MODELING TECHNOLOGY CHANGE AND FIBER CONSUMPTION
IN THE U.S. PULP AND PAPER INDUSTRY

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Abstract.—The USDA Forest Service Pulpwood Model developed at the Forest Products Laboratory enables researchers to make 50-year projections of pulpwood consumption and paper and paperboard production in North America. These projections will be used by the Forest Service in its 1989 Assessment of the U.S. demand and supply of timber. In the model, we introduce changes in product and process technology, based on a survey of likely developments in pulp, paper, and related technologies. For each grade of paper and paperboard, the model projects by region, the most cost-effective combination of technological processes, as well as equilibrium levels of production and fiber consumption to satisfy demand. Our projections indicate substantial growth to the year 2040 in total U.S. paper and paperboard production, and increasing hardwood pulpwood consumption. We also project the mix of technological processes that will be used to make paper and paperboard.

INTRODUCTION

The U.S. Forest Service is modeling future technological change in wood products processing to more accurately project the demand for and supply of timber resources. This work for the 1989 Forest Resource Assessment is being developed in response to the forest and rangeland Renewable Resource Planning Act (RPA) of 1974 and related legislation. For the last assessment, in 1979, the Forest Service developed a timber market modeling system to provide long-term projections of consumption, production, and prices of forest products, as well as growth, removal, and inventory of timber resources. The modeling system was based on the Timber Assessment Market Model (TAMM).

Since 1979, there have been efforts to improve the TAMM system, including those dealing with pulpwood consumption. One effort was the development of PAPYRUS, a spatial equilibrium model for the North American pulp and paper industry. Spatial equilibrium models determine the prices, production, consumption, and trade that balance supply and demand among trading regions. These models provide a method for projecting market equilibria simultaneously for several supply and demand regions. The Gilless-Buongiorno spatial equilibrium model uses separable linear programming to estimate interregional...
market equilibrium based on maximization of consumer and producer surplus. While the PAPYRUS model provides a comprehensive paradigm for modeling consumption, production, and pricing in pulp and paper markets, its excessive product aggregation, regional structure, short time horizon, and lack of detail on future technology, preclude its direct incorporation into the Tamm system as a simultaneously functioning component. Therefore, a new model, the Pulpwood Model, was developed at the Forest Products Laboratory for the 1989 Assessment. This model runs independently of TAMM and will be linked to a small fiber sector in the TAMM system.

The objective of this paper is to describe attributes of the Pulpwood Model, which projects consumption, production, and price 50 years into the future for the 1989 Assessment, scheduled for completion in 1994. These attributes include model structure, regional and product aggregation, final demand, processing technology, and resource supply.

The Pulpwood Model is capable of serving as a simultaneously functioning model in the TAMM system. It develops projections of wood fiber (roundwood and residue) consumption for three aggregated U.S. regions (North, South, and West) and Canada.

MODEL VALIDATION

Validation of the Pulpwood Model consists of determining whether or not it is suitable for the purpose for which it was originally developed. Our model was validated for the base year 1986. The prices and production quantities in the base year for the five endogenous grades in our model are actual prices and quantities as reported by census and trade association reports. We were able to derive the actual prices and production quantities reported for 1986 by adjusting the per capita gross national product (GNP) elasticities in the model for each grade of paper and paperboard.

MODEL STRUCTURE

The Pulpwood Model is an economic model of the future North American (U.S. and Canadian) pulp and paper industry, designed principally to project pulpwood consumption in North America over the next 50 years. The model is based in part on a general price-endogenous linear programming system (PELPS) for economic modeling developed by Gilless and Buongiorno³. We use PELPS as part of our Pulpwood Model. The PELPS model that is incorporated into the Pulpwood Model differs from the PELPS model developed by Gilless and Buongiorno in modeling the North American pulp and paper industry (PAPYRUS

³Gilless, J. Keith, and Joseph Buongiorno. 1985. PELPS: Price-endogenous linear programming system for economic modeling. College of Agricultural and Life Sciences, University of Wisconsin-Madison. Report no. r3329. We are indebted to Professor Buongiorno and UW graduate student Patrice Calmels for teaching us how to use the PELPS system.
model\textsuperscript{4}. We have modified the PELPS model by introducing the detail of various "processes" for manufacturing paper and paperboard, as a means of projecting technological change. We use an updated (1986) data base. We disaggregate the industry into detailed product grades, and incorporate assumptions about future technological change. The projections of pulpwood consumption will be incorporated into the TAMM model in order to project overall trends in the U.S. timber supply and demand situation for the 1989 RPA Assessment.

Commodities

In the Pulpwood Model, we incorporate 14 commodity groups: 8 paper and paperboard grades, construction paper and board, and 5 fiber raw material input commodities, which include hardwood pulpwood, softwood pulpwood, and 3 categories of recycled fiber. We do not model pulp grades separately because most pulp production is integrated with paper and paperboard production in North America. We do not introduce any new product categories because large-scale development of entirely new product grades appears relatively remote in the decades ahead. We project total pulpwood consumption, roundwood and residues together. The TAMM model projects the distribution between roundwood and residues, depending on lumber and plywood mill residue projections.

Paper and Paperboard Grades

We model production and fiber consumption of four paper grades (Newspaper, Printing & Writing, Packaging & Industrial, and Tissue) and four paperboard grades (Unbleached Kraft, Semichemical, Solid Bleached, and Recycled Board). Of the eight grades, production, prices, capacity, and fiber consumption for Newspaper and the paperboard grades are projected using our PELPS model. For the remaining three paper grades (Printing & Writing, Packaging & Industrial, and Tissue), production and fiber consumption are projected exogenously (outside of our PELPS model). These three paper grades totaled 43 percent of total paper and paperboard produced in 1986. Market pulp production is also projected exogenously.

In addition, we develop exogenous projections of production and fiber consumption for construction paper and board grades, including hardboard. We model consumption and prices of five fiber raw material commodities in our PELPS model, and we project consumption of fiber raw material for the exogenous grades. The five fiber raw material commodities are softwood pulpwood, hardwood pulpwood, and three categories of recycled paper, which include old corrugated containers (OCC); old newspapers (ONP); and mixed wastepaper, pulp substitutes, and high grade deinking.

The Pulpwood Model has four supply regions and one demand region. The supply regions are U.S. North, South, and West, and Canada. The one demand region in the model is North America. The U.S. supply regions are aggregates of eight U.S. subregions recognized by the American Paper Institute. The

\textsuperscript{4}Gilless, J. Keith, and Joseph Buongiorno. 1987.
North region includes New England, Mid-Atlantic, East North Central, and West North Central regions. The South region includes South Atlantic, East South Central, and West South Central regions. The West region includes the Mountain & Pacific region and Alaska.

MODELING TECHNOLOGICAL DEVELOPMENT

A key feature of our model is that it provides a means for modeling adoption of new pulp and paper processes in response to changing prices in regional wood and fiber markets. In our model, production capacity for each grade is allocated to discrete technological processes, both current and future. For example, in Unbleached Kraft paperboard, we recognize two conventional processes in North America, an old and a new process, and also two future processes based on foreseeable technological developments. Each process has specific wood or fiber input requirements and nonfiber costs. We provide several current and estimated future production processes for each grade in the model. In each year of the projection period, the model allocates growth of production capacity in each grade to the available processes and supply regions that have the lowest production costs, determined as the sum of non-fiber costs and the cost of wood or fiber. Growth in capacity for future processes begins at specified future dates when the processes are assumed to become commercially available. Since the cost of wood or fiber in the model will depend on regional market equilibrium prices for wood and recycled fiber, the model projects adoption of new process technology partially as a function of developing regional economic conditions. For example, if softwood remains relatively more expensive than hardwood, the model favor adoption of processes that use more hardwood. In addition, the extremes of maximum and minimum hardwood use are defined as options for each process, so that in any period the model can switch from one extreme to the other as a matter of economic substitution within the limits of existing technology.

For the exogenous grades, technological change in wood and fiber use is projected exogenously based on historical and projected future trends for each grade.

Net Exports

The Pulpwood Model does not include a supply-demand equilibrium for markets outside of North America (United States and Canada). Effects of overseas trade are handled in our PELPS model by shifting domestic demand functions for each paper and paperboard grade by a quantity equivalent to net overseas exports from the United States and Canada (which are positive quantities for the five grades included in our PELPS model). This is accomplished in the model by shifting initial demand quantity from the apparent consumption (new supply) quantity to the production quantity for North America, leaving initial price and price elasticities unchanged. Thus, the model actually projects North American production quantity for each grade, rather than apparent consumption, and production includes production for export.
Exogenous Grades and Market Pulp

The Pulpwood Model does not provide a supply-demand equilibrium for three paper grades or construction paper and paperboard, as indicated earlier, nor does it include market pulp as a separate commodity. This is primarily because we lack sufficient data to model the technology of those grades in the same detail as the five grades that are included in the PELPS model, and because we do not have data on regional shipments of market pulp in the U.S. economy. We project production of the three grades and their associated fiber consumption levels exogenously, using trend extrapolation and regression analysis. Likewise, we project production and pulpwood consumption for the construction grades (construction paper, insulation board, wet machine board, and hardboard). We have also developed balancing assumptions regarding the interregional shipments of market pulp in North America. Exogenous projections are derived based on projected U.S. and Canadian production, including production for export. Pulpwood market effects of exogenous grades are handled in our PELPS model by shifting regional fiber supply for pulpwood and recycled fiber from the actual consumption quantity to the quantity required for only the five grades included in the PELPS model, leaving unchanged the initial price and price elasticities for pulpwood supply.

Economic Assumptions for Exogenous Grades

The GNP and population of the United States are the principal demand shifters in our model. The U.S. disposable personal income (DPI) is also used for some of the exogenous projections. We use the same demand shifter for the United States and Canada since the economic rates of growth over the last decade have been similar.

METHODS

The Pulpwood Model has two parts. One is the exogenous part, where production of four paper grades (Printing & Writing, Packaging & Industrial, Tissue) and construction paper and paperboard are projected using linear regression. The other is our PELPS model, where all of the paperboard grades and newsprint are modeled endogenously. The exogenous and endogenous projections of paper and paperboard are added together to obtain total paper and paperboard projections. Our PELPS model includes a linear program that determines equilibrium in a given period and a set of recursive relationships that update the coefficients of the linear program to reflect changes in economic conditions between periods. A PELPS linear program combines regional supply and demand curves, input-output technological coefficients, transportation and net manufacturing costs, and manufacturing capacities. The objective function of this linear program is the net social payoff for the sector, and its optimal solution approximates the spatial equilibrium for the sector. Therefore, the quantities produced, transported, and consumed in this solution match the consumers' marginal willingness to pay to producers the marginal costs of procurement, production, and delivery.

The recursive relationships used to update linear program solutions from period to period are functions of exogenous changes in the economic environment of the sector and previous market equilibria. The changes made to linear program solutions in this updating process include shifting the demand
curves, shifting the supply curves, and changing manufacturing or transportation costs or manufacturing capacities.

The market equilibrium for one period is found by solving a linear program describing economic conditions in the paper, paperboard, and pulpwood sector during that period. The linear program for that period is then updated to account for changes in the economic environment, and the program is solved to obtain the market equilibrium for the next period of the forecast. This process is repeated until the forecast horizon is reached.

The Pulpwood Model is expensive to run. It costs on the average $215 to run the model during the day. The model can be run overnight which decreases the operating cost by 60 percent. If problems occur while the model is running overnight unattended, the cost could exceed the daily cost for running the model. It takes 90 minutes to complete a 50 year projection run.

The updating and maintenance of the model are very simple. Anyone familiar with Fortran 77 programming can operate and make changes to the model within minutes, thereby producing simulated runs.

PROJECTIONS

By the year 2040, we project that total U.S. paper production will increase to 88.1 million short tons from 35.4 million tons in 1986, while total U.S. paperboard production will increase to 59.7 million tons from 35.4 million tons in 1986. A major factor contributing to the increase in paper production will be an increase in the production of Newsprint. Newsprint is projected to increase to 19 million tons of production by the year 2040, which is a 70 percent increase over 1986 (Figure 1). Although our projections show substantial growth to a projected total U.S. paper and paperboard production of 143.8 million tons in 2030, our projections are slightly lower than the "low" projections from the 1979 RPA Timber Analysis report\(^5\). The last Timber Analysis report projected total paper and paperboard production at three levels (low, medium, and high) with levels for the year 2030 at 150.3, 187.9, and 244.8 million tons, respectively.

Figure 1.--Newsprint Production Trend & Projection for U.S., 1960-2040

One of the key features of the Pulpwood Model is its ability to project pulpwood consumption. By the year 2030, we project that total U.S. pulpwood consumption will increase to 166 million cords from 89 million cords in 1986 (Figure 2). The 166 million cords of pulpwood consumption in 2030 is in line with the 2030 low projection of the 1979 RPA (170 million cords). It is above projections of pulpwood consumption in the recent southern timber study\(^6\), which reports consumption at 143 million cords.

Figure 2. -- Total Pulpwood Production

The Pulpwood model also projects consumption of recycled fiber. Projections indicate that the consumption of recycled fiber will increase gradually over the 50 year projection period. Recycled fiber consumption in the United States is projected to reach a level of 37 million tons of consumption by the year 2030 (Figure 3).

Figure 3.---Recycled fiber in the United States, 1986 to 2030
CONCLUSION

This paper describes technical data and assumptions in the Forest Service economic model of future pulpwod consumption in the U.S. pulp and paper industry. We refer to the model as the Pulpwood Model. We use the Pulpwood Model to project regional U.S. pulpwod consumption over the next 50 years.

The Pulpwood Model has some inherent qualities that should make it useful for future analyses of the industry. One quality is its comprehensiveness. The Pulpwood Model is one of the most extensive syntheses of data on the U.S. paper industry that has been attempted. The information collected is very large and quite varied. Many commodities, regions, and grades of paper and paperboard are contained in the data set.

The projections obtained from the model are necessary for long-term policy analysis. Correct prediction of the direction of change is often all that is needed. Experience with the model so far suggests that it does predict trends correctly. The projection of a consumption level of 166 million cords for pulpwod in the year 2030 is consistent with past and current projections for pulpwod for the year 2030. Also, the projection of increased recycled fiber use for the United States in the year 2030 is consistent with the thinking of many experts in the industry. The representation of production technologies is another feature of the model, which allows a good description of the possible substitutions of fiber types in response to changing economic conditions.

There are some shortcomings in the model that we recognize. These shortcomings will be corrected in future work on the model. The fact that it is a very detailed model leads to difficulties in communicating the results. The computer programs have been designed to print out only part of the results, but more could be done to provide reports that can be used directly by decision makers. At a more fundamental level, the considerable detail of the model leads to problems in finding data. We find it difficult to model market pulpwod and the various pulpwod grades endogenously because of a lack of available data with the needed detail.

Another part of the model that can be improved is the development of better estimates for elasticities of supply of pulpwod of different species and types in different regions; little is known about these elasticities. The elasticities used in the model assume that pulpwod speceification types are the same in different regions.

One primary objective for developing the model was to link it with the Tamm model of the solid wood sector. So far, this has been done exogenously. The pulpwod projections from the model are used by Tamm to project roundwood and residue consumption in the United States. Therefore, the mill residues available for the pulp industry are consistent with those predicted for the sawmill and plywood industries. In the future, the Pulpwood Model could be more fully linked to Tamm and timber supply models to provide a simultaneous solution of regional market equilibria for all timber products.