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A recursive linear programming analysis of the future of the pulp and paper industry in the United States: Changes in supplies and demands, and the effects of recycling

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The impacts of increased paper recycling on the U.S. pulp and paper sector are investigated, using the North American Pulp And Paper (NAPAP) model. This dynamic spatial equilibrium model forecasts the amount of pulp, paper and paperboard exchanged in a multi-region market, and the corresponding prices. The core of the model is a recursive price-endogenous linear programming system that simulates the behavior of a competitive industry. The model has been used to make forecasts of key variables describing the sector from 1986 to 2012, based on three recycling policy scenarios. Waste reduction policies that succeed in reducing demand for paper would have the greatest impact on the amount of wood used. But the minimum recycled content policies envisaged currently would have no more effect than what will come about due to unregulated market forces.

Keywords: Linear programming, economic model, pulp and paper, recycling, capacity, demand and supply, international trade.

1. Introduction

For the past two decades, there have been great technological developments in the U.S. paper industry, which have accelerated in recent years. The mills have been continuously modernized, and sophisticated new technology has been applied to reduce environmental pollution and improve product quality. But with the recent solid waste issue, the greatest challenge facing the industry towards the end of the century will be to increase recycling of all paper products.

The solid waste disposal in the United States is a relatively new but very important issue. An estimated 180 million metric tons of municipal solid waste (MSW) is generated each year - well over one-half metric ton per capita - and the number is steadily rising. In 1988, only about 13% of all MSW in the U.S. was recycled and 14% was incinerated, while about 73% was sent to the landfills (EPA [30]). Paper recycling is crucial in solving the landfill crisis, as paper and paperboard are the largest component and account for up to 38% of all MSW (by weight) in 1990 (figure 1). As estimated by the U.S. EPA (EPA [29]), one-third of the U.S. remaining landfill capacity will disappear by 1994 and about two-thirds will no longer exist by the year 2000. In addition to the landfill problem, it is believed that paper recycling can "save trees" and result in a larger forest inventory. Motivated largely by these concerns, government agencies and environmental groups have strongly supported paper recycling programs. Governments have shown their willingness to work with private industry to increase collection of wastepaper, to break down barriers to recycling, and to promote development of markets for recovered paper. By the end of 1992, five states had passed laws to prohibit paper from being disposed in landfills. Eighteen states now offer tax incentives, usually in the form of tax credits, to firms and industries that invest in some aspect of recycling. As of December 1993, thirteen states had passed mandatory newsprint recycling legislation, while fifteen states have launched voluntary paper recycling programs (Alig [1]). However, the biggest boost for recycling in 1993 came from President Clinton's Executive Order establishing recycled content levels for Federal purchases of printing and writing paper.

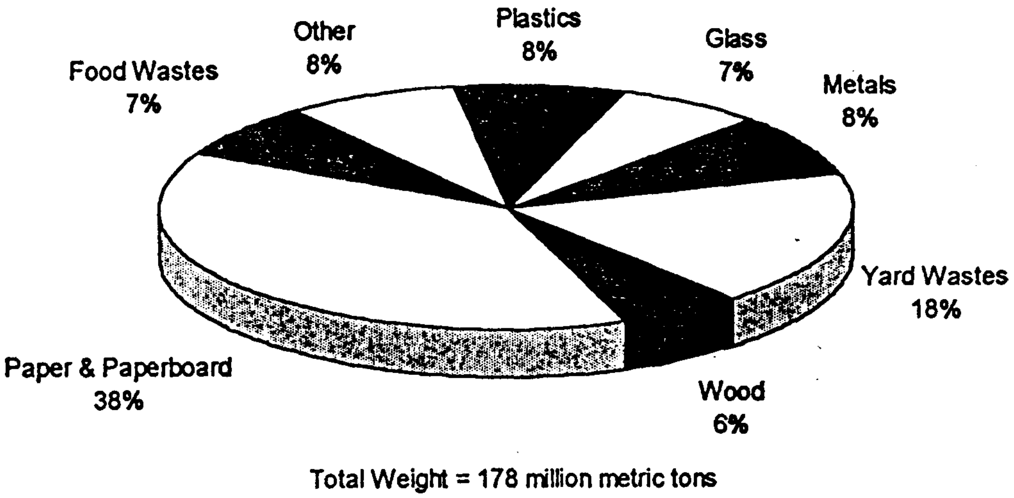

Figure 1. Estimated proportions of materials generated in MSW, U.S. EPA [30].

Within the industry, there has been much improvement in the economics of using recycled fiber. Young [33] points out that for some paper and paperboard grades, it is now cheaper or at least competitive to produce with recycled fiber rather than with virgin fiber, which has not been the case historically.

In response to these developments, more and more recycled fiber has been used in recent years, and this trend will continue over the next decade. The U.S. paper industry has set the goals of 40% paper recovery for recycling by the year 1995 and 50% by the year 2000 (American Paper Institute [5] and American Forest & Paper Association [3]). To achieve these goals and to meet the increasing demand for recycled paper products, the industry will have to expand considerably the capacity of recycling processes. This, in turn, will promote continued technological developments of the recycling technologies to maintain quality standards and machine tunability with recycled fiber in the furnish, and to constantly improve the profitability of recycling.

To address these economic and social issues along with others, the USDA Forest Service, the University of Wisconsin-Madison and Forestry Canada have jointly developed and are still improving the North American Pulp And Paper (NAPAP) model. This paper explains the methodology employed in the NAPAP model and investigates the likely impacts of accelerated use of recovered paper on the U.S. pulp and paper sector, towards the year 2012. The next section consists of an overview of the North American pulp and paper sector to help better understand the industry structure. A mathematical formulation is the theme of the third section. The fourth section describes the model structure, including the regions, commodities and manufacturing processes. The data used in the model are also briefly explained in this section. The projection results of the NAPAP model are discussed in the fifth section. The final section presents the summary and conclusions.

2. The North American pulp and paper sector

North America is the largest pulp, paper and paperboard producing region in the world. It accounts for nearly 50% of worldwide pulping capacity and 40% of paper and paperboard capacity (Miller Freeman [21]).

The United States of America is the world's largest pulp and paper manufacturer and consumer. According to the U.S. Department of Commerce, in 1992, the U.S. paper and allied products industry ranked eighth among U.S. manufacturing industries in terms of value of shipments, and third among the nondurable sectors in sales. The industry's shipment reached $131.3 billion in 1993, accounting for 4% of total U.S. manufacturing shipments. The 628,100 workers employed in the industry represent 4% of the U.S. manufacturing payroll. Of the industry's total value of shipments, pulp, paper, and paperboard represented 5%, 27%, and 12%, respectively.

Canada is the world's second largest pulp and paper manufacturer and the largest exporter of pulp and newsprint. In 1989, the Canadian pulp and paper industry ranked third in terms of value of shipments, behind the motor vehicle and petroleum industries. The shipments totaled C$14.9 billion. Pulp and paper, as well as other forest products, make an enormous contribution to Canada's balance of trade. In 1987, Canada exported forest products valued at $22 billion, nearly 70% of which were pulp, paper, and paperboard.

While the North America pulp and paper sector is considerably more stable than other forest product industries, it still experiences its business cycles. During the 1980s and early 1990s, paper and paperboard production and consumption have been strongly co-related to general economic activity. As in the rest of the world, there are now more and more strong substitute products for paper and paperboard in the U.S. and Canada, including plastics and electronic communications. Newsprint showed slow growth due to inroads by electronic communications and changing reading habits of the general public. Printing and writing grades, however, showed strong growth as the result of the spread of personal computers, photocopying machines and fax equipment. Packaging grades experienced a slower growth because of the competition with plastics in some market segments.

3. The Price Endogenous Linear Programming System (PELPS III)

The NAPAP model was developed using the Price-Endogenous Linear Programming System for economic modeling, PELPS III (Zhang et al. [36]). PELPS III is based on price endogenous linear programming (Hazell and Norton [13]) - a method for combining regional information on supply and demand curves, manufacturing technologies, and transportation costs into spatial sector models. Variants of this method have been used to model a number of agricultural and energy-related sectors (Kennedy [17] and McCarl and Spreen [19]).

PELPS III has a static and a dynamic phase. In the static phase, it computes a multi-region, multi-commodity equilibrium: the quantities and prices that clear all markets at a given point in time. In the dynamic phase, it predicts the evolution of this spatial equilibrium over time. For example, for comparative static problems, two computations under different sets of assumptions are sufficient to show the long-term effect of an import tax (other things being equal). The dynamic phase is needed to predict how a sector adjusts gradually to changes in exogenous variables. This is especially important to predict changes in capacity, since actual capacity always lags behind desired capacity, due to the time needed to install new plants and equipment.

3.1. Static phase

The static phase of PELPS III solves a generalized version of Samuelson’s [23] classical spatial equilibrium problem, for which

> . . . we are given at each of two or more localities a domestic demand and supply curve for a given product (e.g., wheat) in terms of its market price at that locality. We are also given constant transport costs (shipping, insurance, duties, etc.) for carrying one unit of the product between any two of the specified localities.

and from which we wish to know

> What then will be the final competitive equilibrium of prices in all the markets, of amounts supplied and demanded at each place, and of exports and imports?

PELPS III generalizes this problem to represent the production, transportation, transformation, and consumption of several commodities. A commodity may be either a *primary raw material* (such as pulpwood), a ***recovered waste*** (such as waste paper), or a *consumed commodity* (such as newsprint). Consumed commodities may be described as *virgin commodities* (made only of new raw material, such as virgin pulp) or *recycled commodities* (made of recovered wastes, such as recovered paper), or commodities that combine virgin and recycled inputs.

In PELPS III, there are several *demand regions* and *supply regions* in which the demand (supply) of a commodity is described by an equation that gives quantity demanded (supplied) as a function of price. The supply of recovered wastes is constrained by the amount of materials available and by recovery policies. The demand of recycled commodities is constrained by recycling policies.

PELPS III also has *manufacturing regions,* where the production of a commodity, and the consumption of the commodities needed to make it, is modeled as a *process* described by activity analysis (as in Takayama and Judge [24]). Each process has a limited *capacity.* Within a process, a commodity can be made with different combinations of inputs, or *input mixes,* defined by *manufacturing coefficients* giving the amount of each input needed per unit of output. To each input mix corresponds a unit *manufacturing cost.*

PELPS III explicitly models the shipment of commodities between regions. The unit transportation cost includes freight and import or export taxes. Exchange rates are recognized explicitly, so international models are possible.

The solution of the static phase of PELPS III is obtained by maximizing the sum of producer and consumer surplus throughout the sector, it gives the equilibrium quantities produced, transformed, transported, and consumed. The static phase also gives the corresponding prices that clear all markets at a given point in time, subject to the positions of supply and demand curves, the capacities of production by region and process, the manufacturing and transportation costs, the taxes and exchange rates, and the recycling constraints.

The competitive equilibrium is found by solving the following optimization problem.

3.1.1. Objectivefunction

This is the sum of producer and consumer surplus throughout the sector, i.e. the area under the demand curves minus the area under the supply curves, minus the transportation and manufacturing costs:

$$\text{Max } Z = \sum_i \sum_k \int_0^{D_{ik}} P_{ik}(D_{ik}) dD_{ik} - \sum_i \sum_k \int_0^{S_{ik}} P_{ik}(S_{ik}) dS_{ik}$$

$$- \sum_i \sum_k \sum_j T_{ijk} d_{ijk} - \sum_i \sum_k \sum_p \sum_x Y_{ikpjx} m_{ikpx}, \quad (1)$$

where:

each variable refers to the current period, typically a year. The subscripts *i*, *j* refer to regions, *k* to a commodity, ***p*** to a manufacturing process and *x* to an input mix in that process;

P_{ik} is the price expressed in a common currency;

D_{ik} is the quantity demanded;

S_{ik} is the quantity supplied;

T_{ijk} is the quantity transported;

Y_{ikpx} is the quantity manufactured;

m_{ikpx} is the cost of manufacturing, the sum of the cost of transforming input into product and the shipping cost within the region; and

d_{ijk}, the cost of transporting a commodity between two regions, is equal to the sum of the freight cost and the import and export ad-valorem taxes.

3.1.2. Demand and supply constraints

$$D_{ik} = a_{ik}(e_i P_{ik})^{\sigma_{ik}} X_{1ik}^{\delta_{ik}} X_{2ik}^{\tau_{ik}} X_{3ik}^{\alpha_{ik}} D_{ik,-1}^{\eta}, \quad (2)$$

$$D_{ik} \geq D_{ik}^{\mathrm{L}}, \quad (3)$$

$$S_{ik} = b_{ik}(e_i P_{ik})^{\lambda_{ik}} X_{1ik}^{\rho_{ik}} X_{2ik}^{\mu_{ik}} X_{3ik}^{\phi_{ik}} S_{ik,-1}^{\xi_{ik}}, \quad (4)$$

$$S_{ik} \leq S_{ik}^{\mathrm{U}}, \quad (5)$$

where:

for any variable, *V* refers to the current period, while V_{-1} refers to the previous period;

D_{ik}^{L} is a lower bound of demand, and S_{ik}^{U} is an upper bound on supply;

e_i is the exchange rate value of the currency of region ***i*** per unit of the common currency;

X_{1ik}, X_{2ik} and X_{3ik} are demand shifters;

a_{ik} and b_{ik} are constant;

σ_{ik}, δ_{ik}, τ_{ik} and α_{ik} are the demand elasticities;

λ_{ik}, ρ_{ik}, μ_{ik} and ϕ_{ik} are the supply elasticities; and

η_{ik} and ξ_{ik} are partial adjustment coefficients.

3.1.3. Material balancing constraints

In each region, the inflow of a commodity must balance the outflow. Thus, the amount of a commodity received, supplied, and manufactured must be equal to the sum of the quantity used in the manufacturing of other commodities in the same region and of the amount demanded and shipped away to other regions:

$$\sum_j T_{jik} + S_{ik} + \sum_p \sum_x Y_{ikpx} - D_{ik} - \sum_n \sum_p \sum_y a_{iknpy} Y_{inpy} - \sum_j T_{ijk} \geq 0 \quad \forall i, k, \tag{6}$$

where the manufacturing coefficient a_{iknpy} is the amount Of commodity k needed to manufacture a unit of commodity n, in region i, by process p, using input mix y. The shadow price, P_{ik}, of constraint (6) is the equilibrium price of commodity k in region i (Hazell and Norton [13]).

3.1.4. Manufacturing capacity constraints

In each region, the production of a commodity by a process is limited by the existing manufacturing capacity of that process. That is,

$$\sum_x Y_{ikpx} \leq K_{ikp} \quad \forall i, k, p, \tag{7}$$

where K_{ikp} is the capacity of production for commodity k using Process ρ. The shadow price π_{ikp} of equation (7), the value of one additional unit of capacity, plays a key role, in forecasting capacity (see section 3.2).

3.1.5. Recycling constraints

There are two types of recycling constraints, one imposed on demand curves and the other on the supply curves.

If the minimum recycled fiber is restricted for a commodity k, the commodity must be split into sub-commodities by the manufacturing process. For example, the demanded commodity D_{ik}, which can be produced using three processes, may be thought of as three sub-commodities, D_{il}, l = 1,2 and 3. The aggregate commodity and three sub-commodities are then constrained by the following equations:

$$\sum_l \alpha_{il} D_{il} - \alpha_{ik} D_{ik} \geq 0 \quad \forall i, k, \tag{8}$$

$$\sum_l \sum_x D_{ilx} - D_{ik} \geq 0 \quad \forall i, k, \tag{9}$$

where α_{ik} is the desired minimum recycled fiber content required for commodity k, in region i; a_{il} is the ratio of recycled content to virgin content of a sub-commodity l.

For the supply of recovered waste, upper and/or lower bound on supply reflect maximum and minimum recovery rates. Let S_{ir} be the quantity supplied. Then,

$$S_{ir}^{L} \le S_{ir} \le S_{ir}^{U}, \tag{10}$$

where S_{ir}^{L} and S_{ir}^{U} are lower and upper bounds, respectively, on supply of recycled commodity r in region i. These bounds are endogenous (see equations (21) and (22)).

3.1.6. Stepwise approximation of demand and supply

The objective function (1) is defined in part by the area under all demand curves minus the area under all supply curves. These areas are nonlinear functions of the quantities demanded or supplied. PELPS III uses a stepwise approximation to the area under these curves so that the spatial equilibrium can be computed efficiently by linear programming (Zhang et al. [36]).

3.2. Dynamic phase

In its dynamic phase, PELPS III breaks down a multi-period spatial equilibrium problem into a sequence of problems, as in the “recursive programming” approach of Day [11]. This recursive formulation, which simulates partial long-run optimization behavior, also allows a user to include sufficient detail in a model and thus enhance the possibility of successful implementation.

Thus, the dynamic phase of PELPS III is a succession of static phases, one for each period in the forecast. The static calculation in a period gives the short-term equilibrium, subject to the demand, supply, costs, and capacity in that period. The parameters of the programming problem that condition the equilibrium change from period to period, due to exogenous changes (shifts in demand related to population and income growth, shifts in supply, and changes in costs, taxes, and exchange rates) and to capacity changes determined endogenously by the model.

The capacity of production in the next period is a function of the shadow price of capacity in the previous period, past production, and the cost of capacity increase. Thus, PELPS III simulates the rational behavior of suboptimizing agents who forecast the future imperfectly, based on past information.

3.2.1. Shifts in demand

Demand curves are updated between periods to reflect changes in three demand-shift variables, exchange rates, and past changes in demand. Given the competitive equilibrium price and demand in the previous period, $P_{ik,-1}$ and $D_{ik,-1}$ the quantity that would be demanded in the current period at the same price $P_{ik,-1}$ would be:

$$D_{ik}^{*} = D_{ik,-1}\left\{\left(1+\frac{\Delta X_{1ik}}{X_{1ik,-1}}\right)^{\delta_{ik}}\left(1+\frac{\Delta X_{2ik}}{X_{2ik,-1}}\right)^{\tau_{ik}}\left(1+\frac{\Delta X_{3ik}}{X_{3ik,-1}}\right)^{\alpha_{ik}}\right.$$
$$\left.\left(1+\frac{\Delta e_i}{e_{i,-1}}\right)^{\sigma_{ik}}\left(1+\frac{\Delta D_{ik,-1}}{D_{ik,-2}}\right)^{\eta_{ik}}\right\}, \tag{11}$$

where $\Delta V = V - V_{-1}$ for any variable V. The new static phase demand curve is

$$\frac{D_{ik}}{D_{ik}^{*}} = \left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\sigma_{ik}}. \tag{12}$$

When used, lower bounds on demand, D_{ik}^{L}, are shifted exogenously.

3.2.2. Shifts in supply

Supply curves may be updated between periods to reflect changes in the three supply-shift variables, exchange rates and past changes in supply. Given the competitive equilibrium price and supply in the last period, $P_{ik,t-1}$ and $S_{ik,t-1}$, the quantity that would be supplied in the next period at the same price $P_{ik,t-1}$ would be

$$S_{ik}^{*} = S_{ik,-1}\left\{\left(1+\frac{\Delta X_{1ik}}{X_{1ik,-1}}\right)^{\rho_{ik}}\left(1+\frac{\Delta X_{2ik}}{X_{2ik,-1}}\right)^{\mu_{ik}}\left(1+\frac{\Delta X_{3ik}}{X_{3ik,-1}}\right)^{\phi_{ik}}\right.$$
$$\left.\left(1+\frac{\Delta e_i}{e_{i,-1}}\right)^{\lambda_{ik}}\left(1+\frac{\Delta S_{ik,-1}}{S_{ik,-2}}\right)^{\xi_{ik}}\right\}, \tag{13}$$

so that the new static phase supply curve is

$$\frac{S_{ik}}{S_{ik}^{*}} = \left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\lambda_{ik}}. \tag{14}$$

When used, upper bounds on supply are shifted exogenously, except for the endogenous bounds on recovered wastes (see equations (20) and (21)).

3.2.3. Changes in manufacturing and transportation cost

The updated manufacturing cost, which includes changes resulting from changes in manufacturing cost (in real domestic prices) and changes in exchange rate, is

$$m_{ikpx,t} = m_{ikpx,t-1}\left(1+\frac{\Delta m_{ikpx,t}^{i}}{m_{ikpx,t-1}^{i}}\right)\frac{e_{i,t-1}}{e_{i,t}}, \tag{15}$$

where Δ refers to the exogenous change in real manufacturing cost in domestic currency between two consecutive periods.

Transportation costs change from year to year, according to the following equation, with updated freight costs and taxes:

$$d_{ijk} = f_{ijk} + P_{ik,-1} x^{e}_{ik} + P_{jk,-1} x^{i}_{jk}, \tag{16}$$

where x^{e}_{ik} is the export ad-valorem tax and x^{i}_{jk} is the import ad-valorem tax.

3.2.3. Changes in manufacturing capacity

Changes in capacity from one period to the next can either be imposed exogenously by the user or computed endogenously by the model. Endogenous changes in capacity that are determined by the model are computed based on the q theory of investment behavior (Tobin [25]). It suggests that “the rate of investment – the speed at which investors wish to increase capital stock – should be related, if to anything, to q, the value of capital relative to its replacement cost”. Following Tobin’s q theory, the relative gross change in capacity is specified as an increasing function of the q ratio, the shadow price of current capacity (π) divided by the cost of new capacity (c). Empirical results with data of the U.S. pulp and paper industry” suggest that the relative gross change in capacity is a function of the current q ratio, the q ratio lagged one period, and the relative gross change in capacity lagged one period (Zhang [34] and Zhang and Buongiorno [35]).

In PELPS III, for each manufactured process, the gross change in capacity is predicted by the following function:

$$\Delta K^{g}_{ikp} = \left(b_{0ikp} + b_{1ikp} q_{ikp,-1} + b_{2ikp} q_{ikp,-2} + b_{3ikp} \frac{\Delta K^{g}_{ikp,-1}}{K_{ikp,-2}} \right) \cdot K_{ikp}, \tag{17}$$

where K^{g}_{ikp} is the gross production capacity of commodity k by process π in region i at the beginning of the current period; $q = \pi / c$ is Tobin’s q; and b’s are parameters.

Let r_{ikp} be the depreciation rate, then the decrease in capacity due to depreciation is

$$\Delta K^{d}_{ikp} = r_{ikp} K_{ikp,-1}, \tag{18}$$

where $K_{ikp,-1}$ is the capacity level at the beginning of the previous period.

The periodic net change in capacity is then:

$$\Delta K^{n}_{ikp} = \Delta K^{g}_{ikp} - \Delta K^{d}_{ikp} \tag{19}$$

and the capacity level at the beginning of period t is

$$K_{ikp} = K_{ikp,-1} + \Delta K^{n}_{ikp} \tag{20}$$

3.2.4. Changes in recovery rate

Maximum and minimum recovery rates may be updated in each period, exogenously. Changes in recovery rates result in changes in upper and lower bounds for the supply of recovered wastes, according to the following equations:

$$S_{ir}^{L} = \sum_{k} w_{ikr}^{-} \left(\alpha_{ik} \sum_{j} D_{jk,-1} \right), \tag{21}$$

$$S_{ir}^{U} = \sum_{k} w_{ikr}^{+} \left(\alpha_{ik} \sum_{j} D_{jk,-1} \right), \tag{22}$$

where w_{ikr}^{-} and w_{ikr}^{+} are the minimum and maximum recovery rates of recovered waste r from consumed commodity k in region i, respectively; α_{ik} is the fraction of total consumption of commodity k in supply region i.

3.2.5 Changes in other parameters

Changes in other parameters such as manufacturing coefficients, depreciation rates, and recycling coefficients are exogenous.

4. The data

The NAPAP model was first calibrated in static mode for the year 1986, by comparing the model solution with actual production, consumption and prices in that base year. Then, in the dynamic mode, forecasts were made for the years 1987 to 2012. The dynamics of the model were checked by comparing the forecasts for 1986 to 1992 against the actual outcomes.

The parameters of the model are organized in six groups: demand, supply, capacity change, manufacturing, recycling, and transportation. Of these, demand for final products, supply of pulpwood and recovered paper, and capacity changes are represented in the model by econometric equations, while manufacture, recycling, and transportation are represented by activity analysis. Manufacturing capacity for each final product is divided among competing processes and fiber mixes (such as recycled-fiber and virgin-fiber processes, or chemical pulping and mechanical pulping processes). Processes include all of those used at the present time, plus processes that are expected to become available for production at future dates.

4.1. Data for the base year (1986)

4.1.1. Regions and commodities

The demand and supply regions are listed in table 1. The United States and Canada have two demand and five supply (production) regions. The rest of the world consists

Table 1

Regions in the NAPAP model.

Demand	Supply
Canada	Canada East Canada West
United States	U.S. North U.S. South U.S. West
Atlantic	Europe Latin America Other
Pacific	Pacific Rim

of two demand and four supply regions for the U. S., and two net demand regions for Canada (Atlantic and Pacific).

The commodities are listed in table 2. The input commodities are the most important raw materials and recovered paper grades in the North American pulp and paper mills. Intermediate products are exported or used to make final products in North America. Final products correspond generally to the paper and board product grades recognized by the leading industry trade associations in the United States and Canada, American Paper Institute (API) and Canadian Pulp and Paper Association (CPPA). In terms of tonnage, containerboard, particularly linerboard and corrugating medium, has been and will continue to be the main user of recycled paper. On a percentage basis, however, the largest increases are expected in newsprint and tissue and sanitary products (Veverka [3l]). Young [33] also indicates that the recovered paper demand is expected to increase mostly in these grades, because they have the best economics for recovered paper usage.

4.1.2. Demand

The NAPAP model has U.S. and Canadian domestic demand equations for the fourteen final products shown in table 2. It has eighteen foreign demand equations for Canada, and thirty foreign demand equations for the U. S., for pulpwood, recovered paper, pulp, paper, and paperboard commodities. The export commodities are those which were exported to the trading regions (Atlantic and Pacific) in significant quantities in recent decades, or for which significant exports were expected in the near future, while other commodities were added to the principal commodities to balance overall trade.

Table 2

Commodities in the NAPAP model.

Fiber input commodity	Intermediate product	Final product	
Softwood pulpwood	Softwood chemical market pulp	**Paper**	**Paperboard**
Softwood residuals		Newsprint	Linerboard
Hardwood pulpwood	Hardwood chemical market pulp	Coated free sheet	Corrugating medium
Harwood residuals		Uncoated free sheet	Solid bleached board
Old newspapers	Mechanical market pulp	Coated groundwood	Recycled board
Old corrugated containers	Market pulp from recycled fiber	Uncoated groundwood	**Other**
Mixed papers		Tissue and sanitary	Construction paper and board, and other dissolving and special alpha pulp
Pulp substitutes and high grade deinking		Special packaging and industrial kraft packaging and industrial	

The demand equations assume that long-run demand for final products is determined by prices and economic activity. In the short-run, demand may adjust only partially to price, GNP and population changes. The demand equations were estimated econometrically for the U.S. by Lu et al. [18] and by the authors, and for Canada by Baker [7] and Baker [8]. Table 3 shows the elasticities of the U.S. demand for paper and board with respect to own price, income per capita and population.

Table 3

Elasticities of the U.S. demand for paper and board.

Products	Price	Income per capita	Population
Newsprint	−0.54	0.50	0.35
Coated free sheet	−1.16	0.28	1.00
Uncoated free sheet	−1.05	0.50	0.45
Coated groundwood	−0.54	0.38	1.00
Uncoated groundwood	−0.53	0.28	1.80
Tissue and sanitary	−0.26	0.48	0.92
Special packaging and industrial	−1.18	0.21	2.25
Kraft packaging and industrial	−1.01	0.36	5.00
Linerboard	−0.31	0.50	0.30
Corrugating medium	−0.18	0.50	0.30
Solid bleached board	−0.33	0.33	0.66
Recycled board	−0.40	0.50	0.62
Construction paper and board, and other	−0.58	0.26	1.31

For the United States, the historical data on demand quantities were obtained from the American Paper Institute [4]. The price data were derived from the U.S. Department of Commerce's 1989 Current Industry Report series on Pulp, Paper and

Board (MA26A) [27] and the Producer Price Index [28] published by the Bureau of Labor Statistics (BLS), U.S. Department of Labor for the period of 1960 to 1990. The data on GNP and population were taken from the Bureau of Census, U.S. Department of Commerce [26] and the World Tables (World Bank [32]).

4.1.3. Supply

The model has supply equations for softwood and hardwood pulpwood and residues, for each of the U.S. and Canadian supply regions. It also contains supply equations for market pulp and recovered paper grades for those regions, and for the U.S. imports from regions outside of North America. The shifter variables used for estimating supply equations were different in the two countries. For the U. S., roundwood pulpwood supply was related primarily to (1) own price, (2) regional timber inventory, (3) sawtimber stumpage price, and (4) the discount rate (a determinant of timber investment). For Canada, however, roundwood pulpwood supply was determined by (1) own price, (2) labor cost and (3) timber stumpage price, while pulpwood residue supply depended on (1) own price and (2) lumber production (Roberts and Prins [22]). Table 4 shows the supply elasticities of pulpwood in the North and the South of the United States.

Table 4

Supply elasticities of pulpwood in the U.S. North and the U.S. South.

Products	Delivered price	Sawtimber inventory	Stumpage price	Discount rate	Lagged supply
U.S. North					
Softwood pulpwood	0.71	0.25	- 0.01	-	0.25
Hardwood pulpwood	1.32	0.59	0.55	0.78	0.59
U.S. South					
Softwood pulpwood	0.79	0.30	0.11	0.30	-
Hardwood pulpwood	2.98	0.35	0.55	4.12	0.35

Import supplies of the U.S. from Latin America, Europe and Pacific Rim were estimated Durbak et al. [12]. The import supply equations represent the relationship between imported quantities and import prices, export region's production activities and general economic indicators.

4.1.4. Manufacturing processes, coefficients, costs, and capacities

One to four manufacturing processes were specified for each of the intermediate and final products. Additional processes ("new" processes) were also specified to appear at appropriate dates, simulating commercialization of new technologies. Each process was defined by input-output coefficients which described the fiber (i.e., pulpwood, recovered paper, or market pulp per ton of output), fuel and electrical energy, labor, and other manufacturing cost (including capital costs, chemical costs, etc.) needed per unit of output. Several processes had a range of fiber inputs. This allows the model to simulate substitution possibilities, between hardwood, softwood, or recycled fiber. For example, table 5 shows five newsprint manufacturing processes in the U.S. South region. Of those processes, processes 1 to 3 existed in the base year, 1986, and processes 4 and 5 are the "new" processes. In the model, process 4 is introduced in 1988, while process 5 is assumed to become available for commercial adoption in the year 2000 (Ince [14]).

Table 5

Input-output coefficients of manufucturing processes in the U.S. South, per metric ton of newsprint.

	Process[a]				
	1	2	3	4	5
Softwood chemical market pulp (MT)		0.11	-	-	-
Softwood pulpwood (M^3)	2.73 – 2.36	2.02 – 1.81	-	-	2.23 – 1.57
Harwood pulpwood (M^3)	0.00 – 0.29	0.00 – 0.15	0.00 – 0.51	-	-
Old newspapers (MT)	-	-	1.40	0.88	-
Mixed papers (MT)	-	-	-	0.38	-
Purchased fuel (GJ × 10)	0.90	0.30	0.72	0.72	0.20
Electricity (MWh)	1.50	2.50	1.00	0.90	1.60
Labor (hours)	0.46	0.25	0.13	0.13	0.30
Administrative labor (hours)	0.09	0.05	0.03	0.03	0.05

[a] Process 1 = 75% groundwood plus 25% chemical pulp;
2 = 90% TMP plus 10% chemical pulp;
3 = 100% old newspapers;
4 = 30% of coated mixed paper (old magazines) plus 70% old newspapers;
5 = 100% mechanical pulp (TMP or CTMP) with improved pressing technology.

Regional differences in process data reflected differences in regional heat energy requirements and wood density. Higher energy inputs in the U.S. North and Canada were associated with operation in colder climates. Pulpwood and recovered paper input requirements take into account pulp yield and fiber recovery factors. Substantial differences exist in wood density (specific gravity) for pulpwood consumed in different regions, which account for differences in wood volume input requirements by region. Wage rates and energy price data varied by region.

In addition, the data include estimated regional production capacity for each process in the base year. The U.S. regional capacities were obtained from API [6], while the Canadian regional capacities were taken from CPPA [9]. Data for individual mills from Lockwood-Post Pulp and Paper Directory [20] were then used to derive the capacities of individual processes.

4.1.5. Transportation costs, exchange rates, and ad-valorem import taxes

In the model transportation activities are represented by costs of shipping raw materials, recovered paper, and final products from supply/production regions to demand regions. Transportation costs were calculated from the quantities of inter-regional shipments and the costs of the shipments for each commodity. Since both rail and truck are used as means of shipping pulp and paper products in the U.S., the final transportation costs were based on the weighted averages of the two modes. The detailed transportation costs are available in Zhang and Ince [37]. The transportation costs within the Canadian regions were estimated by Jacques [16].

The tariffs for shipments between the U.S. and Canada were based on the import ad-valorem tax rates, and added to the appropriate transportation costs. The import ad-valorem tax rates for the U.S. and Canada were obtained from Miller Freeman [21].

To reduce the size of the model, inter-regional shipments of fiber input commodities, intermediate products and final products, were restricted on the basis of current trade flows. While all possible transportation flows were allowed for shipments of recovered paper and all intermediate and final products within the U.S. or Canadian regions, only a subset of the possible transportation flows were allowed for shipments between other regions. For pulpwood roundwood and residues, shipments were allowed only from Canada to the Pacific and Atlantic regions.

4.2. Exogenous assumptions for forecasts (1987-2012)

The forecasts for 1987 to 2012 were based on assumptions regarding: (1) changes in the shifter variables in the demand and supply equations; (2) changes in the exchange rate between US dollar and Canadian dollar; (3) changes in the U.S. and Canadian import ad-valorem tax rates; and (4) changes in manufacturing, capacity and transportation costs.

4.2.1. Demand and supply shifters

The actual U.S. and Canadian GNP growth rates were used to shift the demands between 1986 and 1992. After 1992, the U.S. GNP growth projected by Wharton Econometric Forecasting Associates were used to make forecasts. Projections of Canadian GNP were provided by Forestry Canada. The projected growth rates of the shifter variables in the U.S. import and the U.S. and Canadian export equations were the averages of the growth rates between 1968 and 1989.

For the U.S. pulpwood supply, the growth rates of the shifter variables such as timber inventory, sawtimber prices, lumber production and residue output were projected using the USDA Forest Service TAMM model. For Canada, however, these rates were estimated by Forestry Canada.

4.2.2. Changes in exchange rates, tariffs, manufacturing and transportation costs, and depreciation rates

The actual U.S./Canada monetary exchange rates for the period from 1986 to 1992 were used. After 1992, the U.S./Canada exchange rate was assumed to remain constant. The ad-valorem import tax rates for the U.S. and Canada were obtained from Miller Freeman [21] for the period of 1986 to 1992. In accordance with the Free Trade Agreement provisions, all tariffs were incrementally phased out between 1987 and 1993. Thus, there is no import tax between the United States and Canada beginning in 1993. The unit costs of manufacturing, capacity expansion and transportation were assumed to remain constant, in U.S. dollars. Given an average 3% depreciation rate in the U.S. pulp and paper industry annually, the old processes were retired at higher than average rates, while the new and future processes were given low or zero depreciation rates.

5. Projections to the year 2012

The model and data described above were used to project developments of the U.S. pulp and paper industry for the years 1986 to 2012. Considering the legislation concerning paper recycling at state and federal level, three alternative scenarios were made in this study.

5.1. Base scenario

The base scenario assumes that the North American pulp and paper industry will evolve according to the future economic and market conditions discussed in section 4.2 above. There are no constraints imposed on the purchase of paper and board nor limitations on how paper is made.

5.2. Minimum recycled content scenario

The Resource Conservation and Recovery Act (RCRA) of 1976 required Federal agencies to develop affirmative procurement programs to purchase products made with recovered materials. This act authorized the Environmental Protection Agency (EPA) to prepare guidelines to designate items that can be produced with recovered materials, and to assist Federal procuring agencies in complying with the requirement to purchase designated items composed of the highest percentage of recovered materials practicable. The final EPA Guidelines for procurement of paper provide minimum recycled content standards for various paper and paperboard grades.

Since all government (including state and local) agency purchases of paper products account for less than 8% of total paper consumption in the U.S., it can be expected that the change in purchase due to the procurement programs would have minimum impacts on the entire industry. Thus, in this scenario, it is assumed that the minimum recycled content standards are applied also to private sector consumers who must ensure that the materials they use contain minimum amounts of recovered paper. Table 6 lists the data assumptions for the minimum recycled content scenario.

Table 6

Data used for the minimum recycled content scenario, by product grade.

End product	Private sector share of total consuption (%)	Minimum recycled content (%)
Newsprint	94	40
Coated free sheet	96	15
Uncoated free sheet	92	20
Coated groundwood	96	15
Uncoated groundwood	96	20
Tissue and sanitary	94	10
Special packaging	96	25
Kraft packaging and industrial	94	25
Lineboard	94	20
Corrugating medium	94	40
Solid bleached board	96	20
Recycled board	96	100
Construction paper and board	94	0

Source: Alig et al. [2].

5.3. Waste reduction scenario

Waste reduction is a management strategy that individuals, communities or even the whole society can adopt as a way to deal with solid waste problems. The goal of waste reduction is to reduce the amount of materials in the waste stream by (1) cutting back on the amount of raw materials used in production, (2) increasing reuse of end-use products, or (3) reducing consumption of intermediate or end-use products. While (1) is a technological solution, (2) and (3) are, in part, cultural solutions. The result of waste reduction would not only reduce waste, but also save raw materials, e.g., pulpwood.

The "waste reduction" scenario incorporated the assumption that policies and programs aimed at reducing volumes of waste (via more efficient product use, public education, disposal fees, etc.) would result in a compounded 1% per year reduction in the U.S. demand for all paper products, at any given prices, beyond the year 1995 (Ince [15]).

5.4. Results and discussion

Forecasts for the U.S. pulp and paper industry, obtained with the NAPAP model for 1986 to 2012, appear in figures 2 to 11. Only the most important results are shown, along with the actual data from 1972 to 1992. The forecasts for 1986-1992 serve to check the accuracy of the NAPAP model.

It is worth noting that, in the "minimum content" scenario, the minimum recycled content standard shown in table 6 could not be applied to uncoated free sheet, special packaging and industrial paper, and solid bleached board, because the technologies modeled in the NAPAP do not allow these grades to use higher percentages of recovered paper. As a matter of fact, the American Forest and Paper Association (AF&PA) recently opposed a strict new Clinton Administration recycling mandate that required all federal agencies to purchase only printing and writing paper with at least 20% post-consumer fiber content. The AF&PA argued that the standard would be hard for many mills to meet without large capital investments. The industry is probably not worried about applying the standard to the government purchases which represent less than 8% of total consumption. But, if such standard were extended to the private sector, many mills could be forced to close, since uncoated free sheet is more than 48% of total printing and writing paper.

5.4.1. Paper and board consumption

Figure 2 shows total paper and board consumption in the U. S., under the three scenarios. The forecasts under base scenario are generally in line with the historical trend. The total U.S. paper and board consumption was forecasted to reach 90 million metric tons by the end of century, and nearly 105 million metric tons by the year 2012, compared to 78 million metric tons in 1992.

The forecasted consumption under the minimum content scenario shows little difference from those under base scenario. This is not a surprise, considering that the minimum recycled content standards had been reached for most paper grades (and correctly predicted by the model), by 1993.

The waste reduction scenario would, however, result in a stagnation of total paper and board consumption beyond 1995. In fact, the consumption, was forecasted to be 86 million metric tons in the year 2000 and 88 million metric tons by the year 2012, which are, respectively, 4% and 16% less than the forecasts under base scenario.

5.4.2. Newsprint price

The forecasts of the U.S. newsprint price, in 1986 dollars, are illustrated in figure 3. Under all three scenarios, the real newsprint price in 1986 dollars. would fluctuated between $500 and $550 per metric ton over the next two decades, although with the waste reduction scenario, the price is projected to be slightly lower, partly due to the

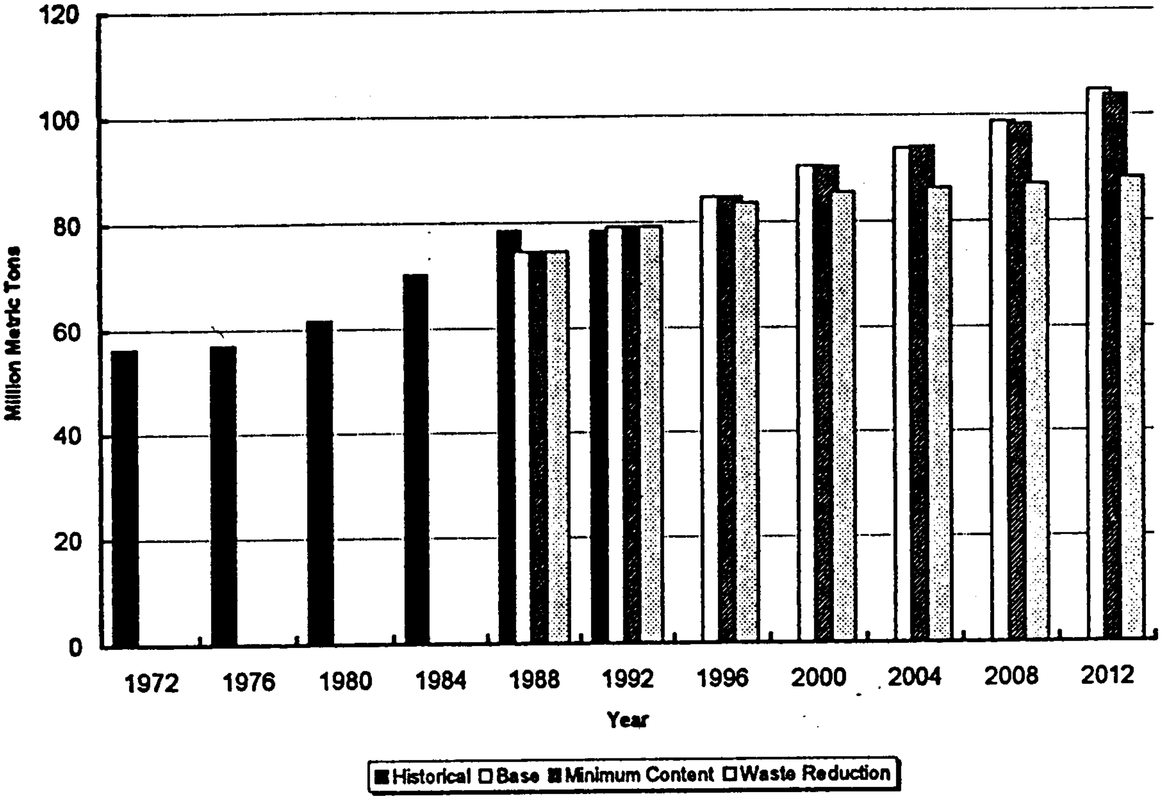

Figure 2. Paper and board consumption in the U.S.

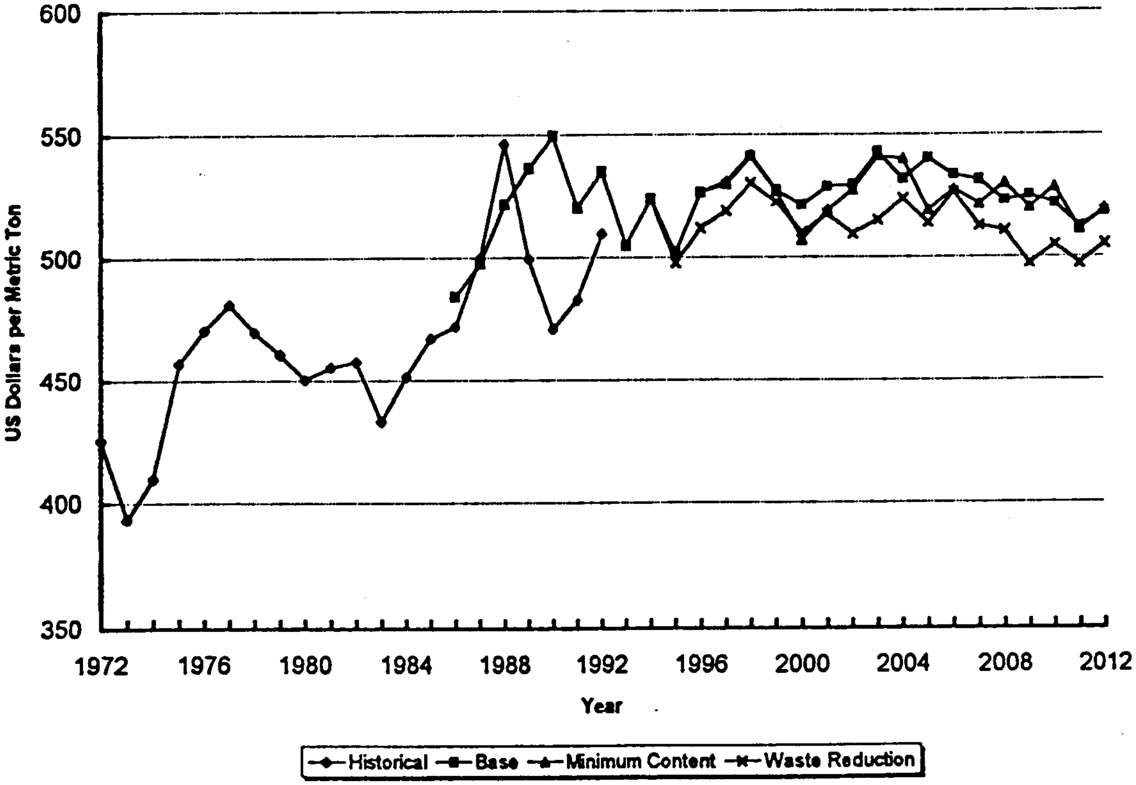

Figure 3. Newsprint price in the U.S., in 1986 dollars.

use of relatively more recycled fiber in production, but mostly due to the reduction in demand. It should be kept in mind that the forecasts were made under the assumption that real manufacturing costs would remain at the 1986 level.

5.4.3. Manufacturing capacity of newsprint

One of the useful features of the NAPAP model is that it forecasts the evolution of paper and paperboard manufacturing technology, by region and process. As discussed above, the model determines annual capacity change for each technological process based on the q ratio, the shadow price of current capacity to the cost of new capacity. As market conditions evolve over time, capacity grows in the regions and for the processes that are most profitable (i.e., with a high q ratio), and declines for those less profitable (i.e., with a q ratio equal zero).

Figures 4 and 5 show predicted manufacturing capacity from 1972 to 2012 for newsprint in the U.S. under the base scenario. The figures show the historical data for 1972 to 1986 (Cremonese [10]), and the NAPAP forecasts from 1987 to 2012. The forecasts in figure 4 imply that the U.S. newsprint capacity would grow faster than the historical trend, as the Canadian share of North America newsprint capacity would continue to decline. The newsprint capacity would reach nearly 10 million metric tons by the year 2012. It is expected that the U.S. South will still have the bulk of total newsprint capacity, with its share dropping only 3% from 61% in 1992 to 58% in 2012. This is mainly because of the increased installation of recycling facilities in the U.S. North and U.S. West, whose shares would increase, respectively, from 11% and 28% in 1992 to 12% and 30% by 2012.

Other results showed that the regional capacity growth would be similar under all three scenarios, except that with the waste reduction scenario, the total U.S. newsprint capacity would only reach 8.8 million metric tons by 2012.

In terms of technology, the processes based on recycled fiber (process 3 and process 4) are forecasted to have the greatest growth in capacity (figure 5), while process 1 (75% mechanical pulp + 25% chemical pulp) would decline and processes 2 and 5 (mainly TMP/CTMP) combined would grow slightly. By the year 2012, the recycled newsprint capacity is expected to account for 52% of U.S. newsprint capacity. It was only 18% in 1990 and 30% in 1992; thus, a substantial shift from virgin fiber to recycled fiber was predicted for the U.S. newsprint industry, regardless of the scenario envisaged.

5.4.4. Imports and exports of paper and board

Figures 6 and 7 show the historical and predicted U.S. imports and exports of paper and board, under the three scenarios. Predicted imports and exports from 1986 to 1992 were lower, compared to actual trade, though net trade was predicted better (figure 8).

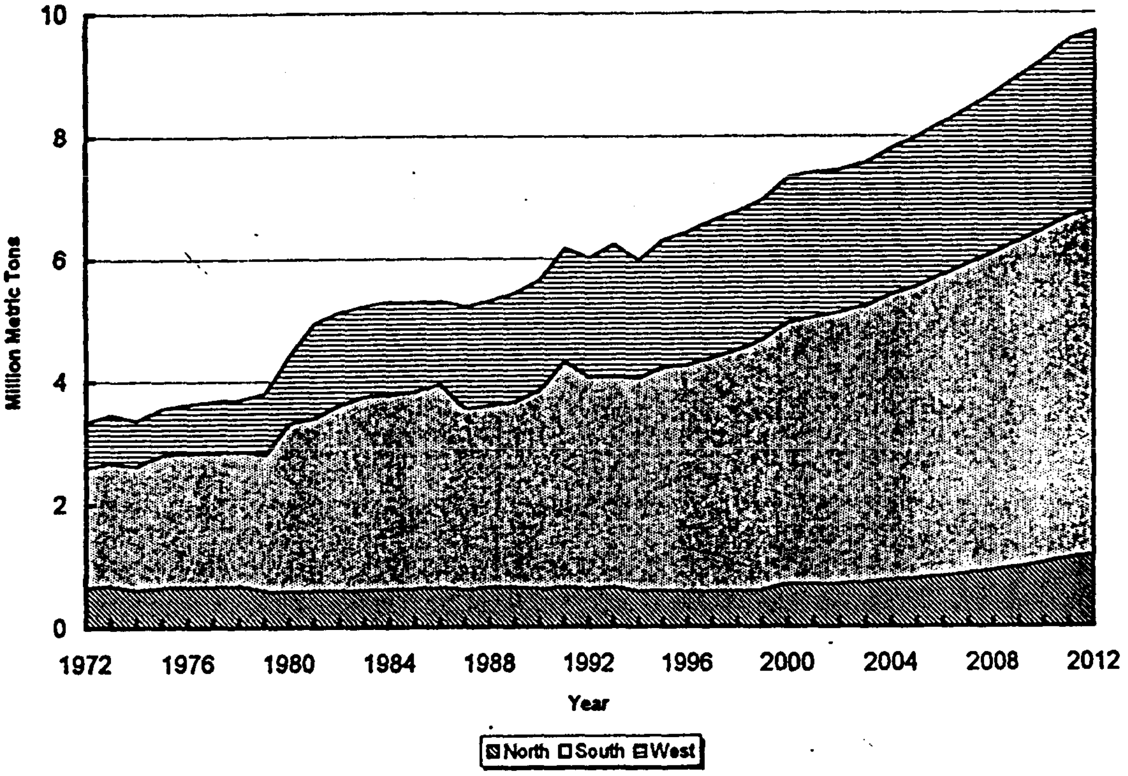

Figure 4. Newsprint capacity, by region, in the U.S.

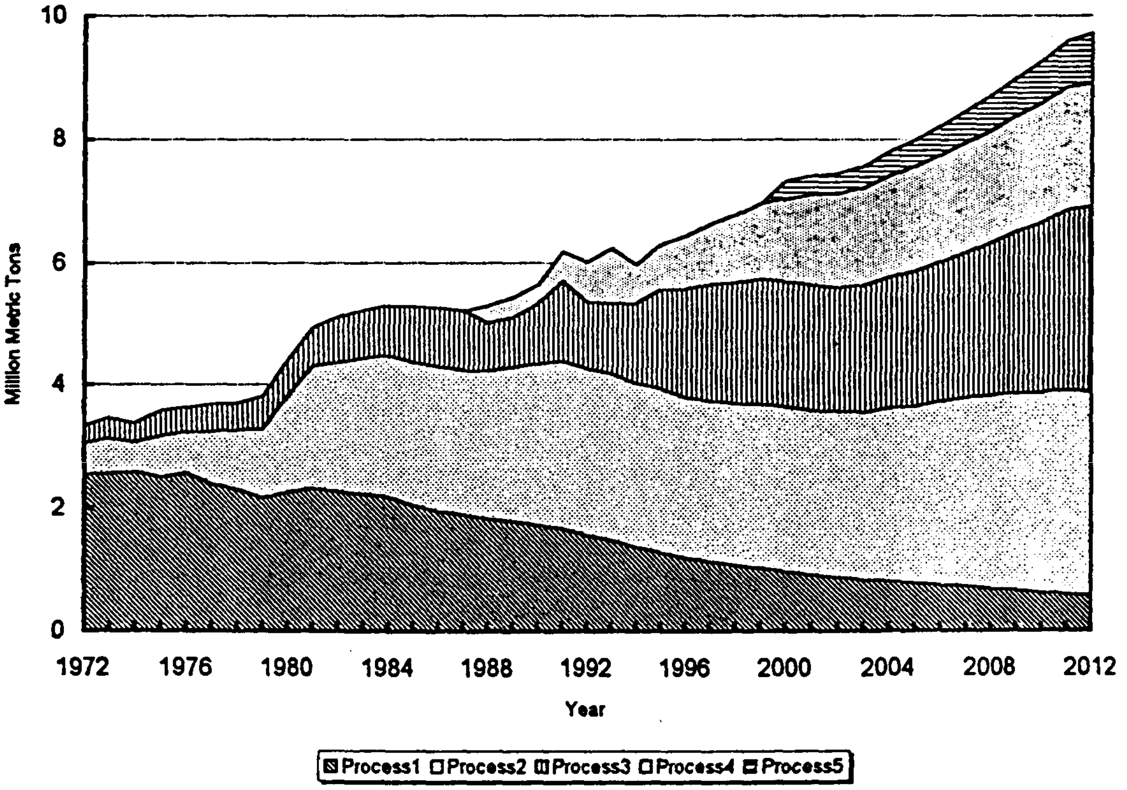

Figure 5. Newsprint capacity, by process, in the U.S.

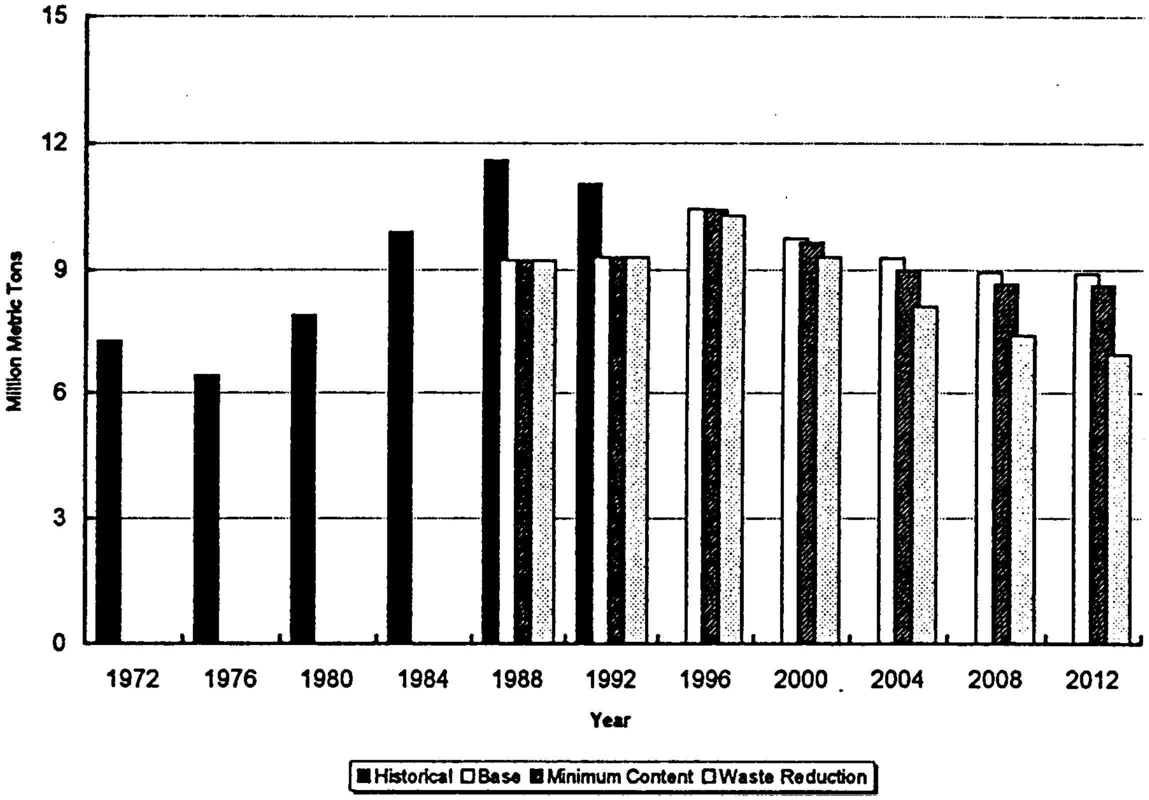

Figure 6. United States imports of paper and board.

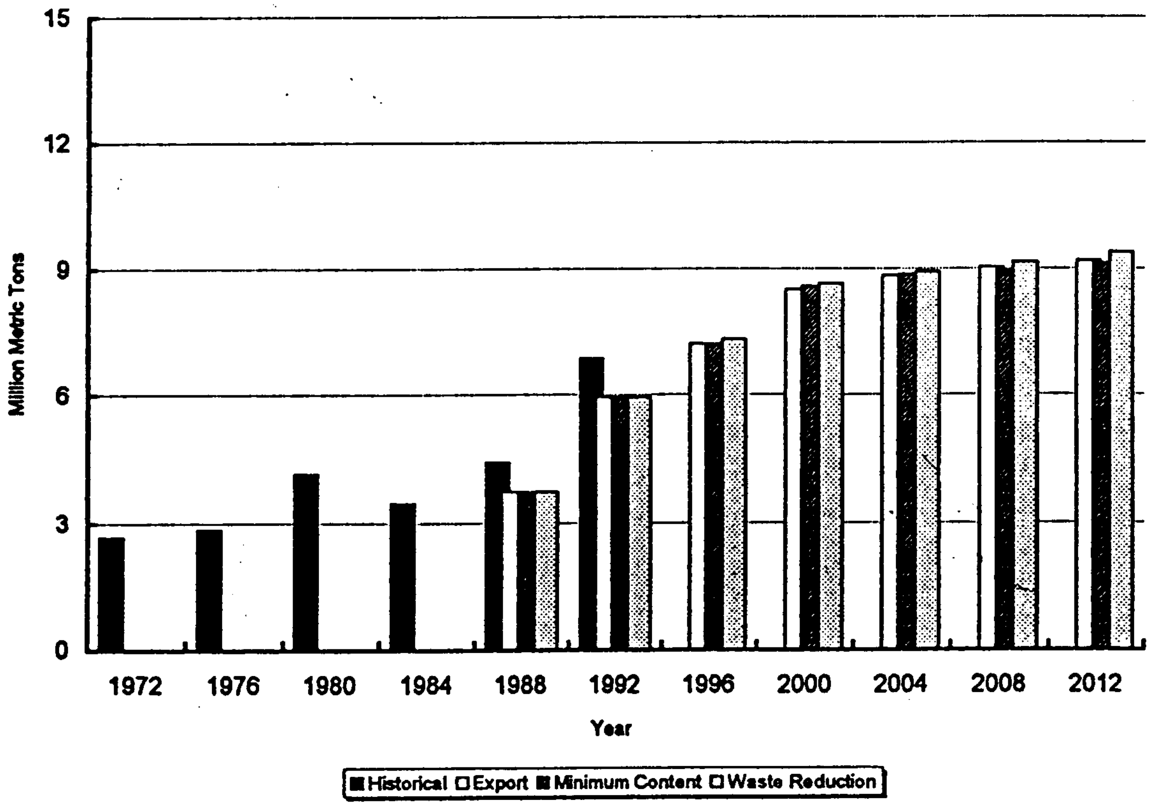

Figure 7. United States exports of paper and board.

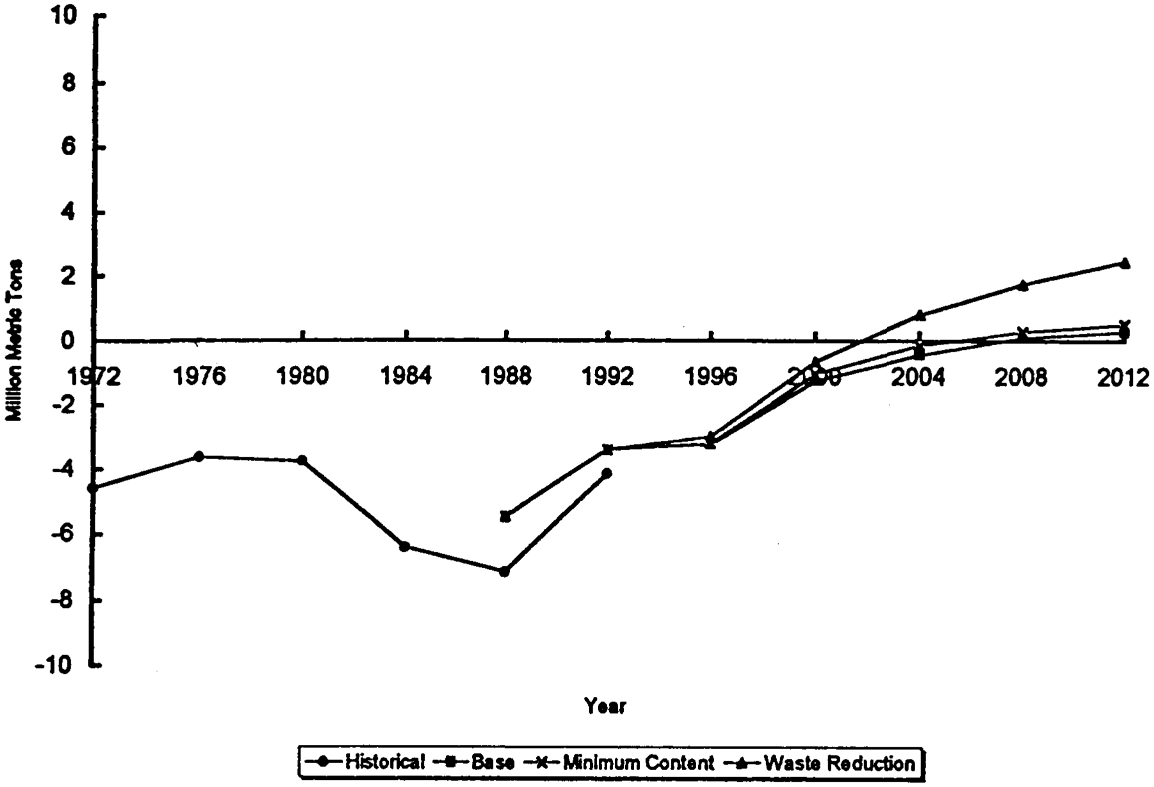

Figure 8. United States net trade of paper and board.

Under the base and minimum content scenarios, the forecasts of the U.S. imports tend to fluctuate around the current level, while the exports are expected to increase, especially between now and the year 2000. These are generally in line with the historical trends, which showed that since 1986, imports had remained around 11 million metric tons, while exports had doubled from 4 to 8 million metric tons. The long-term forecasts under these scenarios were that the U.S. imports and exports would be balanced by the beginning of the next century (see figure 8).

The results under the waste reduction scenario suggest that the U.S. imports of paper and board would gradually decline, while the exports would not differ much from the base scenario. The explanation for this is that with the decreased domestic demand, the need for imports of paper and board will be reduced, and because of its. cost advantages, the U.S. paper industry may experience, for the first time in decades, a trade surplus at the beginning of the 21st century.

5.4.5. Paper recycling rates

Two common measures of recycling performance are recovered paper utilization rate and paper recovery rate. The recovered paper utilization rate is the ratio of recovered paper consumption in paper and board mills to paper and board production. The paper recovery rate is, instead, the ratio of wastepaper collected for recycling and reuse to total paper and board consumption.

The recovered paper utilization rate did not change appreciably in the 1970s and 1980s. Between 1972 and 1985, it remained at about 23%. Since the mid-1980s, there has been a very substantial increase in paper recycling, and the recovered paper utilization rate has reached 30% in 1992. This increase was predicted correctly by the model (figure 9). The waste reduction scenario led to a recovered paper utilization rate slightly higher than the other two scenarios, topping 46% by the year 2012. Under all three scenarios, the model's forecasts imply that the utilization rate would reach 40% in the year 2000.

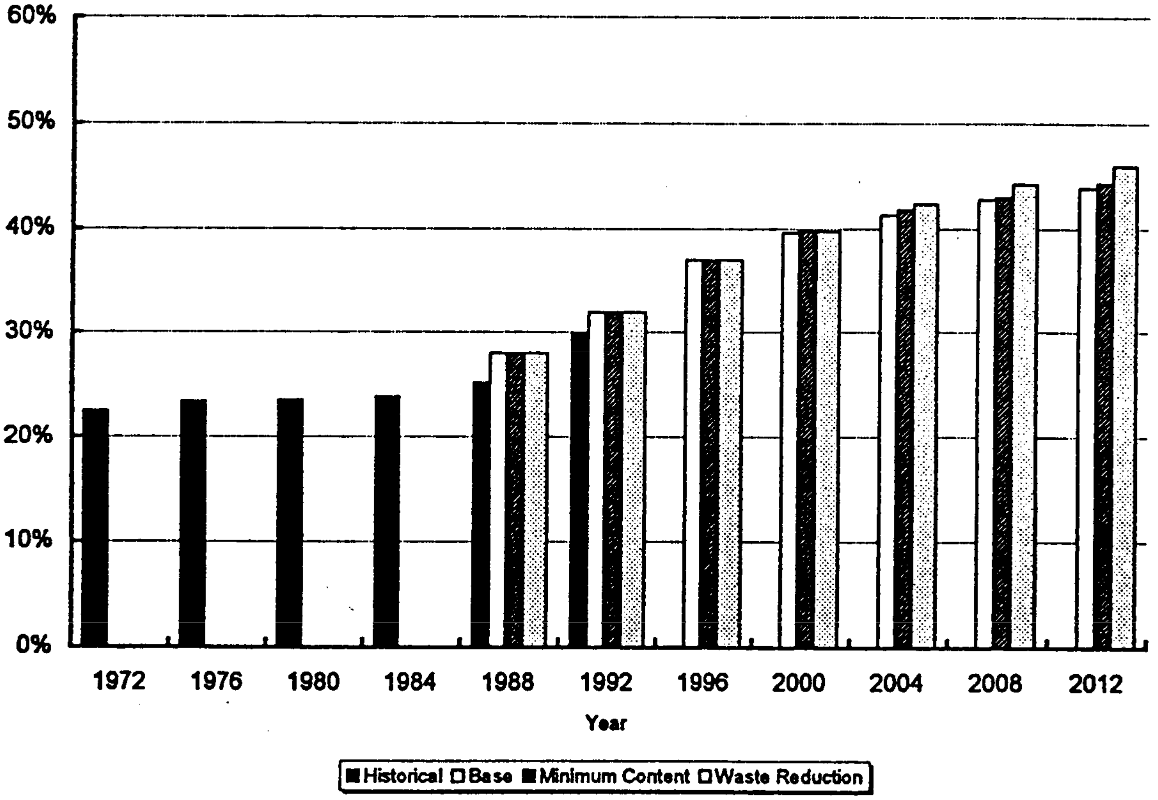

Figure 9. Recovered paper utilization rate in the U.S.

The paper recovery rate had increased gradually in the 1970s and 1980s (figure 10). It grew from 22% in 1972 to 33.6% in 1990, with a fast increase between 1985 and 1990. In 1990, the U.S. paper industry committed itself to recover 40% of all paper for recycling by 1995. However, the industry had reached. this goal in 1993. Subsequently, the AF&PA announced on December 8, 1993, that the industry would recover for recycling and reuse one half of all the paper Americans use by the year 2000.

The forecasts of the NAPAP model reveal that even without any recycling policy, market forces would drive the recovery rate to the 50% target by the year 2000 (figure 10). The minimum content policy (table 6) would have almost no effect on this, but the waste reduction scenario implies recovery rates that increase above 50% after the year 2000.

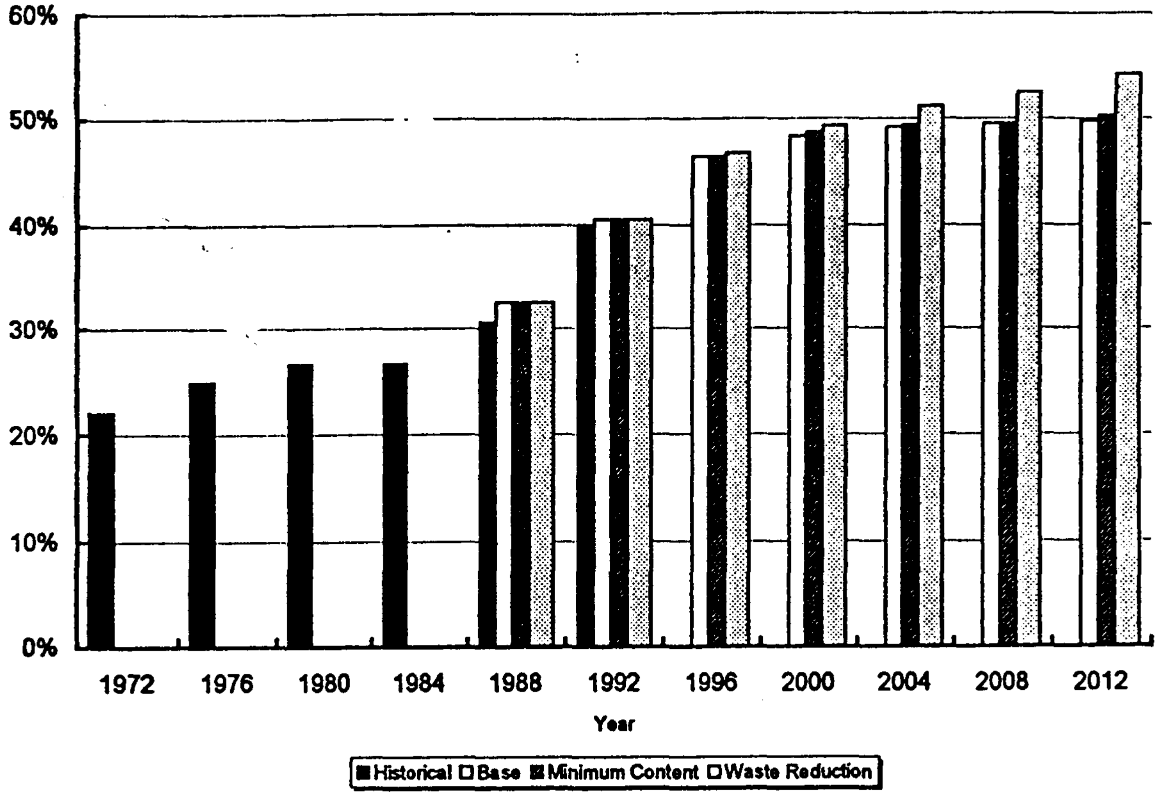

Figure 10. Paper recovery rate in the U.S.

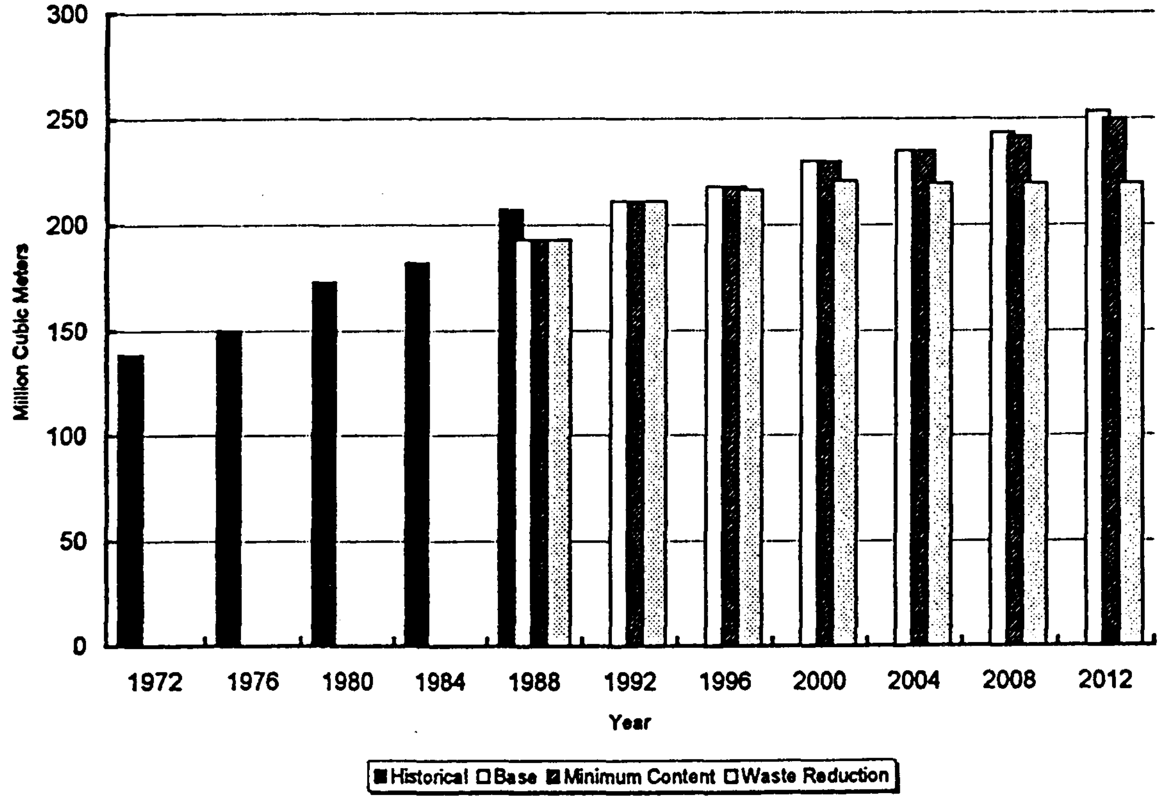

Figure 11. Total pulpwood harvest in the U.S.

5.4.6. Pulpwood harvest and recovered paper supply

The forecasts of the U.S. pulpwood harvest are shown in figure 11. Increased supply of secondary (recycled) fiber, coupled with slower growth in woodpulp production, will lead to only modest growth in pulpwood harvest in the United States, under the base and minimum content scenarios. By the year 2012, the total pulpwood supply will be around 250 million cubic meters. Under the waste reduction scenario, the forecasts indicate that pulpwood harvest would level off after 1995.

5.4.7. Southern pulpwood price index

Figures 12 and 13 show the constant price indexes (1986 = 100) for softwood and hardwood pulpwood in the U.S. South, the primary indicators of U.S. pulpwood prices. Under the base and minimum content scenarios, the softwood pulpwood price is forecasted to drop slightly toward 2012, primarily because of the increased use of recycled fiber. Throughout the projection period, the softwood pulpwood price is forecasted to be around its levels during the 1980s. With the waste reduction scenario, the softwood pulpwood prices are forecasted to decline even more substantially (figure 12).

In contrast to the softwood pulpwood prices, the hardwood pulpwood prices in the U.S. South are projected to drop in the 1990s and then climb to the current level by 2012. This reflects a view that hardwood pulpwood harvests in the U.S. South will be constrained significantly beyond the year 2000, as hardwood timber inventories are expected to decline. Nevertheless, with increased paper recycling, the hardwood pulpwood price is forecasted to remain below its current level, under all three scenarios.

In contrast to the slower growth in pulpwood harvest, substantial increases in recovered paper supply were forecasted by the NAPAP model (figure 14). The amount of paper recovered in the U.S. would jump from 31 million metric tons in 1992 to 44 million metric tons by the year 2000 and 52 million metric tons by the year 2012, under the base and minimum content scenarios. In the waste reduction scenario, the total recovered paper would be lower (48 million metric tons by the year 2012), despite the fact that it leads to a higher recovery rate.

6. Summary and conclusions

The primary objective of this study has been to investigate the impacts of increased paper recycling on the U.S. pulp and paper sector. For this purpose, a dynamic linear programming model of the North American pulp and paper sector, NAPAP, was developed and used in forecasting the developments of the U.S. pulp and paper sector under alternative policy scenarios. The results from 1986 to 2012 indicated that

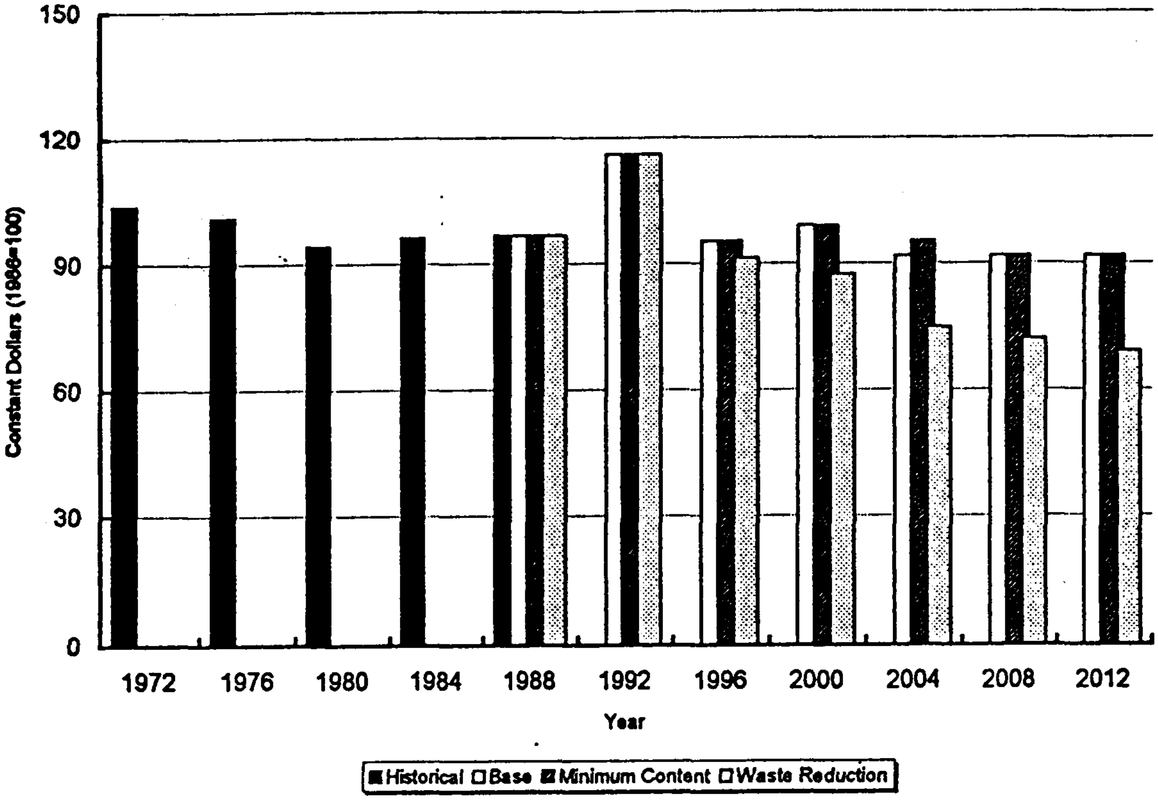

Figure 12. Southern softwood pulpwood price index.

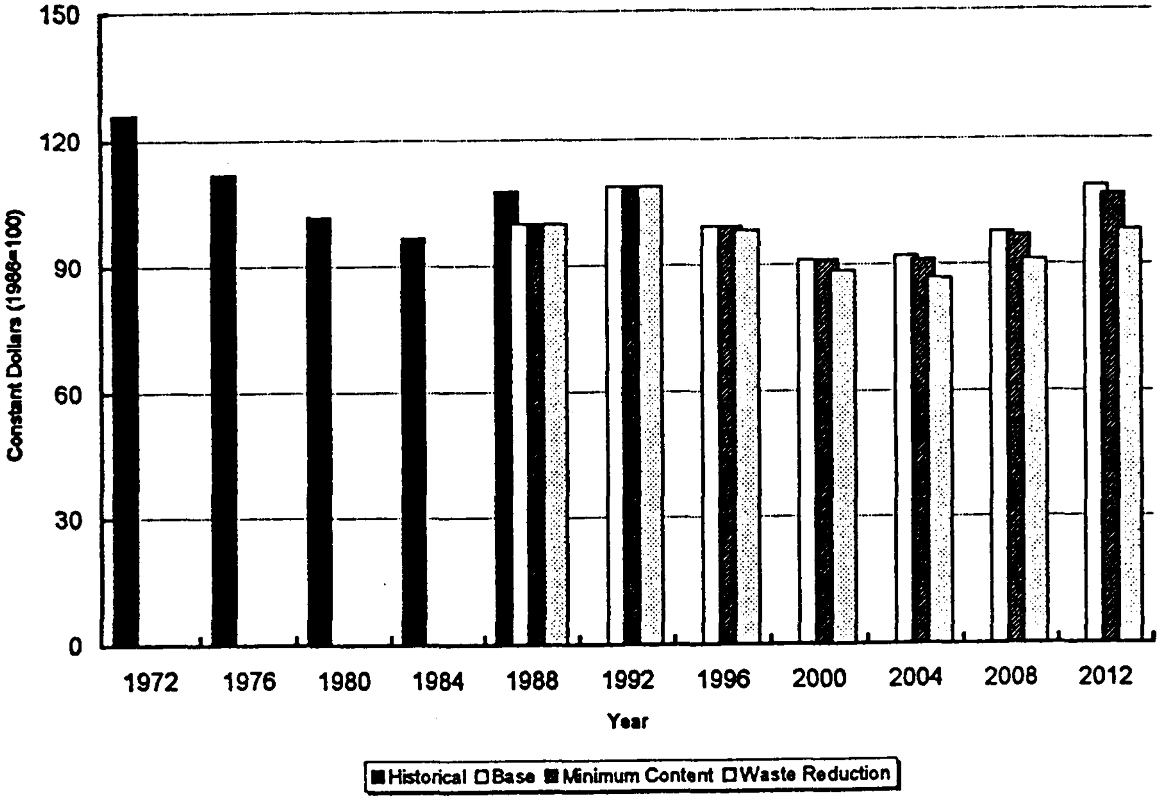

Figure 13. Southern hardwood pulpwood price index.

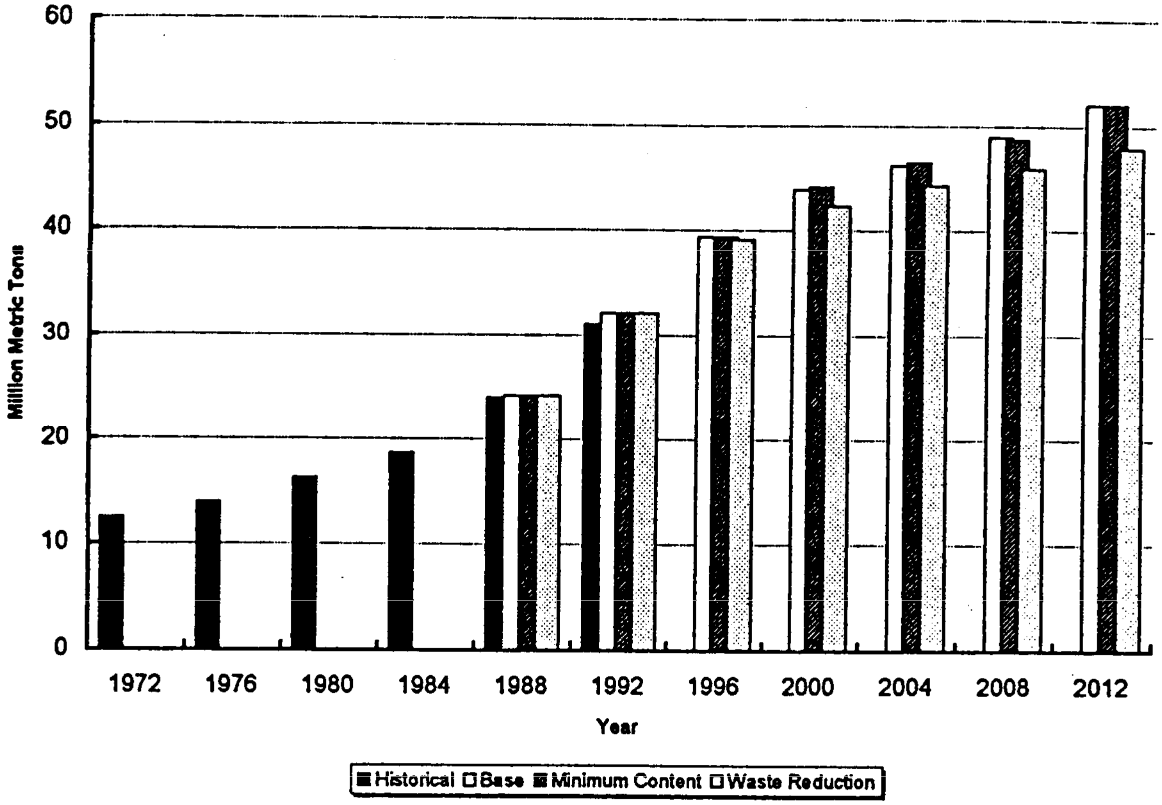

Figure 14. Recovered paper supply of the U.S.

(1) the minimum recycled content standards that is under consideration by EPA would have limited impacts on the U.S. pulp and paper sector; (2) a waste reduction policy leading to a reduction of the U.S. domestic paper and board consumption by 1% per year would have moderate impacts on the sector, although it would stabilize its consumption of pulpwood and reduce the tonnage of wastepaper disposed to landfills; and (3) the U.S. paper industry's goal of reusing and recycling 50% of all paper consumed by the year 2000 would likely be achieved even without government regulations.

The results also suggest that it is critical to assess carefully the international trade equations employed in the model. The U.S. paper industry faces a worldwide, very competitive market. To represent the rest of the world in the same detail as North America is impractical and perhaps not necessary, but better econometric estimates of Pacific and Atlantic import demand and export supply should be sought. Still, the structure of the NAPAP model is already well suited to predict the impacts of international trade agreements, including the North American Free Trade Agreement and the General Agreement on Tariffs and Trade.

The results of the NAPAP model depend on the assumptions made regarding to GNP growth in the United States, Canada, and rest of the world, and the technical coefficients and costs of various manufacturing processes. GNP is the basic economic parameter used to forecast paper and board demand. Greater growth in GNP in Asian and Pacific countries will likely result in greater U.S. exports, which, in turn, will result in more production and stimulate capacity expansion in the U.S. In addition, higher manufacturing costs or lower output-input ratio for an old process relative to those of new processes would cause more capacity addition in new processes and faster depreciation of old processes. Therefore, the forecasts in this study must be viewed just as an example of possible market developments under different recycling policies.

The usefulness of the NAPAP model lies in part in its capability to simulate in some detail technological developments in the pulp and paper industry, and to provide forecasts for a wide range of assumptions. In this paper, the model was used to study the impacts of paper recycling, but, it can also be used to investigate other important environmental issues in the pulp and paper sector, such as process-specific water effluents and air emissions.

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