonconiferous trees

Large trees are used to make three products: logs, pulpwood, and fuelwood. Small trees may be converted only to pulpwood and fuelwood. It is not necessary to use all four growing stock classes in each region. In the current version of the GTM, a single growing stock class is used to make all products in the Soviet Union, Eastern Europe, and China.

For each growing stock class in each region, there is a corresponding short-run timber supply curve. These supply curves are shifted over time in five-year steps. In most cases the timber supply curves are shifted on the basis of inventory development; however, for five regions (Australia-New Zealand, Chile, Brazil, the Soviet Union, and Eastern Europe), the shifts are based on exogenously-stated removals.

5.1 IIASA Timber Supply Curve Methodology

5.1.1 The Static Formulation

The inverse delivered wood supply equation for each growing stock class in each region is expressed as:

$$C_0 = a_0 (H_0 - PUB)^b \qquad 5.1$$

where:

C_0 = base year cost of one cubic meter of timber delivered to the mill; the price is a weighted average of the prices of products produced from this type of growing stock, and the weights are derived from the conversion coefficients

a_0 = position parameter

H_0 = base year harvest of this growing stock class

PUB = exogenous timber harvest set by policy (public harvest)

b = inverse of the price elasticity of supply; in the current version of the GTM, these are invariant to time and harvest level (supply elasticities are presented in Table 5.1)

In the Forest Sector Project, fixed harvest levels (that is, PUB) were implemented only in the U.S. (both West and East).

Table 5.1 Timber Supply Elasticities by Region and Growing Stock Class

	Large Trees		Small Trees	
Region	Coniferous	Nonconiferous	Coniferous	Nonconiferous
WCA	0.33	0.50	0.33	0.50
ECA	0.40	0.50	0.40	0.50
WUS	0.26	0.33	0.40	0.50
EUS	0.40	0.63	0.40	0.63
BRA	0.50	0.50	0.50	0.50
CHI	0.50	0.50	0.50	0.50
RLA	0.40	0.50	0.50	0.50
FIN	0.40	0.59	0.71	0.71
SWE	0.40	0.59	0.71	0.71
WEU	0.33	0.33	0.83	1.00
SUN	1.00	nr	nr	nr
EEU	1.00	nr	nr	nr
AFR	0.50	0.50	0.50	0.50
KIN	0.40	nr	nr	nr
JAP	0.33	0.33	0.33	0.33
SEA	0.33	0.50	0.33	0.50
ANZ	0.50	0.50	0.50	0.50
RWO	0.33	0.33	0.33	0.33

Note: nr = not relevant

5.1.2 Wood Supply Dynamics

5.1.2.1 The Endogenous Regions

Shifting the Supply Curve Over Time

The delivered wood supply elasticity with respect to inventory is assumed to be 1.0. At a given price, this implies the following conditions must hold (with base year inventory defined as I_0):

$$H_1 / I_1 = H_0 / I_0 \qquad 5.2$$

and

$$C_0 = a_0 H_0^{b} = a_1 H_1^{b} \qquad 5.3$$

Equations 5.2 and 5.3 may be combined to yield the following shift factor:

$$a_1 = a_0 (H_0 / H_1)^{b} = a_0 (I_0 / I_1)^{b} \qquad 5.4$$

Thus, the inverse delivered wood supply equation for any future time period may be written:

$$C_1 = a_0 [(I_0 / I_1) H_1]^{b} \qquad 5.5$$

For the regions in which timber supply is endogenously determined, upper bounds are placed on harvest levels. These constraints are precautionary measures, and are rarely binding. It is assumed that harvests in each growing stock class cannot exceed 5% of the available growing stock for a species group. For example, if the growing stock for coniferous species (both large and small trees) is Y, then the large tree coniferous harvest may be (0.05 *x* Y), and the small tree coniferous harvest may be (0.05 *x* Y); hence, 10% of the total inventory may be cut in any period. However, there is some inconsistency in the model for this concept: for single growing stock class regions (China), only 5% of the inventory may be harvested.

Projecting the Timber Inventory

The inventory at the start of the next solution is computed by a simple growth-drain identity:

$$I_{t+1} = I_t - H_t + G_t \qquad 5.6$$

where:

G_t = timber growth

The first step in computing growth is to find the stocking level by species:

$$S_c = I_c \,/\, \text{Area} \quad \text{and} \quad S_n = I_n \,/\, \text{Area}$$

where:

S_c = stocking level for coniferous trees
I_c = coniferous inventory
Area = total exploitable forest area
S_n = stocking level for nonconiferous trees
I_n = nonconiferous inventory

Large and small trees are combined and grown as a single group. Thus, the ratio of large/small trees is assumed to remain constant at the 1970s level. For single-inventory regions (there are 10 such regions), timber inventory levels are projected for coniferous-nonconiferous species combined, and then split on the basis of 1980 levels. Thus, the coniferous/nonconiferous ratio also will remain constant.

The growth rate in growing stock per unit area is now made a function of the stocking level:

$$dS \,/\, S = b_0 + b_1 S + b_2 S^2 \qquad 5.7$$

For several regions, updating of the inventory requires accounting for exogenous changes to the land area and growing stock. Afforestation trends are recognized in Rest of Latin America, Africa, and Southeast Asia. Deforestation trends are incorporated in Rest of Latin America, Africa, Southeast Asia, and Rest of World.

Deforestation is modeled as a constant percentage decline in hectares over time. Thus, the number of hectares removed from the forest will decrease over time.

5.1.2.2 The <u>Exogenous</u> Regions: Australia-New Zealand, Chile, Brazil, the Soviet Union, and Eastern Europe

For the exogenous regions, the timber supply curve is shifted in the manner discussed above; however, the between-period inventory ratio is replaced by the between-period maximum harvest level ratio. This allows the flexibility to incorporate rapid expansion in harvests due to plantation growth, or harvest levels controlled by government policy.

For the Soviet Union and Eastern Europe, harvest levels are assumed to be fixed by government policy: the maximum harvest level is equal to the minimum harvest level. For the emerging regions, the upper harvest limit is equal to the target harvest level as long as the target level is harvested in the previous period. However, if the target level is not harvested, the uncut timber is carried over into the subsequent period. Thus, the harvest limit is:

$$U_{t+1} = T_{t+1} + D_t \qquad 5.8$$

where:

U = upper harvest limit
T = target harvest level
D = upper harvest limit minus harvest in previous period (U_t - H_t)

In these regions, the constant in the timber supply equation is then updated using these upper limits:

$$a_1 = a_0 (U_0 / U_1)^b \qquad 5.9$$

5.2 Theoretical Evaluation of the Timber Supply Methodology

5.2.1 Delivered Wood Price Equations

Wood supply equations are for wood delivered to the mill; thus, they combine the economic effects associated with stumpage prices and harvest and delivery costs.

This aggregation makes it extremely difficult to rationalize the elasticities used in the model, or to alter them in a meaningful way.

In general, it seems clear that the timber supply elasticities used in the model are much too small. As shown below, the inverse of the elasticity of delivered wood supply should be a weighted average of the inverse of the elasticities associated with stumpage costs and logging costs (equation 5.14). Let delivered wood costs be the sum of logging and stumpage costs:

$$W = L + S \tag{5.10}$$

where:

W = delivered wood price

L = logging cost (including harvest and delivery costs)

S = stumpage cost

Taking the derivative with respect to the volume harvested (Q), we have:

$$dW / dQ = dL / dQ + dS / dQ \tag{5.11}$$

Converting to elasticities yields:

$$(dW / dQ) (Q / W) = [(dL + dS) / dQ] (Q / W) \tag{5.12}$$

$$(dW / dQ) (Q / W) = [(dL\ Q\ L) / (dQ\ W\ L)] + [(dS\ Q\ S) / (dQ\ W\ S)] \tag{5.13}$$

$$1 / e(Q,W) = [1 / e(Q,L)]\ SH_L + [1 / e(Q,S)]\ SH_S \tag{5.14}$$

where:

$e(Q,W)$ = elasticity of log supply with respect to delivered wood price

$e(Q,L)$ = elasticity of log supply with respect to logging cost

$e(Q,S)$ = elasticity of log supply with respect to stumpage cost

SH_L = logging share of delivered wood price

SH_S = stumpage share of delivered wood price

Thus, the elasticity of log supply with respect to delivered wood price may be written:

$$e(Q,W) = [\ e(Q,L)\ e(Q,S)\ ]\ /\ [\ e(Q,S)\ SH_L + e(Q,L)\ SH_S\ ] \qquad 5.15$$

In an extremely simplified example, it is easy to show that elasticities associated with access costs are quite high (see Binkley and Dykstra, 1987). Assume a sawmill is located at the center of a circle. The area of the circle is: $A = \text{pi}\ r^2$. If the same volume is available for harvest at every point in the circle, and assuming that the mill pays only transportation costs which are a linear function of distance, then quantity is proportional to area, and transportation cost is proportional to the radius; therefore, we directly observe that the supply elasticity is 2.

Some empirical work also has shown the supply elasticity due to logging costs to be quite high. Using an access-cost model for Coastal British Columbia, Williams (1987) showed that a one Canadian dollar increase in the market value of a cubic meter of delivered wood makes an additional 26 mm m^3 of wood available at the extensive margin. On a base of 131 mm m^3 of wood available at an average price of CND $38/m^3$, the supply elasticity is 7.6.

It is also well known that logging costs account for a significant portion of delivered wood costs. For example, in the coastal region of the U.S. Pacific Northwest, harvest and delivery costs accounted for an average of 45% of delivered wood costs between 1978 and 1982 (FORSIM Review, 1983). In Indonesia, harvest and delivery costs constituted 74% of delivered wood costs in 1984 (Priasukmana, 1986).

Using equation 5.15, and the above information as a guide, we are able to construct some sample values of delivered wood supply elasticities given supply elasticities for the individual components. These values, presented in Table 5.2, quantify the role of harvest and delivery costs in determining delivered wood price elasticities.

Table 5.2 Delivered Wood Supply Elasticities Computed from Stumpage and Logging Cost Elasticities

e(Q,S)	e(Q,L)	SH_S	SH_L	e(Q,W)
0.2	2	0.5	0.5	0.36
0.5	2	0.5	0.5	0.80
0.8	2	0.5	0.5	1.14
0.2	10	0.5	0.5	0.39
0.5	10	0.5	0.5	0.95
0.8	10	0.5	0.5	1.48
0.2	2	0.2	0.8	0.71
0.5	2	0.2	0.8	1.25
0.8	2	0.2	0.8	1.54
0.2	10	0.2	0.8	0.92
0.5	10	0.2	0.8	2.08
0.8	10	0.2	0.8	3.03

Let us consider one other type of wood supply model: wood supply in a mature wood basket. This model is quite different than an access cost model in that access costs are important as a share of total costs, but they are independent of the volume harvested. Wood is effectively assumed to be transported from all areas in a wood basket, and increasing the harvest increases the volume removed from all areas. This contrasts sharply with the notion of obtaining more wood at the extensive margin. This model is consistent with the behavioral assumptions of models of U.S. wood supply (Adams and Haynes, 1980; Cardellichio and Veltkamp, 1981).

If harvest and delivery costs are constant (perfectly elastic), we see from equation 5.14 that the elasticity of delivered wood supply is simply the stumpage price elasticity divided by the stumpage price share. For example, when the stumpage price is 20% of wood costs, the delivered wood supply elasticity will be five times the stumpage supply elasticity.

Finally, it should be noted that logging costs generally are a much greater fraction of wood costs for pulpwood than sawlogs. Thus, elasticities for delivered pulpwood should be significantly higher than those for delivered sawlogs. For example, in the mature wood basket case, if sawlog stumpage is 50% of delivered wood costs, and pulpwood stumpage is 25% of delivered wood costs, the delivered wood supply elasticity for pulpwood should be double that of sawlogs. Another reason to expect pulpwood supply to be more elastic is that (marginal) sawlogs can always be downgraded to pulpwood when pulpwood prices rise; thus, we may observe substitution from sawlogs to pulpwood, but not vice versa. However, as shown in Table 5.1, large tree and small tree supply elasticities are often assumed to be identical in the GTM (the exceptions are WUS, RLA, FIN, SWE, and WEU).

5.2.2 Inventory Projections

The inventory model in the GTM is extremely simplistic. It is unlikely that one can place much confidence in the timber inventory projections generated with this system. While the model seems to perform well relative to the more sophisticated timber inventory projection systems used in the U.S. and Finland (see Binkley and Dykstra, 1987), the discrepancies are sufficiently large that they may lead to very significant price differences. For example, a 10% error in inventory translates into a 25% error in price when the supply elasticity is 1/3.

The model fails to differentiate between the growth of large and small trees. The growth rate for all trees is projected and applied to the total inventory. The split between large and small trees is assumed to remain the same as in the base year. Age class information plays a crucial role in the availability of mature timber in many regions of the world; however, such information is omitted from the GTM.

Finally, the split between coniferous and nonconiferous species also is omitted in many regions of the world. Thus, the share of coniferous species is assumed to remain the same over time. In these cases the model grows the inventory at the same rate, regardless of the species, even though the harvest rates may exhibit quite different paths.

5.3 Sensitivity Analysis

Our sensitivity analysis of this module consists of examining the impacts of changes in timber supply elasticities (Section 5.3.1) and changes in intertemporal timber supply curve shifts (Section 5.3.2). There are four types of timber supply shifts reviewed in Section 5.3.2: 1) changes in rates of timber growth in the endogenous regions; 2) changes in fixed removals in the U.S. West; 3) changes in harvest levels in the emerging regions; and, 4) changes in timber harvest in the Soviet Union.

5.3.1 Timber Supply Elasticity Simulation Results

We have simulated the GTM using a wide range of timber supply elasticities. As with the exercises for demand elasticities, we shift these on a percentage basis; thus, the shifts will be quite different among regions. It is also true (as with demand elasticities) that the effects of changes in timber supply elasticities will depend critically on the timber price paths in the BASE CASE (hence, they depend on the underlying demand and supply curve shifts). Generally (for regions with endogenous timber supply), if prices are rising, more elastic supply curves will cause prices to fall and quantities to increase. If prices are falling, more elastic supply curves will cause prices to rise and quantities to decrease. Thus, increasing elasticities will dampen BASE CASE price changes and accentuate BASE CASE quantity changes. Conversely, less elastic curves will cause price changes to be larger than in the BASE CASE, but quantity changes will be smaller.

In Table 5.3 we compare world output and prices for two simulations using alternative timber supply elasticities to those used in the BASE CASE. In these simulations timber supply elasticities are reduced by 90% from BASE CASE levels (that is, the elasticities are multiplied by 0.1) and also doubled.* The results are consistent with the general description provided above.

First we consider the results for more elastic timber supply. The results for individual regions are very mixed, because of the different price paths that we observe in the BASE CASE (timber prices are rising in some regions, but falling in others). Perhaps the most consistent result is for nonconiferous sawnwood. In the BASE CASE we observe rapid price inflation for nonconiferous sawlogs in virtually all areas of the world. When timber supply curves for nonconiferous large trees are made more elastic, nonconiferous sawnwood production and consumption increase in every region, and prices fall in every region.

The results are not so easily interpreted for coniferous sawnwood and veneer and plywood. Again, the difficulties arise primarily because of the different trends in regional coniferous sawlog prices in the BASE CASE. For example, in the Eastern U.S., where coniferous sawlog prices rise 114% from 1980 to 2000 in the BASE CASE, coniferous log production is 16% higher when the timber supply elasticity is doubled. In contrast, in Western Canada, where BASE CASE coniferous log prices fall 19%, coniferous log production drops 30% from BASE CASE levels due to the flatter timber

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* The model failed to solve for four periods when timber supply curves were made perfectly inelastic for all regions.

supply curve. There are obviously dramatic changes in coniferous sawnwood and veneer and plywood associated with these results. However, as shown in Table 5.3, the changes in world output of coniferous sawnwood and veneer and plywood are quite small, suggesting there are large offsetting changes in regional production. The statistical evidence for these widespread changes is that the mean absolute difference is 7% for coniferous sawnwood, and the mean absolute difference for veneer and plywood is 25%.

A few key changes dominate the market shifts that we observe among users of large coniferous trees. The Eastern U.S., a large importer of Western U.S. veneer and plywood in the BASE CASE, is now able to produce a larger share of its own veneer and plywood requirements (the Eastern U.S. veneer and plywood market share in its own region rises from 31% in 2000 in the BASE CASE to 60% in this scenario). This increase amounted to 7.4 mm m^3, nearly a doubling of Eastern U.S. production (the equivalent of almost 10% of world supply). The Western U.S. loses their lion's share of the Eastern U.S. market, and reduces veneer and plywood production accordingly. The Western U.S. now uses its low-cost timber to produce coniferous sawnwood for the Japanese market. As a result, Western Canada, which exports a large volume of coniferous sawnwood to Japan in the BASE CASE, becomes the marginal producer and cuts back production volumes by 35%.

There are smaller changes to be noted in some of the other regions. Because of reductions in the cost of nonconiferous sawlogs, veneer and plywood production increases in Japan and Southeast Asia. Japan uses the increased production to offset imports from the Western U.S. (coniferous and nonconiferous veneer and plywood are perfect substitutes), and Southeast Asia increases exports to the Rest of World. The Rest of World, in turn, reduces veneer and plywood production, and increases coniferous sawnwood production, allowing them to reduce their volume of imports.

World paper and paperboard output increases modestly for all products, as world prices fall in the 2-3% range. Consumption increases occur in virtually all regions, but the production results are very mixed. The variation in production is caused by the different trends in fiber availability.

Changes in fiber availability relative to the BASE CASE are a function of two factors. First, residue availability differs widely among regions (relative to the BASE CASE) due to the variation in changes in regional sawnwood and plywood production. Nonconiferous residues are higher in almost all cases, but coniferous residues rise substantially in some regions, and fall in others, following the pattern of product output. Second, the timber supply elasticities for small trees have been doubled. As before, the price path in the BASE CASE indicates whether pulpwood production will expand or decrease. The combination of these two factors makes it possible to observe higher residues and higher roundwood pulpwood cut, lower residues and higher roundwood pulpwood cut, etc. Although world coniferous and nonconiferous pulpwood (roundwood and residues) production both increase about 1%, coniferous <u>roundwood</u> cut increases 2%, while nonconiferous <u>roundwood</u> cut declines 2%. In spite of these relative changes in roundwood harvested, coniferous pulpwood prices decline more than nonconiferous pulpwood prices due to the alternative supply curves and regional production mix.

Simulating the GTM with almost perfectly inelastic timber supply curves produces the expected results. Raw material prices shoot up, and drive up product prices to choke off demand. World consumption/production of nonconiferous sawnwood falls the most since its aggregate demand curve is the most elastic. Paper and paperboard prices generally rise less than solid wood products prices because wood costs are a smaller share of product prices. However, relative demand elasticities also play a role. The low demand elasticities for some paper products result in relatively large price increases in spite of the smaller wood cost share.

Two products deserve special attention. First, recycled paper prices remain essentially unchanged since production costs are not directly affected by wood costs. Second, nonconiferous pulpwood prices rise dramatically. The large decline in nonconiferous sawnwood output causes residual nonconiferous pulpwood production to fall 14.3% (compared to only 7.1% for residual coniferous pulpwood). The increased demand for nonconiferous roundwood pulpwood causes the large increase in these prices, and roundwood harvest declines 2.4%.

As with the case of more elastic timber supply curves, the regional impacts can differ substantially. In some regions that experience falling BASE CASE prices, production may increase and prices may fall further. In regions where coniferous sawlogs and coniferous pulpwood are in direct competition, this factor plays a critical role.

Table 5.3 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to Alternative Timber Supply Elasticities

	90% Reduction in Timber Supply Elasticity		100% Increase in Timber Supply Elasticity	
	Output	Price	Output	Price
Solid Wood Products:				
CSAW	- 8.1	13.5	0.9	- 2.1
NSAW	-16.0	17.5	8.7	- 6.6
VEPY	- 4.0	10.3	1.3	- 3.1
BOAR	- 7.8	15.8	1.2	- 2.6
Paper and Paperboard:				
NEWS	- 5.2	11.0	1.5	- 3.4
PRNT	- 2.3	7.9	0.3	- 1.6
HHSP	- 1.1	6.8	0.3	- 2.4
PACK	- 1.9	9.8	0.7	- 3.4
Intermediate Products:				
RCYC	- 1.3	0.3	- 0.2	- 4.6
CWIP	- 2.7	20.5	1.8	- 7.4
NWIP	- 2.0	28.1	0.1	- 1.6
Raw Materials:				
CLOG	- 7.4	48.5	0.1	- 5.6
NLOG	-14.9	43.6	8.9	-12.6
CPWD	- 3.0	54.8	1.2	-14.7
NPWD	- 4.3	160.1	0.8	- 9.1

The next simulation addresses the interaction of timber supply elasticities for large trees and small trees. Changes in large tree supply elasticities have a direct effect on both sawlog and pulpwood availability. Pulpwood prices change as a result and affect the production/consumption decisions for paper and paperboard products. Changes in small tree elasticities affect the price of pulpwood directly. Production costs for sawnwood and veneer and plywood will change as result and affect the production/consumption decisions for these commodities. In regions where delivered sawlog costs and delivered pulpwood costs are identical, alternative timber supply elasticities will have direct impacts in both the solid wood and paper and paperboard sectors.

Based on the arguments presented earlier, and on our own experience with estimating timber supply curves, we believe that the difference between delivered large tree and small tree supply elasticities should be much greater than in the GTM BASE CASE. To analyze the significance of such a change, we increase the small tree supply elasticities by a factor of four, and leave the large tree elasticities unchanged. World output and price changes relative to the BASE CASE in 2000 are shown in Table 5.4.

In general, pulpwood prices fall and reduce the cost of manufacturing paper and paperboard and reconstituted panels. As a result, world output of these commodities rises. Consumption rises (or is stable) in every region, and prices are reduced in all regions.

Table 5.4 Percentage Changes in World Output and Prices Relative to the BASE CASE in 2000 Due to Quadrupling Small Tree Supply Elasticities

	Output	Price
Solid Wood Products:		
CSAW	- 0.0	- 0.4
NSAW	- 0.4	0.4
VEPY	- 0.5	1.4
BOAR	2.0	- 4.1
Paper and Paperboard:		
NEWS	2.1	- 4.7
PRNT	0.6	- 2.2
HHSP	0.5	- 3.3
PACK	1.0	- 4.7
Intermediate Products:		
RCYC	- 0.1	- 5.3
CWIP	2.4	-10.7
NWIP	- 0.2	0.2
Raw Materials:		
CLOG	- 0.5	- 5.3
NLOG	0.2	0.4
CPWD	1.8	-20.3
NPWD	0.9	- 2.2

The more interesting features of this simulation pertain to the interaction of pulpwood and sawlog markets. Table 5.5 shows the percentage changes in the harvest of large and small trees between this scenario and the BASE CASE in 2000. In regions that exhibit rising coniferous pulpwood prices in the BASE CASE (especially the North American regions), small tree harvests increase dramatically as a result of the flatter supply curves. The decline in pulpwood prices causes sawlog prices to fall in Canada, as a result of the direct competition in sawlog and pulpwood markets. (Large tree harvests decline with these price decreases.) The 20% decrease in Western Canadian coniferous sawlog prices makes coniferous sawnwood produced in this region more competitive in world markets: Western Canada increases exports to Japan. These exports contribute to a slight increase in Japanese consumption (coniferous sawnwood prices have fallen), and also replace some Japanese production. The reduction in

Japanese production lowers coniferous sawlog prices and causes a small reduction in coniferous sawlog imports from the Western U.S. and Soviet Union.

The reduction in residue prices has a detrimental effect on the Eastern U.S., particularly with respect to veneer and plywood production. Veneer and plywood prices rise in this region, and production falls (reducing the demand for large coniferous trees). The price increase is sufficient to make the Western U.S. earn higher profits from exporting veneer and plywood to the Eastern U.S. than to Japan. Japan fills the gap in imports by manufacturing more veneer and plywood at home using nonconiferous sawlog imports from Southeast Asia and the Western U.S.

Western Europe, Sweden, and Finland exhibit some interesting changes. Coniferous pulpwood prices rise in these regions in the BASE CASE (although the inflation rates are considerably more modest than in North America). Nevertheless, the availability of cheaper fiber elsewhere reduces the demand for pulpwood from these regions, and large tree harvests, residue production, and small tree harvests fall.

Finally, the substantial reductions in timber harvests in Australia-New Zealand should be noted, particularly because harvests are exogenously determined for this region. In the BASE CASE, Australia-New Zealand must sell a substantial fraction of its mature stock of large coniferous trees for pulpwood, and it is exported to Japan. However, in this alternative scenario, cheaper pulpwood from the Western U.S. and the Soviet Union limit the market for pulpwood from Australia-New Zealand, and they are forced to reduce their timber harvest.[*]

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[*] In the IIASA data base, Japan is a large consumer of coniferous pulpwood produced in Australia-New Zealand. However, the major historical flows of pulpwood between these regions have actually been nonconiferous (eucalyptus) chips exported from Australia.

Table 5.5 Percentage Changes in Timber Cut (by Region and Growing Stock Class) Relative to the BASE CASE in 2000 Due to Quadrupling Small Tree Supply Elasticities

	Large Trees		Small Trees	
Region	Coniferous	Nonconiferous	Coniferous	Nonconiferous
WCA	- 6.9	- 0.1	61.4	41.1
ECA	- 6.7	- 0.4	47.4	-53.1
WUS	0.3	- 4.4	32.7	242.5
EUS	- 6.4	0	61.7	2.1
BRA	- 0.7	0	-24.9	-18.8
CHI	- 2.3	0	0	0
RLA	- 4.6	- 0.4	24.3	1.5
FIN	- 5.0	0.7	- 2.6	- 8.8
SWE	- 4.0	1.1	-41.3	- 6.4
WEU	- 2.1	- 0.1	-26.6	16.0
SUN	0	nr	nr	nr
EEU	0	nr	nr	nr
AFR	0	- 0.8	0	18.3
KIN	0.6	nr	nr	nr
JAP	- 4.8	0	3.9	16.0
SEA	- 3.7	1.1	18.2	3.1
ANZ	- 9.0	0	-20.7	0
RWO	0.1	- 0.1	2.9	0
World	- 1.7	0.2	16.7	9.4

Note: nr = not relevant

The above simulation shows the important interactions between the sawlog and pulpwood sector. No other model available today has the capability to address these dynamics in such depth and at such a broad scale. The results suggest that the interactions are not particularly critical at the world level: the pulpwood supply curves were made very elastic to obtain the fairly small changes shown in Table 5.4. If one is interested in understanding world production, consumption, and price levels, a model such as the GTM is probably unnecessary for analyzing such scenarios. However, if one is interested in the details of regional competition and the simultaneous determination of the most profitable allocation of resources, a model such as the GTM is essential.

Are the above interactions realistic? If one believes the results of the BASE CASE, then these results seem very logical. But clearly, the results are conditional on factors such as the direct competition between sawlogs and pulpwood in Western Canada, the high byproduct revenues from solid wood products production, and the perfect substitutability of coniferous and nonconiferous veneer and plywood in Japan. With a different set of BASE CASE assumptions, one could come to very different conclusions concerning the results of changing the small tree supply elasticities.

Nevertheless, the important aspects of this exercise still hold, and we clearly observe the complexity of the interactions between the pulpwood and sawlog sectors.

5.3.2 Timber Inventory Development Simulation Results

We have simulated the GTM with a variety of alternative rates of intertemporal timber supply curve shifts, and some of these results are presented below. In these exercises, we have altered the volume of timber inventory at different periods in the future; however, we have not changed the assumptions on how cut responds to inventory. These scenarios are grouped according to the different methods of shifting these curves.

5.3.2.1 The Endogenous Regions

To change the rate at which the timber supply curves shift for the endogenous regions, we have changed the parameters in the timber growth equations. Here we present two cases: one in which annual net growth is 25% higher than in the BASE CASE, and one in which annual net growth is 25% lower. For all but one region (Eastern U.S.), percentage growth is expressed as a constant or linear function. Thus, we need only adjust the intercept to attain the desired change in inventory growth.*

Table 5.6 depicts the percentage changes in the inventory of mature standing timber compared to the BASE CASE for each of the two scenarios. These inventory changes obviously generate important changes in prices and harvests. In general, higher levels of growing stock will depress prices and increase harvests, and vice versa. World price and output changes for sawlogs and pulpwood relative to the BASE CASE in 2000 are shown in Table 5.7.

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* Note that these growth rate adjustments will be 25% relative to the BASE CASE only in 1980. After the first model solution the actual growth rate will be sensitive to the endogenously-determined harvest levels, and will no longer differ from the BASE CASE by exactly 25%.

Table 5.6 Percentage Changes in Growing Stock in the Endogenous Regions Relative to the BASE CASE Due to Changing Timber Growth Rates

	1985	1990	1995	2000
25% Growth Rate Decrease:				
Coniferous	- 3.2	- 6.4	- 8.6	-10.5
Nonconiferous	- 2.1	- 4.1	- 5.8	- 7.3
25% Growth Rate Increase:				
Coniferous	3.3	6.4	8.7	11.2
Nonconiferous	2.1	4.2	6.1	7.8

Table 5.7 Percentage Changes in Raw Materials Prices and Output Relative to the BASE CASE in 2000 Due to Changing Timber Growth Rates

	25% Growth Rate Decrease				25% Growth Rate Increase			
		Output				Output		
	Price	Total	Endog	Exog	Price	Total	Endog	Exog
CLOG	23.7	-3.7	-6.0	1.0	-13.8	2.1	3.0	0.1
NLOG	9.8	-2.8	-3.7	0.1	- 7.8	3.3	4.3	-0.1
CPWD	28.2	-1.7	-3.0	2.5	-22.4	1.9	3.7	-4.0
NPWD	17.1	-1.1	-2.2	1.7	-17.5	1.1	2.4	-2.3

Notes: 1) Endog refers to the 13 regions in which timber supply is determined endogenously.
2) Exog refers to the 5 regions in which timber supply is determined exogenously.

Two important behavioral characteristics of the GTM that are evident in these simulations warrant attention. First, because a large share of world timber removals are exogenously-determined (25% in the BASE CASE in 2000), changes in timber growth rates tend to redistribute timber-producing comparative advantage among regions of the world. Obviously, increases in timber growth rates favor the endogenous regions, and decreases in timber growth rates favor the exogenous regions. Although production in the Soviet Union and Eastern Europe are essentially fixed in the model, there is some flexibility in the emerging regions, as is evident in Table 5.7. This results from the fact that the emerging regions do not always harvest their entire allowable cut in each period of the BASE CASE; thus, when prices rise, they may be able to cut more and reduce their carryover, and vice versa. These regions also may be able to move timber between sawlog and pulpwood end uses, depending on the demand for each product.

The second important characteristic of the GTM that we observe is that the results will be significantly affected by the extent to which marginal producers are operating in the marketplace. In the BASE CASE, Western and Eastern Canada are both marginal producers of sawlogs (in terms of wood costs delivered to the mill): some of their sawlog production is downgraded for use as pulpwood. As a result, when timber growth is increased, an increasing volume of sawlogs is pushed out of the market and timber harvests actually fall. The opposite also occurs: lowering timber growth draws a greater volume of sawlogs to market and results in higher harvest levels.

5.3.2.2 Fixed (Public) Removals

In the Forest Sector Project, the option for fixed removals was utilized only in the two regions of the U.S. These removals were assumed to remain constant at 1980 levels in the BASE CASE scenario. Because of the large holdings of Forest Service timber in the U.S. West, fixed removals play a particularly critical role in the production activities of this region. Here we reduce the level of fixed removals in the U.S. West by 10% in 1985, and by 20% for the remainder of the forecast horizon. This scenario tests the sensitivity of the model to fixed removals, both to the level and intertemporal pattern, but clearly is of significant interest from a policy standpoint as well.

Table 5.8 shows the changes in the harvest of large coniferous trees for the primary regions affected by the reduction in Western U.S. fixed removals. Table 5.9 presents the associated percentage changes in coniferous sawlog prices. Western U.S. prices rise 7% in 1985, causing an increase in the harvest of private timber in the region; however, only 17% of the reduction in public timber harvest is replaced by the expansion in private timber harvest in this region (refer to Table 5.8). The additional harvest of private timber in 1985 reduces the volume of private timber available in future periods, so that substitution of private timber for public timber is only 7% in 1990, and private timber harvests in the U.S. West return to BASE CASE levels by 1995 (though prices are significantly higher).

How is the harvest reduction absorbed in forest products markets throughout the world? The primary impact on Western U.S. markets is to reduce log exports. We also observe a gradual reduction in veneer and plywood production. Coniferous sawnwood is unchanged in the first two periods and actually rises slightly in subsequent periods. Japan finds that it is no longer profitable to import the large volumes of sawlogs that it did in the BASE CASE. It increases its harvest of domestic sawlogs by a modest amount in the short-run, but handles the shortage primarily by substituting coniferous sawnwood imports from Western Canada for domestically-produced coniferous sawnwood. Western Canadian coniferous sawnwood exports to the Eastern U.S. (via the Western U.S.) are eliminated as the Eastern U.S. imports coniferous sawnwood from Eastern Canada, and expands its production of veneer and plywood. Harvest increases also occur in China.

The results for Western Canada need some elaboration. Western Canada expands its harvest of large coniferous trees by a small amount, but expands its production of coniferous logs by much more. This result is due to the fact that Western Canada is a marginal producer of sawlogs. Thus, the increases in sawlog prices attract logs from pulpwood markets. However, much of the reduction in pulpwood production is offset by increases in Eastern Canada and the Eastern U.S. so that paper and paperboard markets experience only a minor effect.

Finally, it is important to note that the results mask the fact that a large coniferous tree in one region is not the same as in another. For example, the GTM has only one type of tree in China and one unit yields 0.11 coniferous logs. Thus, although the reduction in Western U.S. log exports to China is small, China must increase its harvest substantially to obtain an equivalent volume of sawlogs. Because of joint production (with fixed proportions assumptions), the model generates some curious results. For example, the reduction in the availability of large trees in the U.S. West leads to relatively large increases in fuelwood consumption in China.

Table 5.8 Absolute Changes (mm m^3) in Coniferous Large Tree Removals Relative to the BASE CASE Due to Reduced Fixed Removals in the Western U.S.

	1985	1990	1995	2000
Western U.S.:				
Total Removals	-4.5	-10.2	-10.9	-10.6
Fixed Removals	-5.4	-10.9	-10.9	-10.9
Private Removals	0.9	0.7	0	0.3
Eastern U.S.	1.4	1.7	1.7	2.5
Western Canada	0	2.0	1.5	0.2
Eastern Canada	0.8	0.6	0.5	0.2
China	1.0	0.7	4.0	1.5
Japan	0.3	0.4	-0.2	0
World Total	-1.0	-4.8	-2.4	-5.5

Table 5.9 Percentage Changes in Coniferous Sawlog Prices Relative to the BASE CASE Due to Reduced Fixed Removals in the Western U.S.

	1985	1990	1995	2000
Western U.S.	7.3	11.5	6.3	8.9
Eastern U.S.	4.2	4.8	3.8	6.7
Western Canada	0	9.3	6.5	0.6
Eastern Canada	5.4	3.2	2.8	1.5
China	3.0	2.0	10.9	5.4
Japan	3.8	6.7	-2.0	0.7
World Total	3.4	2.5	2.0	3.1

5.3.2.3 The Emerging Regions (Brazil, Chile, Australia-New Zealand)

The emerging regions are of particular interest because of the rapid growth in harvest levels over the forecast horizon. Here we test the sensitivity of the model results to the harvest levels in these regions. For this scenario we have assumed that the harvest increases are only one-half of the volume projected in the BASE CASE.

Harvest reductions in the emerging regions and the remainder of the world are shown in Table 5.10, along with world price trends. One of the interesting features of this scenario is that the harvest outside the emerging regions barely responds to removal reductions in 1985 and 1990. This may be attributed to the timber mix: much of the reduction in the early periods are small nonconiferous trees that are used as fuelwood, and hence not traded in the GTM.

Since harvest reductions are concentrated in the coniferous market in this scenario, we direct our comments to these results. The brunt of the harvest reduction in Brazil is borne at home. Most of the reduction is in large trees, and this significantly reduces the production of coniferous sawlogs. By 2000, domestic consumption of coniferous sawnwood is reduced 22% as prices rise 30%. This dramatic change is relatively isolated from the world market: since Brazil does not trade coniferous sawnwood with other regions of the world historically (largely due to high tariff rates), transportation costs with most regions remain prohibitively high. Only the Western U.S. is able to capture a small amount of market share in Brazil. Veneer and plywood production also decreases by a small amount, and this is reflected in reduced exports to Japan.

The reduction in coniferous large tree production in Brazil also reduces the amount of coniferous pulpwood produced by a significant amount (3.2 mm m^3 in 2000): part of this reduction is accounted for directly by large tree removals, and part is due to the reduction in sawmill and plywood mill residues. The reduction in small coniferous tree harvests has almost no effect on pulpwood markets however, since only 4% of each unit is pulped and the remainder is used for fuelwood. Pulpwood impacts are fairly widely distributed. Coniferous pulpwood exports to the Rest of Latin America are reduced by about 1 mm m^3, resulting in higher harvest levels in that region. Brazil is forced to reduce its production of reconstituted panels, newsprint, and packaging papers, resulting in reduced consumption at home, as well as reductions in exports and increases in imports.

Unlike Brazil, Chile is a large exporter of coniferous sawlogs in the BASE CASE. Harvest reductions in Chile result in large reductions in log exports to the Rest of Latin America (2.0 mm m^3 by 2000) and China (2.7 mm m^3 by 2000). The Rest of Latin America responds by increasing coniferous log production by 1.4 mm m^3, while China increases production by 1.8 mm m^3. China also imports an additional 0.9 mm m^3

of sawlogs from the Western U.S. There is also a small reduction in coniferous sawnwood and veneer and plywood production in Chile.

Coniferous pulpwood production also drops significantly in Chile, and the impact is felt in distant regions. The reduction in 2000 amounts to 3.1 mm m^3 of pulpwood, which had been consumed in pulp mills in Chile. As a result, coniferous white pulp production and exports fall 0.6 mm m^3. The majority of these exports were destined for Western Europe which looks to Sweden as an alternative supply source.

Australia-New Zealand presents a very different case: a region that is export oriented, but dependent on pulpwood markets. The reduction in coniferous harvests in this region is approximately equally split between large and small trees. However, in the BASE CASE Australia-New Zealand is a marginal producer of sawlogs and unable to export these profitably. The logs are downgraded and exported as pulpwood. The harvest reduction in this scenario results in a decline in pulpwood production of 6.8 mm m^3: this entire amount constitutes a reduction in exports to Japan.

More profitable pulpwood markets in Japan encourage increased imports from the Soviet Union (3.9 mm m^3) and the Western U.S. (2.0 mm m^3). This result is particularly interesting in the case of the Soviet Union since their harvest levels are fixed. They divert 1.1 mm m^3 of exports from Finland and the remaining 2.8 mm m^3 is recovered from sawlogs sold as pulpwood; thus, sawlog exports to Japan must be reduced by the equivalent amount.*

The final issue we address in this scenario is: how does Japan cope with the reduction in Soviet sawlog exports? One might speculate that imports from the U.S. would increase. Surprisingly, log exports from the U.S. to Japan also decline, and by a substantial volume (2.5 mm m^3 in 2000, and the reduction was even greater -- 6.0 mm m^3 -- in 1995). However, Japan reacts by importing higher volumes of coniferous sawnwood: an additional 1.8 mm m^3 from the Western U.S. in 2000, and 1.5 mm m^3 from Western Canada. The Western U.S. is able to sustain the higher levels of coniferous sawnwood production (for exports to both Japan and Brazil) and higher sawlog exports to China due to a small increase in sawlog production, a reduction in sawlog exports to Japan, and a reduction in veneer and plywood exports. Of course, further production/consumption adjustments occur in the Eastern U.S. and Eastern Canada as a result of these changes.

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* This occurs due to reclassification of sawlogs to pulpwood. Soviet pulpwood is able to reach such high values because transportation costs to the Japanese market for pulpwood are only one-third those of sawlogs (USD 4/m^3 versus USD 12/m^3).

Table 5.10 Absolute Changes (mm m^3) in Tree Removals and Percentage Changes in World Prices Relative to the BASE CASE Due to Harvest Reductions in the Emerging Regions

	1985	1990	1995	2000
Coniferous Trees:				
Brazil	-1.1	-3.1	-10.2	-19.7
Chile	0	-0.8	- 3.3	- 9.6
ANZ	-0.3	-1.3	- 4.3	- 7.7
Nonconiferous Trees:				
Brazil	-4.9	-7.2	- 7.7	-15.7
Chile	-0.1	-0.2	- 0.2	- 1.3
Emerging Region Total	-6.4	-12.5	-25.7	-54.0
All Other Regions	0.2	0.4	6.8	27.9
Percentage Changes in World Prices:				
Coniferous Logs	0.3	0.9	7.9	11.4
Coniferous Pulpwood	1.0	0.6	4.9	36.5
Nonconiferous Logs	0.2	0.8	1.2	2.1
Nonconiferous Pulpwood	1.5	3.0	7.1	18.7

This last simulation is testimony to the fact that GTM simulation results can be quite labile. There are several examples of how critical the value of different parameters are in the model solution, for example, the relative cost of transporting sawlogs and pulpwood from the Soviet Union to Japan. One of the more disturbing changes is that a reduction in harvest in the emerging regions alters the competitive position of the Western U.S. such that it ships fewer sawlogs and more sawnwood to Japan. What is the justification for this result?

In this scenario, there is a small reduction in Australia-New Zealand coniferous pulpwood exports to Japan in 1990. The increased price of pulpwood attracts higher levels of pulpwood imports from the Western U.S., and causes slightly higher residue prices. A small increase in lumber profitability causes the Western U.S. to ship less sawnwood to the Eastern U.S., and more to Japan. (The adjustments are minor, however, and the Western U.S. does not increase production since it is constrained on a capacity bound.) Coniferous sawnwood exports from the Western U.S. to Japan increase from 0.77 mm m^3 in 1985 to 0.94 mm m^3 in 1990. Recall that transportation costs are formulated as a step function and jump among liner, discount, and charter rates at various tonnages. For coniferous sawnwood, the hurdle rate for moving from discount to charter rates is 0.93 mm m^3 (the volume equivalent of 500,000 long tons). Since transportation costs are recursively linked to volumes, coniferous sawnwood transportation costs between the Western U.S. and Japan fall from USD 53.1/m^3 in 1990 to USD 42.4/m^3 in 1995. This decline is just sufficient to improve the welfare of these regions by trading sawnwood, rather than sawlogs.

5.3.2.4 The Soviet Union

It seems appropriate to discuss the role of alternative levels of timber harvest in the Soviet Union: this region has vast quantities of mature standing timber and its future role in the world market remains very uncertain. However, in spite of the special attention given to the centrally-planned economies in the Forest Sector Project, the model of this region remains a weak link in the GTM structure.

In the version of the GTM being used at CINTRAFOR, changing the level of planned removals in the Soviet Union translates into changes in product output levels: final product production is a direct function of these removals. In the current model structure, there appears to be no reasonable way to determine how much of the increase in removals will be consumed at home and how much will be available for export, either as logs or product.

The second, related stumbling block in implementing alternative harvest levels is that it remains unclear as to how log utilization standards should be changed over time. The model is designed so that resource utilization coefficients are endogenously adjusted on the basis of domestic production levels. However, this provides no allowance for excess raw material production to be exported. Based on some of the original computer code used at IIASA, it appears that log requirements for domestic production were determined, and then additional logs were produced such that total utilization of a tree remained stable at 1980 levels. However, such a scheme is clearly inappropriate if final product output, and hence utilization standards, are rising over time. (Incidentally, tree utilization in the GTM for the Soviet Union in 1980 is very low: two-thirds of every tree harvested is removed from the woods, of which 72% is used as sawlogs and pulpwood, and 28% is used as fuelwood.)

As a result of these difficulties, we were unable to implement a version of the Soviet module that had reasonable simulation capabilities, particularly with regard to changing exogenous harvest levels. In our BASE CASE, Soviet raw material exports were fixed at approximately the level used in the Forest Sector Project base case.

5.3.3 Some Comments on the Evaluation of the GTM Timber Supply Module

In spite of its high degree of simplification, the timber supply module of the GTM captures many of the fundamental relationships that are essential to modeling this sector. Among the strengths of the model are its inclusion of four growing stock classes, and its ability to include resource utilization rates that link resources to product -- logs, pulpwood, and fuelwood -- output. The model also incorporates specialized methods of handling regions with rapidly growing plantations and policy-controlled harvests. Afforestation and deforestation trends may also be exogenously specified.

Building a model of resource behavior that encompasses the entire globe is obviously an enormous task. One cannot hope to incorporate the extensive detail imbedded in a model such as TAMM (Adams and Haynes, 1980). Due to the limitations of the model structure, and the poor quality of data associated with many of the important timber supply concepts, the GTM must be used with extreme caution in studying global resource development.

Simulations of alternative timber supply elasticities produce reasonable results. It is clear that the direction of changes is very sensitive to the original timber price trajectories. When timber supply curves are made more elastic, regions characterized by rising prices and increasing timber scarcity will gain at the expense of those with abundant supplies. The opposite occurs when timber supply curves are made less elastic. The actual solutions can produce a wide array of results at the region and product level, due to the extensive and complex interactions that exist in the model. The GTM was simulated to analyze the interaction of elasticities for large and small trees. The model has the unique ability to consider the changing value of residues, and the changing economic relationships between the solid wood and paper and paperboard sectors. No other forest sector model can simulate behavior for such a variety of important relationships, though one must remember that the parameter estimates in the model are often based on little or no data.

Simulations that affect the rate of shifts in timber supply curves also produce very interesting and intuitively plausible results. Clearly, if timber supply becomes relatively more plentiful in one region, it gains share of the world market. The magnitude of the effects will differ depending on such factors as the size of the change, the products produced in the region, the importance of the region in world markets, and historical trading patterns with other regions. Among other things, these simulations have highlighted the lability of model results to the structure and parameter estimates used in the model.

There are serious questions to be raised concerning the treatment of timber supply as a sequence of short-run events, that is, using annual supply elasticities to solve the model in five-year steps. The model also fails to incorporate any features that allows the timber supply sector to make endogenous adjustments to different price paths: investments in forest land and silvicultural activities are excluded from the model. These features suggest that the resource constraints in the GTM will yield unrealistic results if model simulations lead to widely-divergent price trajectories.

The fixed proportions assumptions in sawlog and pulpwood production also generate some important modeling questions. Relative price changes in timber markets often lead to changes in the relative harvest of trees of different sizes. If pulpwood prices rise, it is likely that more sawlogs will be harvested for pulpwood, and vice versa. In fact, sawlogs are often consumed as pulpwood, even though their prices are not identical (the U.S. South offers a good example). In the GTM, pulpwood prices must rise to the level of sawlog prices before sawlogs will be harvested for pulpwood. Although this formulation is reasonably intuitive, and may be implemented mathematically in a straightforward fashion, it portrays market behavior unrealistically. The problem is particularly crucial since the Canadian regions are marginal sawlog producers in the BASE CASE, and this has serious consequences for the interpretation of much of the sensitivity analysis.

6. TRADE AND TRANSPORTATION

The GTM incorporates an elaborate transportation and trade sector to account for the costs of shipping products between any two regions in the model. The structure provides the capability to analyze a variety of economic and policy scenarios concerning transfer costs between regions. There are two key components in this module: transportation costs and trade barriers (including tariff and nontariff barriers).

6.1 IIASA Trade and Transportation Methodology

6.1.1 Transportation Costs

Transportation cost equations are structured as follows:

$$T_{ij} = C\, D_j^{\,b}\, Q_{ij}^{\,c}\, X_{ij}\, Z_{ij}$$

where:

T = transportation cost in USD/long ton
i = product
j = route
C = constant
D = distance in 100 nautical miles
Q = quantity shipped on route in previous period, 000s of long tons
X = adjustment factor for discount rate
Z = adjustment factor for charter rate

It is important to note that the transportation cost depends on <u>last period's</u> shipment volume. The use of discount rates and charter rates is also linked to the previous shipment volume. The liner rate is applicable to shipments less than or equal to 100,000 long tons.* The discount rate is effective for shipments greater than 100,000 and less than 500,000 long tons. For shipments which are equal to or exceed 500,000 long tons, the charter rate is applied. For certain commodities -- recycled paper, white pulp, newsprint, and packaging paper -- the charter rate is always the relevant rate,

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* For shipments less than 100,000 long tons, this quantity also applies. This formulation has the desirable property that "reasonable" transportation rates are computed even if no shipments are made.

regardless of the tonnage. Before being used in a model simulation, freight rates obviously must be converted from USD/long ton to USD/m^3 or USD/metric ton.

6.1.2 Trade Barriers

There are three types of trade barriers in the GTM: trade bans, trade quotas (that is, inertia constraints and fixed flows), and tariffs. Trade bans are used extensively in the GTM and are implemented simply to reduce computational costs. The rules for determining whether trade is permitted on each individual arc were as follows. The first step was to determine whether trade occurred in the historical data for 1980 (this was the case for 1283 flows). The second step was to eliminate the flow if a small volume was shipped (the cutoff was 10^5 cubic meters or metric tons). This excluded 662 flows, leaving 621 active corridors (1283 minus 662). The third step was to open trade in potentially profitable corridors. If the [import price / (export price + transportation cost)] in 1980 was greater than 1.05, the arc was opened. This added 535 flows. Finally, there must be at least one import flow and one export flow for each product in each region, which resulted in 61 additional flows. Thus, there are 1217 (= 621 + 535 + 61) possible positive trade flows in the GTM solution, out of a total of 4590 theoretically-feasible flows (18 regions *x* 17 regions *x* 15 products).

Trade flows are restricted so that they do not increase or decrease radically from the previous period. The rationale for inertia constraints is that we have observed that historical flows between trading partners adjust relatively slowly. Trade flow constraints are determined as follows. First, the shipment in the previous period is multiplied by inertia adjustment factors,* so that the current flow is bounded as follows:

$$L\ F_{t-5}\ \ .\text{le.}\ \ F_t\ \ .\text{le.}\ \ U\ F_{t-5}$$

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* There appears to be some discrepancy between the values of the inertia multipliers used in the Forest Sector Project (Kornai, 1987), and those used in our version of the GTM. In the FSP, inertia multipliers varied across regions, whereas we use the same factors for all regions.

where:

F = trade flow
t = current solution year
.le. = less than or equal to
L = 0.5
U = 2.0

Second, an alternative upper bound is calculated and used if it exceeds ($U \times F_{t-5}$). This alternative upper bound is computed as:

$$B_t = \max \{\min[a\ Q_{t-5},\ b\ C_{t-5}],\ TRLIM\}$$

where:

B = alternative upper bound
Q = production in the exporting region
C = consumption in the importing region
a = b = 0.10
TRLIM = trade limit = 0.5 mm m^3 or mm metric tons

Obviously, this adjustment is critical in the case of new (potential) trade flows which are zero in the previous year.* Finally, we should note that some flows, particularly those between the Soviet Union and Eastern Europe, are fixed at 1980 levels.

Where relevant, tariffs are included as a part of the total shipment cost. Tariffs are proportional to import price and computed as:

$$a \times (\text{export price} + \text{transportation cost})_{t-5}$$

where:

a = tariff rate, expressed as a fraction

This tariff is then added to the transportation cost to determine the total transfer cost for that arc.

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* In the Forest Sector Project, it appears uncertain as to whether this alternative upper bound was intended to be used for only "new" flows, or for all flows (if this bound exceeded the existing bound). Our version of the model provides this alternative for all flows; however, the choice is clearly arbitrary.

6.2 Theoretical Evaluation

6.2.1 Transportation Costs

A serious problem exists due to the fact that final product supply curves reflect costs at the mill, yet final product demand curves represent prices at the point of consumption. This omission indicates that prices determined within a region will be inconsistent, since there is only one price computed for each region. In cases where one region ships to another, the transportation costs reflect port-to-port charges; thus, intraregional transport costs are omitted on both ends. Since intraregional costs are omitted in all cases, the errors in assessing regional competition may be comparatively small.

The combination of the step function formulation for transportation costs and the fact that transportation costs depend on last period's shipment volume creates artificial barriers to entry. Obviously, transportation costs should depend on the current volume of shipments. With this recursive formulation, a region may find it profitable to expand production, but fail to do so because it is locked into an unfavorable transportation rate. While consideration of distance and volume in determining transport cost seems to be appropriate from a theoretical standpoint, its implementation is poor and impairs simulation flexibility. This is especially true since one has little information on whether a given volume of annual trade is transported in many small shipments or in several large ones.

6.2.2 Trade Bans

The justification for the extensive use of trade bans in the GTM is that reducing the number of potential trade flows reduces computational time,* while including them may not change the model results significantly. In a long-run simulation tool like the GTM, it is not possible to assess the future possibilities for trade flows on the basis of historical patterns and historical profitability. This is particularly true if one introduces economic or policy scenarios that significantly alter the competitive relationships of different regions. Thus, widespread elimination of trade flows could significantly distort the results of scenario analysis.

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* To assess the time and cost savings that we obtain from implementing trade bans, we solved the model for four forecast periods with and without trade bans in effect. When the trade bans are removed, the model required approximately 25% more iterations to reach an optimal solution in each period.

Trade bans also provide a clear example of problems that may arise when one segment of the model is conditional on another segment that may be misspecified. In this case, many minor flows are eliminated because they don't meet potential profitability criteria. However, they are examined using high transportation costs that may not be relevant if a sizable volume of trade could be generated.

6.2.3 Inertia Constraints

Trade inertia constraints are justified on the grounds that trade flow patterns appear to adjust slowly over time. If trade flows adjust slowly due to factors such as long-term contracts and consumer tastes, then these are factors which cannot be accounted for in the economic specification of the model, and alternative methods of incorporating these factors should be considered. On the other hand, if trade flows adjust slowly because costs or capacity adjust slowly, then trade flows should adjust properly if the model is specified correctly. Regardless of the specification of costs and capacity, a high probability remains that trade flows will adjust too rapidly because of the assumptions of the spatial equilibrium model, that is, the overall model structure may be misspecified. In this case, one must seek an alternative model structure if one hopes to forecast trade flows with any accuracy.

Trade inertia bounds seem to be an inappropriate method to address the above difficulties. Not only are the bounds arbitrary, but they generate "noneconomic" behavior. Although quantity adjustments are slowed by these constraints, the resulting price movements contradict the basic assumptions of the model. Products may be delivered to a region at a substantial premium over domestic goods. These higher-priced items have no effect on demand levels since only equilibrium prices are considered in the demand formulation. Due to their inability to account adequately for both quantity and price effects, inertia constraints are of dubious value in the GTM.

6.2.4 Tariffs

The GTM offers a great deal of flexibility in terms of implementing tariffs on any commodity imported by any region. The only drawback with the tariff formulation is that the tariff is based on the price of the commodity delivered in the previous period. This will lead to minor errors in the case of high-value commodities.

However, for low-value commodities such as logs, this could significantly influence the model results, particularly if prices are changing much over time.

6.3 Sensitivity Analysis

Sensitivity analysis for the trade and transportation sector is described in the following section. These tests were relatively easy to implement because of the flexibility of the GTM with regard to trade-related issues.

6.3.1 Transportation Costs

Here we explore the importance of the recursive-step function formulation for transportation costs. The following example from the BASE CASE illustrates the general nature of problems encountered. Australia-New Zealand loses market share to the U.S. West and Soviet Union in the Japanese coniferous sawlog market in the early projection periods. However, as plantations mature and the harvest of large coniferous trees in Australia-New Zealand expands, this region has already lost its favorable 1980 shipping rate and is unable to recover its competitive position.

The evidence against the GTM transportation formulation is clearly seen in a scenario in which we halve the rate of increase in the timber harvest in the emerging regions. (This scenario was discussed in detail in Section 5.3.2.3.) The burden of the harvest reduction of large coniferous trees in Brazil is absorbed at home. The rapid increase in domestic coniferous sawnwood prices and concomitant consumption reduction remains relatively isolated from the world market. Since Brazil does not trade coniferous sawnwood with other regions of the world historically (in part due to very high tariffs), transfer costs remain extremely high even when the tariff is removed in 1990.

One test of this structure may be conducted by assuming that transportation costs are not sensitive to the quantity of material shipped, and thus remain fixed over time. We assume that the most favorable rates (charter rates) are obtainable and that the transportation cost that applies for a shipment of one million long tons per year is the appropriate rate. Although the purpose of this test is to eliminate erratic transportation rate fluctuations, the details of the results will obviously depend on the cost level (hence the shipment volume) that has been selected.

This scenario has very little impact on world output levels, as we would expect. The "new" transportation rate is very similar to the original transportation rates for corridors with a significant volume of trade. However, there are some notable changes in production and bilateral trade flows because some regions are now able to compete more effectively in the world market. For example, with the restructured transportation cost module, Australia-New Zealand retains its competitive position in solid wood markets, and exports coniferous sawlogs and sawnwood to Japan, China, and the Rest of World when plantations mature.

A brief description of changes in the nonconiferous sawlog market will demonstrate the general nature of changes in this simulation. In the BASE CASE 373.8 mm m^3 of nonconiferous logs are produced in 2000, and 41.3 mm m^3 are traded. Southeast Asia is by far the largest exporter (34.1 mm m^3) and it ships logs almost exclusively to Japan (18.9 mm m^3) and China (14.9 mm m^3). The Eastern U.S. ships 3.6 mm m^3 of nonconiferous logs to Western Europe and Western Canada ships 2.0 mm m^3 to Japan. There is a dramatic shift in this pattern of trade when the new transportation costs are implemented. Worldwide nonconiferous log production in 2000 is virtually unchanged at 372.9 mm m^3. However, the Eastern U.S. now exports 1.4 mm m^3 of nonconiferous logs to Western Europe and 9.6 mm m^3 to Japan. Total exports of nonconiferous logs from Southeast Asia are substantially reduced: 5.9 mm m^3 are shipped to Japan and 17.5 mm m^3 to China. Western Canada ships 1.6 mm m^3 to Japan.

The dramatic trading realignment for nonconiferous logs occurs primarily for the following reasons. The Eastern U.S. does not export nonconiferous logs to Japan in 1980 and thus projected transportation rates are prohibitive. However, in this scenario, the Eastern U.S. is able to penetrate the Japanese market when nonconiferous log prices rise. The relevant transportation costs along these arcs (in 1980 USD/m^3) in 2000 are:

	BASE CASE	Alternative
SEA to JAP:	47.8	51.3
SEA to KIN:	46.4	49.0
EUS to WEU:	52.8	54.3
EUS to JAP:	141.4	63.5
WCA to JAP:	54.2	54.2

The price of nonconiferous logs in Japan is lower in this alternative simulation due to the availability of a cheaper supply source. The price in Southeast Asia is also reduced due to the decline in production.

6.3.2 Trade Bans

To test the importance of the widespread use of trade bans in the GTM, we have simulated the model with all corridors open to trade. We implemented this scenario by developing a small Fortran program to rewrite the ATFU file so that all arcs were appropriately represented.

Percentage changes in output and trade at the world level in 2000 are shown in Table 6.1. Output changes are significant for only a few commodities; however, there are some dramatic changes in the volume of trade. Trade in some commodities rises sharply, but there also are some significant decreases. The number of positive flows for each commodity is also shown by commodity. The increases in the number of flows are generally quite small, undoubtedly because of the high transportation costs on most routes that have little or no trade in the historical period.

To understand some of the forces that drive these changes, consider six of the new flows that occur in nonconiferous sawnwood markets. The Eastern U.S. dominates production in the BASE CASE, accounting for 28% of the world total in 2000. When all trading corridors are opened, production in this region increases by 14%, or by 5.5 mm m^3. The corresponding increase in exports in 8.1 mm m^3. Over half of these new exports are shipped to countries (Brazil, Chile, and Finland) to which trade was banned in the BASE CASE. Western Canada also ships nonconiferous sawnwood to the Rest of World in this case, while the Western U.S. exports to Japan and the Rest of World (previously prohibited regions). Because of the complexity of product and region relationships in the GTM, it is not possible to predict which flows will become positive when trade corridors are opened. Only three of the above six flows would be profitable in the BASE CASE, but the changing patterns of production and consumption cause positive flows to occur on all six arcs in this simulation.

Table 6.1 Percentage Changes in World Output and Trade Relative to the BASE CASE in 2000 Due to Eliminating All Trade Bans, and Number of Positive Trade Flows in Both Scenarios

	Percent Change		Number of Positive Flows	
	Output	Trade	BASE	No Trade Bans
Solid Wood Products:				
CSAW	0.4	2.3	47	51
NSAW	2.8	32.1	40	46
VEPY	-	-	29	31
BOAR	-	4.5	17	18
Paper and Paperboard:				
NEWS	- 0.2	- 2.2	26	31
PRNT	- 0.4	- 0.9	23	26
HHSP	- 0.1	-10.0	4	5
PACK	-	- 4.4	41	42
Intermediate Products:				
RCYC	- 0.2	- 1.7	17	23
CWIP	- 0.1	- 8.2	34	37
NWIP	- 0.7	2.7	27	32
Raw Materials:				
CLOG	0.6	- 9.5	29	28
NLOG	1.9	- 9.5	17	17
CPWD	- 0.1	4.8	30	29
NPWD	- 0.2	25.7	11	16

6.3.3 Inertia Constraints

There are two modifications that we implement in the GTM to conduct a simulation demonstrating the importance of the inertia constraints. First, we change the potential adjustment in trade flow bounds as follows: the lower bound is reduced from 50% of the previous flow to only 1%; the upper bound is increased from 200% of the previous flow to 999%. Second, we change the trade limit on new flows from 0.5 mm m^3 or 0.5 mm metric tons to 9.99. These modifications essentially open the trade window on all corridors so that trade flows are not bounded.

Table 6.2 summarizes the resulting percentage changes in world output, prices, and trade relative to the BASE CASE in 2000. As with the "no trade ban" scenario, the output changes at the world level are fairly small, while the changes in world trade are quite dramatic. Price changes are also relatively minor, except for some of the raw materials. Thus, we have obtained similar output and price results using a less constrained version of the original problem. This suggests that it may be feasible to assess general trends in world output and prices without being overly concerned about trade patterns on individual arcs.

Note that the largest increase in world output occurs for nonconiferous sawnwood. In the BASE CASE solution in 2000, 82% of the volume of nonconiferous sawnwood traded is constrained. The active bounds are the upper limits in almost all cases. When the trade bounds are released, trade flows expand, and production shows significant increases.

Table 6.2 Percentage Changes in World Output, Prices, and Trade Relative to the BASE CASE in 2000 Due to the Elimination of the Inertia Constraints

	Output	Price	Trade
Solid Wood Products:			
CSAW	1.6	- 1.9	7.3
NSAW	4.2	1.5	10.1
VEPY	0.2	- 0.1	-17.6
BOAR	0.4	- 0.7	-12.8
Paper and Paperboard:			
NEWS	- 0.2	- 0.2	5.5
PRNT	0.1	- 0.1	- 0.8
HHSP	-	- 0.1	-10.0
PACK	0.1	- 0.2	- 6.2
Intermediate Products:			
RCYC	- 0.6	0.7	28.7
CWIP	- 0.8	1.2	- 2.8
NWIP	- 0.8	- 3.0	- 2.0
Raw Materials:			
CLOG	1.6	0.3	- 9.0
NLOG	3.0	5.1	17.4
CPWD	-	12.1	-10.7
NPWD	- 0.4	-14.4	53.3

The number of positive trade flows in the BASE CASE and the "no inertia constraints" scenario are presented in Table 6.3. As expected, the bounds are critical in diversifying trade among producing and consuming regions. When the bounds are removed, trade patterns become much more highly concentrated than they appear in the BASE CASE.

While the more balanced distribution of trade flows in the BASE CASE is clearly more consistent with historical trade patterns, a very high percentage of trade is established at trade bounds. The middle two columns of Table 6.3 show the percentage (by volume) of trade flows that are binding in the two cases. As a result of these active constraints, the solution levels are highly artificial and likely to poorly predict future trade flows. Thus, it is important that we not overemphasize the usefulness of inertia constraints in obtaining a balanced trade solution.

The next to last column of this table shows the number of flows in the BASE CASE that are needed to account for 90% of the trade volume. In spite of the inertia constraints, it is clear that the majority of BASE CASE trade still occurs on a limited number of arcs.

Table 6.3 Number of Positive Flows and Percentage of Binding Flows in the BASE CASE and "No Inertia Constraints" Scenario in 2000, and BASE CASE Concentration of Flows in 2000

	Positive Flows		Binding Flows Percent by Volume		Largest BASE CASE Trade Flows	
	BASE	No Inertia	BASE	No Inertia	Number	% Trade
Solid Wood Products:						
CSAW	47	10	25	3	13	91
NSAW	40	11	82	1	16	91
VEPY	29	10	33	0	4	94
BOAR	17	4	45	11	4	90
Paper and Paperboard:						
NEWS	26	12	4	0	6	91
PRNT	23	8	8	0	5	91
HHSP	4	2	25	1	3	90
PACK	41	12	34	0	13	90
Intermediate Products:						
RCYC	17	8	52	2	9	91
CWIP	34	19	11	0	11	90
NWIP	27	14	44	0	10	91
Raw Materials:						
CLOG	29	9	32	2	4	90
NLOG	17	5	8	0	3	91
CPWD	30	7	32	3	9	92
NPWD	11	6	86	0	4	92

6.3.4 Tariffs

A simulation considering the importance of tariffs differs from the previous three simulations in an important way. The previous three simulations constitute direct tests of model structure. Although a simulation involving tariffs also provides a useful test of model behavior and structure, it constitutes an important test of alternative forest sector policies as well.

We choose to examine a scenario in which all tariffs are eliminated. In the current version of the GTM, all tariffs are set to zero by simply changing the flag for trade liberalization in the ACEN file. Tariffs are quite significant in the BASE CASE, but vary considerably across products, regions, and time. For example, nonconiferous sawnwood tariffs in 1985 are: Canada, 2%; Brazil, 56%; Chile, 50%; Rest of Latin America, 30%; Africa, 20%; Southeast Asia, 40%; and Rest of World, 50%. All of these tariffs are removed in 1990. On the other hand, tariffs for veneer and plywood in 1985 are: Canada, 15%; U.S., 20%; Brazil, 56%; Chile, 50%; Rest of Latin America, 30%; Finland and Sweden, 2%; Western Europe, 11%; Africa, 20%; Japan, 20% or 10%, depending on the country of origin; Australia-New Zealand, 30%; and Rest of World, 50%. The tariffs are removed in 1990 for only Brazil, Chile, Rest of Latin America, Africa, and Rest of World. For the other regions the tariffs are halved, and held at that level for the remainder of the forecast horizon.

Percentage changes in world output, prices, and trade relative to the BASE CASE in 1985 and 2000 are shown in Table 6.4. Generally, we observe significant increases in trade for final products. The outcomes for intermediate and primary products are more erratic, due to the shifting producing and consuming patterns for final products. As with other scenarios, there are a large number of indirect impacts that occur due to the complex region and product interactions.

Given the high levels of tariffs in the BASE CASE, particularly in 1985, the changes in the levels of world output and prices appear relatively small. Two factors that contribute to this behavior are: 1) many corridors are closed to trade due to trade bans; and, 2) transportation costs remain high on many corridors because of the small volume of trade (often due to high tariffs) in the historical period. Thus, the impacts are quite limited in scope. Consider some of the 1985 results for solid wood products. Nonconiferous sawnwood trade increases 25% over BASE CASE levels. In spite of the widespread removal of high tariff rates, this result is almost entirely due to a large increase in exports from Southeast Asia to the Rest of World. In contrast, there is almost no change in the level of world coniferous sawnwood trade. However, there are significant changes in trade on five arcs (still a relatively small number of corridors). We observe large increases in exports from Western Canada to Japan, Eastern Canada to the Eastern U.S., and Sweden to Africa, and large decreases in exports from Western Canada to the Western U.S. and the Western U.S. to Eastern U.S. The pattern of results for veneer and plywood trade lies somewhere in the middle. Trade rises 9% due to increased exports from the Western U.S. to Eastern U.S., Finland to Western Europe, and Southeast Asia to Rest of World.

Table 6.4 Percentage Changes in World Output, Prices, and Trade Relative to the BASE CASE in 1985 and 2000 Due to the Elimination of All Tariffs

	1985			2000		
	Output	Price	Trade	Output	Price	Trade
Solid Wood Products:						
CSAW	- 0.2	1.0	- 0.7	- 0.5	0.6	6.2
NSAW	1.6	- 0.6	25.4	3.5	- 2.0	4.8
VEPY	- 0.4	2.4	8.7	1.1	- 1.3	34.8
BOAR	- 0.1	0.3	2.8	- 0.4	0.9	5.3
Paper and Paperboard:						
NEWS	0.8	- 1.0	0.7	- 0.5	1.1	3.5
PRNT	0.2	- 0.6	1.3	- 0.1	0.3	1.0
HHSP	-	- 0.1	-	- 0.1	0.3	-
PACK	-	-	6.6	- 0.1	0.2	25.6
Intermediate Products:						
RCYC	- 0.4	- 0.1	0.3	- 1.3	- 1.2	-14.9
CWIP	0.3	0.2	- 0.2	-	1.7	-11.7
NWIP	- 0.1	- 0.8	- 2.4	-	0.7	2.7
Raw Materials:						
CLOG	- 0.1	- 1.1	- 8.0	1.6	4.1	- 7.2
NLOG	1.2	2.9	- 2.7	- 0.4	- 0.7	-28.3
CPWD	0.3	0.2	- 1.5	0.2	4.5	14.6
NPWD	-	0.1	16.5	0.1	3.4	31.7

There is another tariff scenario that is of interest, particularly to analysts in North America. Unlike the Forest Sector Project simulations, our BASE CASE includes a 15% tariff in the U.S. on coniferous sawnwood imported from Canada. We have run a simulation eliminating this tariff. Because this change is quite specific, the simulation results are more tractable. At the world level, we observe very little or no change in production and prices.

At the regional level however, there are some important shifts in production and trade of coniferous sawnwood. Table 6.5 presents percentage changes in price, and volume changes in production relative to the BASE CASE in 2000 for some key regions that produce coniferous sawnwood. Some of the changes are straightforward, such as the increase in prices in all regions except the U.S., the increase in Canadian output, the reduction in U.S. output, and the increase in European production. However, some changes, such as the reduction in Japanese production and regional shifts, are complicated by the interaction of products and the solution of the previous periods. Also, the magnitude of the price changes is distorted by the presence of binding trade constraints in the BASE CASE solution (particularly on Canadian to U.S. flows).

The results for other commodities provide some insight into the behavior of sawnwood markets. Although coniferous sawnwood prices in the Western U.S. decline, coniferous sawnwood production and exports increase due to the reduction in plywood exports to the Eastern U.S. and the reduction in coniferous sawlog exports to Japan. The increase in coniferous sawnwood production in Canada occurs in the East -- this is made possible by upgrading a substantial volume of pulpwood to sawlogs. The higher prices for Canadian lumber causes a reduction in overseas exports, and results in higher production in Western Europe, Finland, and Sweden. Finally, Australia-New Zealand increase shipments of coniferous sawnwood to the Rest of World. As with Eastern Canada, this is made possible by upgrading pulpwood logs to sawlogs.

Table 6.5 Percentage Changes in Prices and Volume Changes in Production and Trade Relative to the BASE CASE in 2000 Due to Removal of the U.S. Tariff on Canadian Coniferous Sawnwood

	Price	Production		Exports (mm m^3) to:		
	% change	mm m^3	EUS	WEU	JAP	RWO
WCA	0.9	- 0.7			- 0.7	
ECA	1.6	3.1	5.9	- 2.8		
WUS	- 9.1	2.7			2.4	
EUS	- 5.8	- 4.6				
FIN	1.1	0.1		2.9		- 1.3
SWE	1.1	0.1		- 0.7		- 0.6
WEU	1.0	0.2				
JAP	0.7	- 1.8				
ANZ	0.7	1.0				1.0

6.3.5 An Alternative Trade and Transportation Formulation

We have examined three key features of the specification of the trade and transportation sector: transportation costs, trade bans, and inertia constraints.* The theoretical discussion suggests there are problems with the specification that cause trade to be unduly restricted. The simulations and sensitivity analysis suggest these are generally of minor importance with respect to world production and price levels; however, they critically affect trade and regional production patterns. It is quite possible that some impacts were significantly understated because of the interaction of these three components. For example, modified transportation costs may have a much greater impact when trade bans are eliminated and/or inertia constraints are removed.

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* We do not include tariffs in this group since they are more properly classified as a policy issue rather than an issue in model specification.

Here we test the overall importance of the BASE CASE specification by conducting a simulation with simultaneous changes to all three elements: transportation costs are fixed at charter rate levels, trade bans are eliminated, and trade inertia constraints are removed.

Table 6.6 shows percentage changes in world output levels, and compares percentage changes in trade relative to the BASE CASE in 2000 across the relevant scenarios. Since it is difficult to summarize these results, we provide only the following observations. First, changes in trade between the simulation with the combined changes and the BASE CASE are dramatic, particularly for the intermediate and primary products. Second, the direction of the changes is unpredictable. For example, coniferous sawlog shipments increase, while coniferous sawnwood shipments fall; however, we observe the opposite pattern for nonconiferous sawlogs and sawnwood. Third, the relationship between the combined case and individual cases is also unpredictable. For example, veneer and plywood trade tends to decrease when the inertia constraints are released, and increase when transport costs are reduced; however, the combined result falls between these. In coniferous sawnwood trade, each individual case causes coniferous sawnwood trade to increase, but the combined result shows a significant decline. The opposite result -- reductions in trade for all of the individual scenarios, but increased trade for the combined case -- occurs for packaging papers.

The results for the number of trade flows are interesting. The total number of positive trade flows in 2000 in the scenario in which inertia constraints are eliminated is 137. In the alternative trade and transportation scenario (the combined case), we observe 172 positive trade flows. This compares with 392 flows in the BASE CASE and 432 flows in the case with trade bans removed, but the original inertia constraints and transportation cost module retained.

Table 6.6 Percentage Changes in World Output in the Alternative Trade and Transportation Scenario and Percentage Changes in Trade for Several Trade Scenarios Relative to the BASE CASE in 2000

		Trade Scenario			
		Combined Changes	Charter Rates	No Trade Bans	No Inertia Bounds
	Output	Percent Change in Trade from BASE			
Solid Wood Products:					
CSAW	1.5	-15.1	6.1	2.3	7.3
NSAW	5.5	9.9	0.9	32.1	10.1
VEPY	2.3	9.2	12.4	-	-17.6
BOAR	1.2	- 7.5	44.4	4.5	-12.8
Paper and Paperboard:					
NEWS	- 0.9	- 3.4	0.3	- 2.2	5.5
PRNT	- 1.0	25.6	11.3	- 0.9	- 0.8
HHSP	- 0.1	-15.0	20.0	-10.0	-10.0
PACK	0.2	2.4	- 3.6	- 4.4	- 6.2
Intermediate Products:					
RCYC	- 1.7	-30.9	-	- 1.7	28.7
CWIP	- 0.5	-48.6	- 6.3	- 8.2	- 2.8
NWIP	- 2.4	-25.2	- 7.4	2.7	- 2.0
Raw Materials:					
CLOG	3.2	86.8	- 4.5	- 9.5	- 9.0
NLOG	1.0	-39.1	- 7.1	- 9.5	17.4
CPWD	- 0.3	42.7	2.7	4.8	-10.7
NPWD	- 0.6	186.0	55.9	25.7	53.3

The increased flexibility in the trade and transportation sector suggests that prices should have a greater tendency to equilibrate across regions. To test this notion, we compute the standard deviation of prices for the 18 regions in the 2000. The results for a selection of commodities are shown in Table 6.7. As expected, the alternative formulation of the trade and transportation sector insures that prices show less divergence at any point in time.

Table 6.7 Standard Deviation of Regional Prices (in USD/m^3) in 2000 for the BASE CASE and the Alternative Trade and Transportation Scenario

	BASE CASE	Combined Changes
Coniferous sawlogs	19.9	13.4
Nonconiferous sawlogs	29.1	19.9
Coniferous sawnwood	24.8	17.6
Nonconiferous sawnwood	26.9	14.9
Veneer and plywood	42.2	28.0

7. MISCELLANEOUS FEATURES OF THE GTM:
EXCHANGE RATES AND THE CENTRALLY-PLANNED ECONOMIES

In this section, we explore several important features of the GTM that have been discussed only briefly within the major modules. These include exchange rates and the modules for the Soviet Union, Eastern Europe, and China.

7.1 Exchange Rates

7.1.1 IIASA Methodology

Indexes of real exchange rate adjustments in the GTM are computed as:

$$XCR_{jt} = PI_{jt} / X_{jt}$$

with:

$$PI_{jt} = PPI_{jt} / PPI_{US,t}$$

$$X_{jt} = XCHG_{jt} / XCHG_{j,1980}$$

and, where:

XCR_{jt} = factor to adjust currency of region j to real U.S. dollars in period t

PI_{jt} = producer price index of region j relative to U.S. in period t, PI(1980) = 1.00

X_{jt} = relative nominal exchange rate of currency of region j between 1980 and period t

PPI_{jt} = producer price index in region j in period t

$PPI_{US,t}$ = producer price index in the U.S. in period t

$XCHG_{jt}$ = exchange rate of currency of region j per U.S. dollar in year t

Using the example from Kallio (1987), we calculate XCR for Sweden in 1985 as:

$PI_{SWE,1985}$ = 1.3

$XCHG_{SWE,1985}$ = 8.65 Krona / USD

$XCHG_{SWE,1980}$ = 4.20 Krona / USD

$X_{SWE,1985}$ = 2.06

$XCR_{SWE,1985}$ = 1.3/2.06 = 0.63

Thus, in terms of costs, Sweden improved its competitiveness relative to the U.S. between 1980 and 1985: Swedish costs fell 37% when measured in U.S. dollars. Although Sweden experienced 30% higher inflation, the marked depreciation of the Krona caused the relative decrease in Swedish costs.

The intuition behind the exchange rate adjustment is straightforward. Real costs in a foreign currency are converted to real U.S. dollars by multiplying by real U.S. dollars per real foreign dollar.

Real exchange rate adjustments are applied in three parts of the model: product demand curves, timber supply curves, and product supply curves (excluding capital). Items which are not adjusted by exchange rates are capital costs and transportation costs.

The curves which are adjusted by the real exchange rate are simply multiplied by XCR. If XCR is less than one, then the U.S. dollar has appreciated relative to foreign currencies. In the case of a final product demand curve, the curve shifts downward on a percentage basis (that is, it rotates downward from the quantity intercept). Thus, consumers in the foreign region can purchase the same quantity of goods with fewer U.S. dollars. For timber and product supply, the curves also rotate downward: foreign producers are willing to produce the same quantity of goods for fewer U.S. dollars.

7.1.2 Sensitivity Analysis

The BASE CASE exchange rates show substantial appreciation of the U.S. dollar between 1980 and 1985, and this trend is moderately reversed in 1990: by 1990, the U.S. dollar was projected to recover 2/3 of the real devaluation that occurred between 1980 and 1985. To test the sensitivity of the GTM to exchange rate changes, we simply change all relative exchange rates to 1.00. Thus, the relationships between the U.S. dollar and other currencies remain at 1980 levels. In the current version of the GTM, this modification is easily implemented using a 0-1 lever in the ACEN file.

As we discussed in the BASE CASE review (Section 2.2.2), the change in exchange rates over time contributes significantly to the pattern of BASE CASE price projections. In Table 7.1, we present the percentage changes in world output and prices compared to the BASE CASE for 1985 and 2000. As we would expect, prices rise dramatically for all products (except recycled paper) in 1985. The depreciation of the dollar (relative to the BASE CASE) results in significant upward shifts in demand and supply curves expressed in U.S. dollars. We also observe price increases across all commodities in 2000; however, the price increases are much smaller since the exchange rate shifts are substantially less in later periods.

World output also increases for all commodities in 1985 and for all commodities except recycled paper in 2000. We observe this fairly uniform output behavior primarily because demand curves shift relatively more than supply curves. The supply curve shift is limited because capital costs, a significant component of total costs for new technologies, are not affected by exchange rates. The influence of this specification is easily demonstrated by comparing these results with a revised "BASE CASE" scenario in which we assume that capital costs are adjusted by exchange rates. Output changes at the world level in 1985 are: CSAW, 0.2%; NSAW, 1.5%; VEPY, 0.5%; BOAR, -0.3%; NEWS, 3.1%; PRNT, 0.5%; HHSP, 0.7%; and, PACK, 1.3%. All changes are significantly less than those in the alternative presented in Table 7.1. It should be noted that the changes are still nonzero, as identical shifts in demand and supply curves would suggest. If the initial production levels for a simulation are established on production bounds, the result in the alternative simulation is unpredictable and will depend on the step sizes.

At the regional level, prices rise for all commodities in all regions except for coniferous pulpwood in Brazil and for recycled paper in three regions. These changes are easily explained. In Brazil, increases in coniferous sawnwood production generate higher levels of production of manufacturing residues. As a result, the demand for coniferous <u>roundwood</u> declines and coniferous pulpwood prices fall. Recycled paper production in Chile, Rest of Latin America, and Sweden is slightly reduced from BASE CASE levels. Because these regions utilize slack resources, the price decreases are substantial. Since there is no change in recycled prices in several regions, average world prices decline.

The variation in price changes across regions differs significantly across products. For products where trade is truly international (and trade bounds do not play a dominant role), price increases are very similar across regions. For example, the increase in world coniferous white pulp prices is 17.1% in 1985, with regional increases ranging from 13% to 20% and the standard deviation being 1.8. In contrast, world household and sanitary paper prices rise 15.3%, but the increases range from 4% to 50% and the standard deviation is 13.2.

The U.S. provides a particularly interesting case with respect to price changes. Since all exchange rate changes are measured relative to U.S. currency, U.S. consumer demand, product supply, and timber supply curves do not shift; however, the demand for U.S. products in other regions drives prices upward. The increases are sometimes as large as world price increases; however, in many cases the increases lag behind due to trading patterns or trading restrictions.

Production and consumption shifts at the regional level present a much less uniform, and more complicated picture. For example, changes in the consumption of all final products is always nonpositive in 1985 in the four regions comprising Canada and the U.S. This is due to the fact that prices rise, but demand curves do not shift in the U.S. and shift by only a minor amount in Canada. Production usually increases for final products from these regions; however, in some cases production decreases due to shifts in the regional product mix. Obviously, the net result is that exports from these regions generally rise.

Regional changes in consumption tend to be positive in most other regions, except the Soviet Union. The Soviet Union always experiences decreases in consumption. Soviet production is fixed by the timber harvest level, and the higher product prices around the world induce them to export a larger share of their output to earn foreign exchange. The bulk of production changes are positive, but it is more difficult to generalize about these changes due to trading adjustments. Total final products trade increases substantially for all commodities except plywood.

Table 7.1 Percentage Changes in World Output and Prices Relative to the BASE CASE in 1985 and 2000 Due to Constant Relative Exchange Rates

	1985		2000	
	Output	Price	Output	Price
Solid Wood Products:				
CSAW	1.4	18.0	1.8	4.6
NSAW	2.1	28.7	6.1	6.4
VEPY	1.6	19.2	0.9	4.6
BOAR	3.2	19.1	1.6	3.4
Paper and Paperboard:				
NEWS	4.9	13.0	1.1	4.8
PRNT	2.4	17.5	1.2	4.6
HHSP	1.3	15.3	0.5	4.2
PACK	2.4	13.8	1.0	3.5
Intermediate Products:				
RCYC	1.8	- 0.2	- 0.3	0.5
CWIP	2.3	17.1	0.9	6.0
NWIP	2.3	13.6	1.1	1.8
Raw Materials:				
CLOG	1.3	23.7	3.0	8.0
NLOG	2.0	37.9	3.3	8.8
CPWD	3.0	38.0	1.4	12.1
NPWD	2.7	31.4	1.5	0.1

7.2 The Soviet Union

7.2.1 IIASA Methodology

The Soviet Union is modeled very differently than the free market regions of the world. Total timber removals (all species and all sizes) are specified as a scenario parameter. Prior to solving the model in each period, final products production is computed as a function solely of total timber removals. These values are then fixed, and not affected by the model solution.*

Due to some uncertainty concerning model behavior in the original computer code, we have reprogrammed the GTM to behave as we believe was intended in the Forest Sector Project. The growth rate in production between the base year (1980) and the projection year is first calculated. The demand curve for each final product is then shifted by this factor.

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* Some of the model equations lead to drastic reductions in production in the long run. This appears to have been due to some confusion in the use and implementation of linear spline functions. We have constructed an alternative set of equations that lead to fairly moderate production changes in the future.

Consumption and trade between regions is then endogenously determined. If the Soviet Union is initially a net exporter, then it will have an increasing amount (in absolute terms) of product to export at initial prices. However, it need not consume its target level. If prices are sufficiently high in export markets, it will forego some domestic consumption to increase export earnings. There are no nonwood manufacturing costs in the Soviet Union and prices are determined by trade with other regions. However, there is a timber supply curve, and wood prices (log use net of residue yields) establish a lower bound on product prices. When trade does not occur, the previous period's solution is used to determine product prices.

The pulp market is handled in a similar manner. The amount of pulp required in paper production is computed as the consumption figure. Pulp production is then set equal to last period's pulp production plus the absolute change in pulp consumption. Trade patterns are then established based on supply and demand conditions and prices in other markets.

Although total timber removals are determined exogenously, the split of removals between different end uses remains to be calculated. If the production of coniferous sawlogs, nonconiferous sawlogs, coniferous pulpwood, and nonconiferous pulpwood depended solely on final (and intermediate) product production, then these numbers would already be determined. However, there is a significant volume of trade in raw materials that must be accounted for. The computation of primary material production must account for the volume of net exports.

Since net exports and tree utilization should be simultaneously determined, there appears to be no way to adequately determine this allocation. (This issue was also discussed in Section 5.3.2.4.) Based on the original IIASA computer code (provided by Markku Kallio), it appears that the Forest Sector Project incorporated a scheme whereby total timber utilization in the base year (1980) was held constant over time. The procedure was: 1) compute primary material demands for domestic uses as a function of total timber removals; 2) compute the domestic primary material share of total harvest (for example, if 120 mm m^3 of coniferous sawlogs are needed and total timber harvest is 360 mm m^3, the coniferous sawlog share is 0.333); 3) sum the shares in the base year (these shares are 0.367 for CLOG, 0.055 for NLOG, 0.045 for CPWD, 0.016 for NPWD, and 0.184 for FUEL, and they sum to 0.667); and, 4) adjust each share, except FUEL, so that the new shares sum to the base year total. The excess production is then available for export. For example, if 0.33 of the total harvest is necessary for domestic coniferous logs, and the adjusted figure is 0.38, then 0.05 of the harvest will be converted to coniferous sawlogs available for export.

There is one obvious problem with the above scheme. If domestic usage is increasing over time, then no material will be available for export. The procedure also does not allow for improved resource utilization over time. Due to this drawback, and since we have changed the domestic production equations, we have fixed primary material exports so that they basically agree with exports in the Forest Sector Project base case. Clearly, this eliminates model flexibility with regard to changing raw material export levels.

7.2.2 Theoretical Evaluation

There are several conceptual and empirical problems with the model of the Soviet Union that make it difficult to use in the GTM. One problem is that the product supply curves are estimated over a short historical period, and their applicability to long-run projections must be questioned. A second, more important problem, is that they are linked directly to timber harvest. As a result, there is no simple way to allocate increased harvests to domestic production and foreign export. For example, the Soviet Union could greatly expand Siberian log production to increase log exports; however, in the current formulation of the model, harvest increases will be converted into final products within the Soviet Union.

Even if we were able to model final product production accurately, the model still lacks any mechanism for determining timber utilization. As mentioned earlier, the Forest Sector Project approach will result in changing export allocations in a fairly arbitrary fashion. This is particularly important because current resource utilization is quite low indicating there may be significant opportunities for improvement.

7.2.3 Sensitivity Analysis

Direct sensitivity analysis of the Soviet Union module is of comparatively little value for two reasons: 1) the model operates such that endogenous production and consumption adjustments are very much in balance in the Soviet Union; and, 2) due to problems in the primary materials export sector, we have made the model quite rigid so to produce the Forest Sector Project results. For example, if we expand the total Soviet timber harvest in the latter periods from 430 mm m^3 to 600 mm m^3 per year, there are large increases in domestic production and these are effectively matched by increased domestic consumption. Changes in prices and trade and very minor. As a result, the large harvest increase has virtually no impact on international forest products markets.

The model could be reprogrammed so that harvest increases find their way into higher log export volumes. Although we have not conducted this analysis, such a scenario is reported by Dykstra and Kallio (1987b).

There are other scenarios concerning the Soviet module that one might consider. For example, one could change the conversion coefficients for manufacturing final products, thus changing the domestic wood requirements in a given period. However, due to the basic structural difficulties in the current version of the Soviet module, we did not examine such scenarios at this time.

7.3 Eastern Europe

The model of the Eastern Europe has some similarities with the Soviet Union, although it has some unique features of its own. As with the Soviet Union, total timber removals are specified as a scenario parameter; however, removal levels are held constant at 1980 levels and these are imbedded into the computer code.

Production and consumption of final products are increased by the growth rate in demand, and fixed at that level. If demand grows rapidly, then it would be necessary to import significant quantities of raw materials; however, BASE CASE growth is very modest and even negative for some products. For example, solid wood products output changes from 34.6 mm m^3 in 1980 to 30.6 mm m^3 in 2000 (and continues to gradually decline thereafter). In contrast, paper and paperboard production increases from 4.9 million metric tons in 1980 to 5.6 million metric tons in 2000. Since these changes are quite small, increased raw material imports are not a key modeling issue.

It should be pointed out that the theory of demand is similar to that employed for the Soviet Union: a demand curve is shifted and consumption is determined by a target lower bound that may be exceeded at some cost. Due to the specification of the model, it is a mathematical fact that Eastern European consumption is always equal to the lower bound in equilibrium. Thus, no penalty function (or demand curve) is actually included in the GTM for this region.

The pulp market is handled as in the Soviet module. The amount of pulp required in paper production is computed as the consumption figure. Pulp production is then set equal to last period's pulp production plus the absolute change in pulp consumption. Trade patterns are then established based on supply and demand conditions and prices in other markets.

Although total timber removals are determined exogenously, the split of removals between the different end uses remains to be calculated. As with the Soviet Union, these are based domestic production requirements plus exports. Again, exports pose a difficult modeling problem. However, because exports are a fairly small percentage of total production, we simply utilize the procedure provided in the GTM. Exports are determined by summing the lower bounds on exports from the previous period. This ensures that there will be at least enough material to satisfy trade requirements. However, with this mechanism, exports are gradually phased out over time.

One last item that should be mentioned is fixed trade flows. Because of institutional considerations, trade between Eastern Europe and the Soviet Union is fixed in many cases. These flows are held constant over the forecast horizon.

Trade between Eastern Europe and regions other than the Soviet Union is endogenously determined. As with the Soviet Union, there are no nonwood manufacturing costs and prices are determined by trade with other regions. However, there is a timber supply curve, and wood prices (log use net of residue yields) establish a lower bound on product prices.

7.4 China

The China module is a mixture of free market and centrally-planned forces. Demand for final products in China is modeled in the same manner as for the free market economies.

The supply sector is different from the free market models in several important ways. First, there are no nonwood manufacturing costs (like the Soviet Union). Second, capacity does not adjust on the basis of profitability, since profits are not clearly defined. Instead, there is an upper bound on capacity that is shifted by the same percentage as the shift in product demand. Hence, production will increase to meet necessary consumption levels. Prices are determined by trade, or in the event that there is no trade, by last period's prices. As with the Soviet Union, wood costs provide a floor for final product prices.

Because of the structure of the Chinese module, the GTM allows for significant expansion of final product industries. Before it is profitable for China to import final products, it can expand production until wood costs reach the level of total costs in other regions. However, the expansion of the timber harvest is controlled by the possibility of log imports from other regions. China imports a significant volume of logs from the Western U.S. because they are less expensive than logs produced domestically.

The demand and supply of intermediate products works in much the same way, and reflects a combination of the free market and Soviet models. The upper bound on paper and paperboard products is used to determine the upper bound on intermediate product production; however, actual production will depend on the outcomes in the final products market.

The demand and supply for logs is based on a free market structure. Log demands are determined from the equilibrium solution for final and intermediate products. Log supply is based on timber inventory and prices. Log prices are determined from the intersection of these two functions, and foreign trade ensures that log prices do not deviate from levels consistent with the price of logs available from other regions.

8. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS*

This section summarizes our evaluation of the IIASA Global Trade Model. Here we highlight our major conclusions and provide recommendations for modifying and improving the GTM. Sections 8.1 and 8.2 provide descriptions of the overall strengths and weaknesses of the model. Sections 8.3 to 8.7 discuss the major modules -- the organization parallels that of the manuscript. Some broad conclusions are presented in the final section.

8.1 Overall Strengths of the GTM

The GTM provides new opportunities to understand the interactive behavior of forest products markets, due to the simultaneous determination of production, consumption, and prices for final products, intermediate products, and raw materials. The availability of residues from sawnwood and plywood production affects the cost of fiber in pulp and paper production. At the same time, the price of fiber in pulp and paper production affects the profitability of sawnwood and plywood manufacturing. Sawlogs may also be downgraded to pulpwood when markets warrant such a shift.

The GTM opens new and rich opportunities to study forest sector and trade analysis, due to its breadth of regional and product coverage. Regional models often miss many of the complex linkages that characterize forest sector markets, thus misrepresenting the impacts of important forest sector policies.

8.2 Overall Weaknesses of the GTM

In any economic model with a worldwide scope, the supporting data base will be weak due to poor (or nonexistent) data in many regions. Although IIASA had the advantage of access to an extensive network of forest scientists throughout the world, it was not possible to meet adequately many of the model's data requirements. Problems with the data base are complicated by poor documentation of unpublished data sources: in many cases it is extremely difficult to replicate or update these data.

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* Much of the material in this section was presented at the symposium "Forest Sector and Trade Models: Theory and Applications," which was held at the University of Washington on November 3-4, 1987. Thus, it was previously published (see Cardellichio and Adams, 1987) as part of the symposium proceedings.

Data base problems raise serious questions concerning model maintenance and future development.

Recommendation: GTM users should consider developing their own data base. At minimum, all data and parameter estimates should be updated to 1985, or a more current year.

It is generally not possible to validate large-scale economic models according to any rigorous or systematic criteria. Difficulties in validating the GTM are compounded by the fact that its cost structure mimics long-run behavior; thus, GTM projections are not valid for a single point in time. Furthermore, the GTM is a spatial equilibrium model: by virtue of its underlying assumptions, it will not reproduce actual trade flows with much accuracy, and this may lead to faulty assessment of its predictive power. Thus, for a given set of exogenous assumptions, the predictive accuracy of the GTM is highly uncertain. It follows that the accuracy of model simulations of alternative economic or policy scenarios -- the answers to "what if" questions -- will also be highly uncertain. GTM validation must be subjective and its structural design and parameterization will remain a matter for debate.

The specification of economic behavior in the GTM is much too rigid for long-run simulations which involve significant changes in endogenous variables. The only endogenous economic adjustments in the GTM are short-run changes in final product demand and delivered wood supply. This suggests the model will yield unrealistic results for simulations involving major economic or policy shocks: it is likely that price responses will be exaggerated, while quantity responses will be understated. The lack of appropriate adaptive behavior and feedback mechanisms is evident in several areas of the model: technologies defining raw and intermediate material consumption are exogenous; manufacturing costs are exogenous; timberland area and silvicultural investment are exogenous (furthermore, timber supply is perfectly inelastic for a significant share of the world's production); trade bans and inertia constraints are exogenous; and, product demand and timber supply elasticities are independent of price trajectories.

8.3 Final Product Demand

Final product demand is modeled as a nonlinear function of price where the hypothesized relationship is a constant-elasticity form; however, linear approximations of these functions are utilized in the GTM spatial solution. Linear demand curves choke off final products demand too rapidly when product prices are rising. Thus, if demand curves are thought to be nonlinear, linearization of these curves will lead to projections or policy simulations with unintended or misleading demand responses.

Recommendation: Final product demand curves should be nonlinear.

There are two critical problems with the demand function specification in the GTM. First, cross-price elasticities are infinite for coniferous and nonconiferous plywood, but zero for all other commodities. The assumption that coniferous and nonconiferous plywood are perfect substitutes will mislead model users in understanding how economic and policy changes affect the relative use of coniferous and nonconiferous logs. Cross-price elasticities for commodities other than veneer and plywood have been omitted from the demand specification. Since price trajectories differ markedly across products, this is likely to be an important simplification. Since the potential for substitution is not endogenously incorporated in the GTM, the power of the GTM as a <u>long-run</u> simulation tool is significantly weakened.

Recommendation: Final product demand curves should incorporate cross-price elasticities.

The second problem with the demand specification is that demand is estimated as a function of real income only. This formulation does not adequately reflect the varied array of end uses for which forest products are employed. As a result of this simplification, the parameter estimates associated with the demand functions are likely to be biased and inconsistent, and the ability to simulate demand-side changes is unduly restricted.

Recommendation: Final product demand curves should incorporate appropriate end-use indicators.

8.4 Product Supply

Product supply is modeled as a horizontal-step function, consisting of three steps corresponding to "old," "current," and "new" production technologies. Fixed proportions are assumed for resource use within each step. Under this formulation, regions tend to specialize in the production of particular commodities. As a result, the product mix in different regions and the associated pattern of trade may differ substantially from historical patterns.

Recommendation: Product supply curves should be smoothly increasing: it may prove wise to collapse the three distinct technologies to a single technology to simplify data collection and updating, but the capacity expansion sector would need to be modified accordingly.

The product supply curve is very restrictive in the assumption of fixed proportions within each step of the supply curve. Furthermore, technology choice is independent of prices: the third technology (new) is always the technology to be added and the first technology (old) is always the technology to be retired, the retirement rate being exogenous. The evolution of relative wood-labor-capital input costs has no effect on the optimal technology mix over time. Not only do different wood input prices have no effect on the adoption rate of different technologies, they also have no effect on the use of labor or capital. While we recognize that there is little useful empirical work from which to develop parameters to describe such behavior, it is essential to understand that product supply evolves rigidly in the GTM regardless of the different price paths generated by policy simulations.

The IIASA version of the GTM is designed so that every region approaches identical technology targets in the long term. There are four important cases: 1) efficiency in wood, pulp, and wastepaper consumption; 2) transfer rates from coniferous to nonconiferous pulpwood use; 3) generation of usable residues and wood waste in lumber and plywood manufacture; and, 4) recovery rates for paper and paperboard. Since regions start with very different technologies, some regions improve dramatically while others stagnate. Given initial technological states, the rate of convergence often seems much too rapid. Also, the assumed transition is sometimes inappropriate. Ideally, technological goals should depend on prices; at minimum, technological development should be consistent with historical trends, current status, and economic reality.

Recommendation: Technology targets should be made more flexible to allow for variation among regions and products.

8.5 Timber Supply

The GTM recognizes two timber resource categories based roughly on size: "large trees" yielding primarily sawlogs and "small trees" yielding primarily pulpwood and fuelwood. Timber supply curves representing the marginal cost of timber delivered to the mill appear too inelastic, especially for long-run resource analysis. In many regions of the world, harvest and delivery costs account for a substantial portion of delivered wood costs, and elasticities associated with access costs tend to be much higher than those estimated for stumpage alone. Since harvest and delivery costs are a much greater fraction of delivered wood value for small trees than large trees, it follows that supply elasticities for small trees should be substantially higher than those for large trees. The fact that marginal sawlogs can always be downgraded to pulpwood when pulpwood prices rise also argues for more elastic small tree supply. However, large tree and small tree supply elasticities often are assumed to be identical in the GTM.

Recommendation: The timber supply sector should be reconstructed with separate models of stumpage and harvest and delivery costs.

There also are some serious theoretical questions to be raised concerning the model of timber inventory development. The age-class structure of the timber inventory is a critical element which is ignored due to the highly-aggregated nature of the model. Investments in forest land and silvicultural activities are excluded from the model. This yields timber supply curves that are too inelastic in the long term; hence, the model will generate unrealistic results if simulations lead to widely-divergent price trajectories. The rigidities in the timber supply sector for the "exogenous" regions are, by definition, more extreme. While there is some flexibility in the emerging regions (those with rapidly-growing plantation forests) because they are not forced to cut the prespecified volume of removals in a each period, the adjustment potential is modest at best.

Recommendation: Age-class information should be incorporated in the inventory model where possible.

The GTM incorporates the assumption that trees are converted to sawlogs, pulpwood, and fuelwood in fixed proportions, and that these proportions do not change over time. While it is reasonable to expect some degree of joint production to occur, the rigidity of this interdependence is unrealistic. It is extremely difficult to make these proportions respond to price patterns in any realistic fashion, but possibilities for change should be recognized.

Recommendation: Timber conversion coefficients should be allowed to change over time, particularly in regions where significant technological improvements are anticipated.

8.6 Trade and Transportation

The transportation cost formulation in the GTM creates artificial barriers to entry that often restrict trade. Transportation costs are formulated as a step function of the volume shipped so that costs fall sharply as shipments expand and one moves from liner rates to discount rates to charter rates. Although this may be a good explanatory model of observed transportation rates, the formulation causes a particularly serious problem in the GTM since the cost on each arc is based on <u>last</u> period's shipment volume. Thus, if two regions do not trade historically, or trade only a small volume, trade between these regions will be discouraged in the future.

Recommendation: Transportation cost coefficients should be single-valued on each arc.

The GTM incorporates trade inertia bounds that restrict trade in any period to be no greater than twice last period's volume, and no less than 50 percent of that volume. While the hypothesis that trade adjusts slowly due to factors such as long-term contracts and marketing relationships is tenable, the trade inertia bounds in the model are arbitrary and generate "noneconomic" behavior. Although quantity adjustments are slowed by these constraints, the resulting price movements contradict the basic assumptions of the model. If the argument for inertia constraints is that trade flows are slow to adjust, they are of questionable value in the GTM because of the inability to account adequately for <u>both</u> quantity and price effects. Due to the basic assumptions of a spatial equilibrium model, trade flows cannot be modeled with much accuracy in spite of the false promise of inertia constraints. Against this minimal (and doubtful) gain in model realism looms the fact that such constraints greatly complicate the analysis and interpretation of model results.

Recommendation: Trade inertia constraints should be eliminated.

A large number of flows in the GTM are subject to trade bans solely to reduce model computational costs. Since alternative policies can have diverse impacts on potential trading partners and significantly alter trading patterns in the long run, valuable information is lost and simulation results are biased by excluding so many flows on the basis of historical behavior.

Recommendation: Trade bans should be eliminated.

8.7 The Centrally-planned Economies

In spite of the special attention given to modeling the Soviet Union in the Forest Sector Project, the model of this region remains a weak link in the GTM. Although the Soviet Union has a huge inventory of timber and a vast potential for exporting wood to world markets, changing log utilization standards and the allocation of timber removals between domestic and foreign markets are poorly-designed features of this module. The GTM lacks the flexibility to handle harvest and trade adjustments in this region in a reasonable fashion.

Recommendation: Models of the centrally-planned economies should be restructured. Given the difficulties with integrating these regions into the GTM framework, it may be prudent to make these regions exogenous.

8.8 Conclusions

The GTM provides a versatile and sophisticated system for analyzing the global forest sector. Its basic structure and region/product coverage make it the superior choice for examining policies that have international repercussions. Previous modeling efforts have failed to incorporate many critical interregional and interproduct linkages. While the strengths of the global approach are well-known, it should be clearly recognized that the GTM is a first-generation model that requires significant additional development to realize its full potential as an analytical system.

Based on our theoretical review and extensive sensitivity analysis of the model, we believe that the utility of the GTM as a tool to simulate forest sector behavior can be markedly improved by several changes in the model structure and specification. We have indicated our major recommendations by section in the foregoing discussion.

There are many areas where the GTM lacks sound economic relationships and feedbacks. However, many of these areas are not amenable to additional modeling work due to our poor understanding of the behavioral responses involved, particularly on a worldwide basis. Furthermore, the data needed to parameterize many of these relationships simply do not exist. Silvicultural activities and technological change are perhaps the most critical areas of concern. Analysts must recognize these shortcomings in interpreting the results of model simulations.

Finally, because the GTM is exceedingly complex, we believe that intimate familiarity with the model structure, parameterization, constraints, and operational characteristics is a prerequisite to understanding the implications of a model simulation. Thus, users must make a substantial resource commitment to utilize the GTM for internal research. For analysts who make the investment, the GTM will prove to be an indispensable tool for forest policy and forest industry research. However, it should be clear that the GTM will never accurately forecast or predict policy impacts. The reasons are well-known to those familiar with the modeling process and include the following: there will always be unrealistic features of the model structure and assumptions; the underlying data are of poor quality or nonexistent in many regions of the world; the model cannot be statistically validated; many economic relationships defy quantification; and, structural change remains difficult to model and even more difficult to predict. The real contribution of the GTM is that it provides a logical and consistent framework to study forest sector issues in an experimental setting. As a result, it helps users formulate appropriate questions and facilitates intelligent dialogue concerning the future of the global forest sector. The challenge remains to communicate this information beyond the research level.

LITERATURE CITED

Adams, D.M. and Haynes, R.W. 1980. The 1980 softwood timber assessment market model: structure, projections, and policy simulations. Forest Science Monograph 22. 64 pages.

Binkley, C.S. and Dykstra, D.P. 1987. Timber supply. *In* M. Kallio, D.P. Dykstra, and C.S. Binkley (Editors), The Global Forest Sector: An Analytical Perspective, John Wiley & Sons, New York. pp. 508-533 (Chapter 21).

Cardellichio, P.C. and Adams, D.M. 1987. U.S. experience with the Global Trade Model. *In* P.A. Cardellichio, D.M. Adams, and R.W. Haynes (Editors), Forest Sector and Trade Models: Theory and Applications -- Proceedings of an International Symposium, November 3-4, 1987, Seattle. pp. 41-51.

Cardellichio, P.A. and Binkley, C.S. 1984. Hardwood lumber demand in the United States: 1950 to 1980. Forest Products Journal, 34(2): 15-22.

Cardellichio, P.A. and Veltkamp, J. 1981. Demand for Pacific Northwest timber and timber products. Study Module II-A, Forest Policy Project, Washington State University.

Dykstra, D.P. and Kallio, M. 1987a. Introduction to the IIASA Forest Sector Model. *In* M. Kallio, D.P. Dykstra, and C.S. Binkley (Editors), The Global Forest Sector: An Analytical Perspective, John Wiley & Sons, New York. pp. 459-472 (Chapter 19).

Dykstra, D.P. and Kallio, M. 1987b. Scenario variations. *In* M. Kallio, D.P. Dykstra, and C.S. Binkley (Editors), The Global Forest Sector: An Analytical Perspective, John Wiley & Sons, New York. pp. 648-672 (Chapter 29).

FORSIM Review. 1983 (December). Published by Data Resources, Inc., Lexington, MA.

Kallio, M. 1987. Forest industry modules. *In* M. Kallio, D.P. Dykstra, and C.S. Binkley (Editors), The Global Forest Sector: An Analytical Perspective, John Wiley & Sons, New York. pp. 534-559 (Chapter 22).

Kallio, M., Dykstra, D.P., and Binkley, C.S. (Editors). 1987. The Global Forest Sector: An Analytical Perspective. John Wiley & Sons, New York.

Kornai, G. 1987. Trade barriers and inertia in international trade. *In* M. Kallio, D.P. Dykstra, and C.S. Binkley (Editors), The Global Forest Sector: An Analytical Perspective, John Wiley & Sons, New York. pp. 569-578 (Chapter 24).

Kuh, E., Neese, J.W., and Hollinger, P. 1985. Structural Sensitivity in Econometric Models. John Wiley & Sons, New York.

Priasukmana, S. 1986. The trade and investment opportunities of the forestry sector in East Kalimantan. *In* G.F. Schreuder (Editor), World Trade in Forest Products 2, University of Washington Press, Seattle. pp. 207-223.

Spelter, H. 1985. A product diffusion approach to modeling softwood lumber demand. Forest Science 31(3): 685-700.

Williams, D.H. 1987. The extensive margin of the mature stock of timber in the coastal region of British Columbia. *In* P.A. Cardellichio, D.M. Adams, and R.W. Haynes (Editors), Forest Sector and Trade Models: Theory and Applications -- Proceedings of an International Symposium, November 3-4, 1987, Seattle. pp. 239-246.