

Chapter 4

NORTH AMERICAN PULP & PAPER MODEL (NAPAP)

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Abstract. This chapter describes the development and structure of the NAPAP model and compares it to other forest sector models. The NAPAP model was based on PELPS and adapted to describe paper and paperboard product demand, pulpwood and recovered paper supply, and production capacity and technology, with spatially dynamic market equilibria. We describe how the model predicts paper and paperboard product demands and trade flows over time, concurrently with regional capacity changes and corresponding shifts in process technology based on Tobin's q theory of capital investment. We describe how the model was tested and calibrated and then provide examples of applications.

Keywords: pulp and paper model, technology forecasting, pulpwood markets, paper recycling

4.1 INTRODUCTION

The NAPAP model was designed to work within the context of the RPA Timber Assessment to project ongoing and future economic trends in the US and Canadian pulp and paper sectors. The model was designed to take into account changes in demand and supply for all primary pulp, paper, and paperboard products) changes in industry capacity by process and region, and regional markets for hardwood pulpwood) softwood pulpwood, and recovered paper. Six North American supply regions (Canada East and West, US North, Southeast, South Central, and West) were represented in the latest version of the model, along with three demand regions (Canada, USA, and the rest of the world).

The NAPAP model uses Samuelson's theory of spatial market equilibrium and price-endogenous linear programming. Regional supply and demand functions are combined in the NAPAP model with regional manufacturing inputs and costs, transportation costs, and exchange rates to compute annual production and consumption from 1986 to 2050. Each year, short-run production is allocated optimally among competing production processes and regions, with production limited by available capacity.

Over the long run, the model predicts changes in production capacity among competing processes and regions as a function of marginal values and costs of capacity expansion, using Tobin's "q model" of capital investment. Production capacity, costs, and input requirements are modeled by process for each of 12 categories of paper and paperboard and five categories of wood pulp, encompassing the full spectrum of production processes for all pulp and paper products produced in the USA and Canada. Evolution of manufacturing technology is projected as a result of projected changes in production capacity by process, in response to projected shifts in regional market values for products and raw materials. The NAPAP model also projects the trade between the USA, Canada, and the rest of the world, determined in part by exchange rate variations.

4.1.1 Historical context

Papermaking is an ancient activity, but it was not until the late 19th century that wood fiber began to be used commercially on a wide scale to make paper, replacing agricultural plant fibers and rags with a much more abundant source of natural cellulose fiber. Modern paper machine development changed papermaking from a slow and laborious process to an increasingly capital-intensive and highly automated technology geared toward mass production.

The widespread use of corrugated shipping containers, offset printing, print advertising, and sanitary paper products transformed paper and paperboard markets. Increased demand, and technological developments such as the efficient kraft (or sulfate chemical) pulping process and much more efficient larger capacity paper machines caused significant expansion in US pulp and paper industries in the 20th century. During this period, US wood pulp production increased from around 1 million tonnes (metric tons) in 1900 to a recent peak of over 61 million tonnes in 1995 (Figure 4-1).

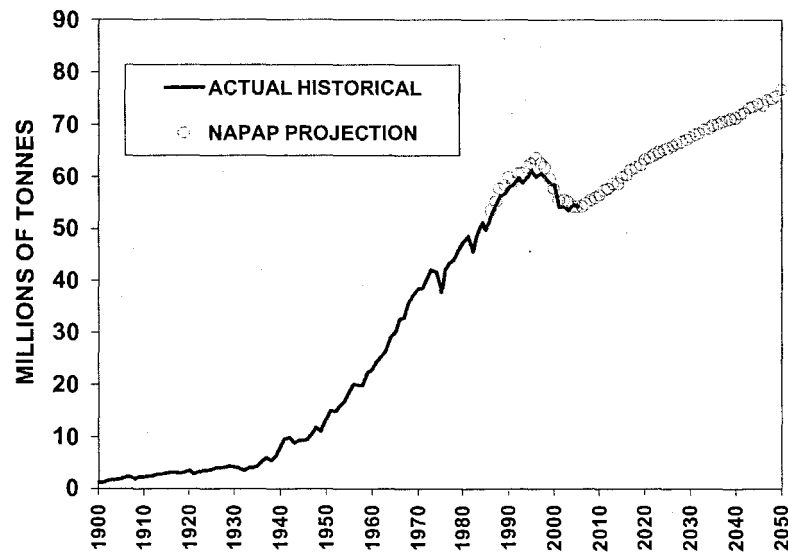


Figure 4-1. US wood pulp production, 1900 to 2005 (AF&PA, API), and NAPAP model projections from 1986 to 2050 (includes estimated output of dissolving pulp and wood pulp for construction paper and board).

The 20th-century expansion of US demand for pulpwood was recognized in the various Timber Assessments. The 1958 Outlook Study (USDA FS 1958) US pulpwood consumption was projected 40 years into the future (to the year 2000) at three different levels (lower, medium, and upper) relating to different assumptions about trends in population, gross national product (GNP), and prices. In the 1960s, regression analysis was introduced by the Forest Service to provide more sophisticated statistical projections of US paper and paperboard consumption (Hair 1967), and such projections appeared also in the 1980 RPA Timber Assessment (USDA FS 1982). Looking back at these earlier studies, it is apparent that the US pulpwood consumption and US production of paper and paperboard projections were generally much higher than actually occurred in subsequent years.

Development of the first prototype of the NAPAP model began in the mid-1980s, when US production of wood pulp was still rapidly increasing (Figure 4-1), but questions were also being raised about the future of pulpwood consumption. The consumption of pulpwood at that time was expanding more rapidly than any other industrial wood use in the USA. However, hardwood pulpwood use was expanding more rapidly than softwood use in the 1980s, an indication of changing papermaking technology (Ince 1985, 1986), while paper recycling was also becoming important (Haynes 1989).

Forest managers in the public and private sectors were interested in the expanding US wood pulp production during the 1980s because it was a market opportunity for timber, but there were also concerns about resource adequacy and sustainability. The Forest Service realized a need to predict more precisely the growth in US wood pulp production along with related technological changes and attendant trends in pulpwood requirements, and thus the Forest Service initiated research that led to development of the NAPAP model.

The first prototype of the NAPAP model (the FPL Pulpwood model) became operational at FPL in the late 1980s, and results showed that market conditions were driving major changes in fiber use within the US pulp and paper industry. For example, recognizing that increased paper recycling was being driven by a glut of cheap recovered paper and rising landfill costs, future pulpwood needs and pulpwood prices were projected to grow more slowly than projected previously (Ince 1990). It was recognized also that increased use of hardwood pulpwood was being driven by technical changes and lower prices for hardwood pulpwood (Ince 1989). Model development was thus focused from the outset on modeling evolution of production capacity and use of different wood species and recycled fiber in the context of evolving markets for pulp, paper, paperboard, and related fiber raw materials.

The NAPAP model was developed further in the 1990s to provide more detailed projections of trends in paper recycling, wood use, and likely impacts of technical change on the long-range timber market outlook (Ince 1994b). The analysis helped to explain why growth in wood pulp output began to wane in the early 1990s, as recycled fiber displaced wood pulp, particularly in softwood-based products such as newsprint and linerboard (Ince 1994a). The model explained that this change was resulting at that time in stagnant US softwood pulpwood consumption, but expanded use of hardwood from the 1980s to 1990s.

US wood pulp production peaked in the mid-1990s and then declined (Figure 4-1) marking the most significant change in wood use by the US pulp and paper industry of the 20th century. The Asian financial crisis of 1997 began to make it apparent that overall growth in the US pulp and paper industry was being offset by economic globalization. By the late 1990s it was clear that domestic pulp and paper markets were being driven increasingly by the forces of economic globalization and declines in exports (Ince 1999b). Earlier, in the 1980s and early 1990s, the US pulp and paper industry benefited from expanded

global markets with increased exports, and production continued to expand up to the year 1999. Since the mid-1990s, however, US imports of pulp and paper products increased, exports declined, and domestic demand for paper and paperboard in packaging and advertising slowed as imports of all manufactured goods rose rapidly. Forest sector models need to be flexible to deal with such significant shifts in trade and industry growth patterns, and the NAPAP model provided the needed flexibility via adjustments in demand and trade assumptions.

The latest version of the NAPAP model, developed in the late 1990s, was used to project the impacts on trade and product demand of economic globalization, along with concurrent trends in paper recycling, trends in pulpwood markets, and changes in pulpwood utilization (Ince 2002). Projections produced with the model in 2001 (Haynes 2003) anticipated the continued downturn in US wood pulp production that occurred in the early 21st century (Figure 4-1), associated mainly with impacts of globalization. Projections made with the model in 2001 suggested a gradual recovery in US wood pulp output from 2000 to 2050, but with about half the growth relative to the preceding half century.

4.2 NAPAP MODEL—ORIGINS AND OBJECTIVES

The theoretical and methodological roots of the NAPAP model are in the economics and agricultural sectors. Samuelson (1952) showed how spatial market equilibria could be found by solving a mathematical optimization problem, obtaining prices, quantities, and trade flows that maximize net social payoff across regions.

In the agricultural sector, development of such spatial equilibrium models in the late 1960s and their use in policy simulation experiments served as examples for forestry research (see for example Naylor 1972 who described the form of the policy simulation approach still used today). By the early 1980s, with Forest Service support, a general computer programming system was developed at the University of Wisconsin by Gilless and Buongiorno (1985) to enable the design of regional market models using the theories of Samuelson and others. Known as PELPS, it was used by Gilless and Buongiorno (1987) to develop the pulp and paper sector (PAPYRUS) economic model of the North American pulp and paper industry.

The development of a broader US forest sector model, with emphasis on solid wood products, was also supported by the Forest Service as a timber resource modeling framework to meet the needs of the RPA legislation. The resulting model, TAMM (Adams and Haynes 1980, 1996), provided an integrated structure to predict regional prices, consumption, and production in stumpage and product markets. TAMM has been used for several decades to forecast market activity and to explore various policies. In the 1990s, the NAPAP model was linked to TAMM and other models, becoming part of the RPA modeling framework.

The NAPAP model was a successor to PAPYRUS, designed to project in greater detail wood fiber consumption and technological changes in the North American pulp and paper sector. In the USA and Canada, more than 99% of the raw material for pulp, paper, and paperboard is wood or recycled wood fiber. Consumption of wood and recycled fiber in the two countries was increasing throughout most of the 20th century. From 1970 to 1988 (when work on the NAPAP model began), annual pulpwood consumption in the USA and Canada had climbed from approximately 225 to 320 million m³ (Miller Freeman 1990). Concurrently, recovered paper consumption increased from approximately 11 million tonnes in 1970 to 21.6 million tonnes in 1990 (API 1970–1992; CPPA 1992).

Development of the NAPAP model was guided by practical observation and economic theory. Various aspects of technical change, prices, production, capacity, and trade in the industry had been described extensively by previous writers (Schmookler 1966; Mansfield 1968; Guthrie 1972; Rosenberg 1976, 1982; Berard 1977; Gold 1977; Strange 1977; Landau and Rosenberg 1986).

Economic theory explained in general how such phenomena are interrelated by competition in free markets. The objective of the NAPAP model was to simultaneously project technological changes, shifts in supply and demand for wood fiber raw materials, production, capacity changes, trade, and price equilibria throughout the pulp and paper sector.

4.2.1 Background

The NAPAP model was an application of the third generation of the PELPS system. Developed at the University of Wisconsin-Madison, and sponsored by the Forest Service and FPL, PELPS and the related

PAPYRUS model were to meet requirements of the RPA legislation, under which the Forest Service makes periodic assessments of long-term supply and demand for forest resources (see Gilless and Buongiorno 1987, pp 1–2).

The Forest Service had long made nationwide assessments of the timber resource situation in the USA prior to RPA legislation, but it was not until the early 1980s that they began to project the future equilibrium between demand and supply and attendant prices (USDA FS 1982). Initially, this was done only for softwood sawtimber, lumber, and plywood, with TAMM (Adams and Haynes 1980; also see Chap. 1). A similar model was not available for the pulp and paper sector. Thus, in planning model development in the early 1980s, in consultation with interested parties in industry and universities, the Forest Service outlined the specifications of a model of the North American pulp and paper industry.

4.2.2 Specifications

The Forest Service pulp and paper model envisioned in the mid-1980s had the following requirements (Gilless and Buongiorno 1987): (1) reflect the regional character of the industry, especially of the forest resources on which it depends, while recognizing the international setting in which the industry competes; (2) recognize the key role played by competitive markets, with endogenous prices reflecting the balance between demand and supply forces within and outside the industry; (3) represent technical processes of pulp and paper with enough detail to explain how they are selected under different economic conditions, and how they evolve over time in relation to competitive markets; (4) project regional shifts of manufacturing capacity as a result of evolving supply and demand conditions in North America and the rest of the world, especially with regard to availability of pulpwood and other fibers; and (5) link the model with TAMM to reflect the interrelationships between the solid wood products (lumber and plywood) and the pulp and paper sectors.

The initial attempt to meet these objectives led to the PAPYRUS model of the North American pulp and paper industry (Gilless and Buongiorno 1987). PAPYRUS evolved out of earlier models discussed in Buongiorno (1981), Buongiorno and Gilless (1983b, 1984), and Gilless (1983).

Although PAPYRUS did meet several of the Forest Service requirements, it was never actually linked to the TAMM model nor applied in the RPA Timber Assessments. Its shortcomings included its inability to simulate technical change even though capacity was allocated among different product grades and regions as a dynamic process. Also, PAPYRUS had enough regions but fewer product grades than needed in technology assessment studies of the pulp and paper industry.

Nevertheless the general modeling framework developed for PAPYRUS was available as PELPS (Gilles and Buongiorno 1985). Thus, by the mid-1980s a general methodology for economic modeling of large industrial sectors was available, with demonstrated applications to the pulp and paper sector.

4.2.3 FPL pulpwood model

The Forest Service anticipated a need for quantitative technology assessment research several years prior to the 1989 RPA Timber Assessment. Noteworthy technical changes were beginning to affect wood use in forest products then, such as expanded use of hardwood fiber in kraft linerboard in the South and OSB as a replacement for softwood plywood (Ince 1986), along with other improvements in paper recycling technology for newsprint and containerboard. As a result, in 1985, researchers at FPL were invited by RPA Timber Assessment staff to assess technological changes in wood use within the forest product industries. Peter Ince focused on the pulp and paper sector and sought to develop an improved economic model based on PELPS methodology with other FPL researchers, in cooperation with Joseph Buongiorno and students at the University of Wisconsin-Madison (Ince et al. 1987; Howard et al. 1988). The resulting model, developed in the late 1980s, was the FPL Pulpwood model (Ince 1989), which provided projections of the pulp and paper sector for the 1989 RPA Timber Assessment (USDA FS 1989; Haynes 1990).

The FPL Pulpwood model was a second-generation application of PELPS, with much more production detail than PAPYRUS. The FPL Pulpwood Model had eight categories of final products, matching the principal product categories recognized by the US and Canadian industry trade associations. This followed the recommendation of the former American Paper Institute (predecessor to American Forest & Paper Association [AF&PA]) based on data availability, and the fact

that each product category is produced with unique processes, and each has a distinct market.

The FPL Pulpwood model also introduced a new method of technology forecasting, which became the prototype for later NAPAP model development in the 1990s. This method distinguishes production capacity not only by product and region, but also by process. Pulp, paper, or paperboard mills tend to be large and capital-intensive facilities that cannot be readily moved or switched from one production process to another without considerable expense. It was observed that technical change and capacity expansion were both the result of competitive economic behavior, as evidenced by frequent industry announcements of mill closures, capacity expansions, or mill renovations, justified by market conditions, competitive advantages of newer mills, or more efficient production processes.

The FPL Pulpwood model simulated this competitive evolution of production technology by allocating changes in capacity among competing processes as a function of their marginal economic value (Ince 1989). In essence, this approach captured some elements of Schumpeter's "creative destruction" theory of industrial evolution (Schumpeter 1943). The FPL Pulpwood Model development led to improved microcomputer versions of PELPS, including PELPS II (Calmels et al. 1990), and PELPS II PLUS (Zhang et al. 1991) that were designed specifically to model capacity change by process as well as by region.

The FPL Pulpwood model provided pulp and paper industry projections for the 1989 RPA Timber Assessment (Ince 1989; USDA FS 1989; Haynes 1990). One of the more significant findings was that processes based on recycled fiber would likely become more competitive and rapidly obtain a larger share of production capacity in North America during the 1990s (Ince 1990). This was due to rapid increases in landfill waste disposal fees and in recovery of paper and paperboard for recycling (to avoid landfill disposal), which increasingly made more and cheaper recovered paper available for recycling in the early 1990s.

Projections derived from the FPL Pulpwood Model and Forest Service TAMM model in 1990 predicted that expansion of paper recycling would accelerate in the 1990s, with significant impacts on future timber prices and timber consumption in North America. For example, instead of rising real pulpwood prices in the South that had been projected earlier, the results showed that softwood pulpwood prices would peak in the late 1990s and then gradually decline, largely due to increased paper recycling (Ince 1990). The projections also indicated

that sawtimber prices would increase less than previously projected (Ince 1990). These projections were later corroborated by actual market trends of the 1990s.

4.2.4 NAPAP model

Following these findings, the Forest Service decided to further study timber market impacts of increased paper recycling, and to report results in the 1993 RPA Timber Assessment. In addition, in 1990 the Forest Service and Forestry Canada launched a cooperative research effort to develop a new economic model of the entire North American pulp and paper sector. Initiated by Ince, the project would continue to use the PELPS methodology and collaboration with the University of Wisconsin-Madison. This collaborative research led to the first version of the NAPAP model and its applications (Ince 1994b; Zhang et al. 1996), in conjunction with development of PELPS III (Zhang et al. 1993).

Finally, the latest version of the NAPAP model was developed by Ince in the late 1990s (Ince 1999a) for the 2000 RPA Timber Assessment (Haynes 2003). In this version, the South was divided into two subregions, and the printing and writing paper commodity group was divided into coated and uncoated free sheet, and coated and uncoated groundwood paper. In addition, US pulp and paper imports and exports were analyzed to project trade impacts on US pulp, paper, and paperboard markets.

4.3 OTHER MODELS AND RELATED LITERATURE

Prior to the development of PELPS, PAPYRUS, and NAPAP models, there were few comprehensive economic forecasting models of the US pulp and paper sector. Earlier studies of the North American pulp and paper industry took a more general approach than economic modeling (such as synoptic books on the evolving industry structure by Guthrie 1972, or Strange 1977), or involved models intended to examine issues other than timber supply and demand, such as energy consumption (a popular topic during the “energy crisis” of the 1970s). General economists seldom dealt with the pulp and paper sector per se, and forest economists concentrated on the “solid wood” subsector (lumber, plywood, sawtimber, etc.). An exception was McKillop’s (1967)

econometric model which covered the solid wood as well as the pulp and paper industry, albeit at a much aggregated level.

From a forestry perspective, the focus of market modeling on lumber and plywood made sense because higher prices have always been paid for larger diameter sawtimber (used for lumber or plywood) than for pulpwood, and forestry was traditionally focused on sawtimber as the primary product. However, pulpwood consumption had grown to such proportions by the 1970s that North American foresters began to view pulpwood as an important element in the forest economy. Also, technical developments had increased the ability of industry to substitute smaller “pulpwood-quality” logs for larger diameter logs in products such as OSB, which began substituting for softwood plywood in the 1980s, and “small-log” lumber and plywood mills were being built to utilize smaller diameter timber. Furthermore, with the advent of economic models that simulated the changing timber growth and inventory, it became apparent that trends in pulpwood consumption could have a large bearing on the long-run timber supply and demand outlook in North America (Adams and Haynes 1980).

One example of a model of the pulp and paper sector designed to analyze energy issues was the model developed by the National Center for Analysis of Energy Systems at Brookhaven National Laboratory (Pilati et al. 1980). The Brookhaven model was designed to project future regional energy resource consumption in the US pulp and paper sector. Described as “a regional dynamic mathematical programming model” it determined annually the investments and production activities that minimized total discounted costs. It considered the energy requirements and costs of processing three fiber types into various categories of pulp, and pulp into seven paper and paperboard products. Regional demands for paper products were specified exogenously over a 25-year time horizon. The model was validated for a base year (1975) and applied to make energy demand projections, technology assessments, and energy policy studies.

Like the NAPAP model, the manufacturing part of the Brookhaven model was based on activity analysis, with input/output coefficients and costs by process. However, it was not a market model. The Brookhaven model determined production activity and capacity growth for competing processes based on cost minimization. It did not deal with the price-responsive demand of the end products. Rather, it described how a planned economy should best allocate its activities and investments to meet a predetermined demand.

Another relevant example of previous modeling work was the ETA (Energy Technology Assessment)-MACRO model (for large-scale energy technology assessment) of the US energy sector (Manne 1981). ETA-MACRO was designed to estimate the extent of linkages between the US energy sector and the rest of the national economy. It merged ETA (a process model for energy technology assessment) and a macro-economic growth model, with substitution between capital, labor, and energy inputs. The model simulated a market economy. Supplies, demands, and prices were matched through dynamic nonlinear programming. With higher energy prices, greater amounts of energy became available and consumers were induced to conserve. Although technically different, the PELPS system and NAPAP model incorporate similar producer and consumer responses to changing prices.

The market equilibrium formulation of PELPS and the PAPYRUS model was based on earlier optimization-based models of the energy sector (Kennedy 1974; Manne 1979), and of agriculture (Duloy and Norton 1975). The dynamics of PELPS were influenced also by recursive programming ideas of Day (1973), as applied by Abe (1973) and Nelson (1973), and the systems dynamics concepts of Forrester (1980). PELPS was ultimately a synthesis of econometrics, mathematical programming, and systems dynamics (Buongiorno 1996).

The optimization-based approach employed by PELPS beginning in the early 1980s was distinct from the reactive programming approach of the leading US forest sector model at that time (Adams and Haynes 1980). There was, however, another model of softwood timber markets at that time encompassing paper and paperboard products based on linear programming (Haynes et al. 1978). There were also a number of other forest sector models that were being developed contemporaneously with the development of PELPS, PAPYRUS, and the FPL Pulpwood model in the 1980s.

4.3.1 Contemporaneous forest sector models

A number of comprehensive forest sector models were developed contemporaneously to project market conditions in industry sectors that rely on regional forest resources and markets. Examples include the forest sector model for Sweden (Lonner 1991) and the wood supply and demand analysis of the UK (Whiteman 1991). In the 1980s a global forest sector trade model was developed by the Forest Sector Project at IIASA in Laxenburg, Austria, with research contributions

from numerous forest sector modeling specialists around the world (Kallio et al. 1987). Like PELPS, the IIASA-GTM was a spatial equilibrium model, based on optimization and recursive programming. Indeed, the first operational version of the GTM used the PELPS software (Buongiorno and Gilless 1983a; p.xi in Kallio et al. 1987).

However, IIASA's GTM represented production technologies and commodities at more aggregate levels than the NAPAP model. In particular, there were only three paper and paperboard commodity groups: newsprint, other printing paper, and packaging paper and board (similar but not identical to the three commodities used in the PAPYRUS model). Such broadly aggregated commodities were not suitable for analyzing the more detailed technological changes desired for the RPA Timber Assessments, although they were appropriate in the wide sector and geographic coverage of the GTM. The approach with the NAPAP model, instead, was to describe the pulp and paper sector in much finer detail and then link it to TAMM. The result was a more comprehensive and detailed modeling system for analysis of the North American forest sector suitable for RPA Timber Assessment objectives, including the objective of technology forecasting.

4.3.2 Spatial equilibrium modeling

Samuelson (1952) described a spatial equilibrium model as one for which:

... [W]e 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?

Samuelson showed that solution of the spatial equilibrium problem was equivalent to the solution of a mathematical programming problem involving maximization of "net social payoff," defined as the sum of producer and consumer surplus for each region, minus transportation costs between and within regions. A spatial equilibrium model simulates the competitive market equilibrium in an interregional economy (finding the competitive equilibrium of supply, demand, and prices for

all commodities) by maximizing the net social payoff among all regions and commodity markets in the model.

Iterative procedures to solve the spatial equilibrium problem were developed initially by Fox (1953), Judge and Wallace (1958), Tramel and Seale (1959), Schrader and King (1962), and Yaron (1967). A quadratic programming solution was used also by Takayama and Judge (1964b) for the special case of linear supply and demand curves.

Samuelson's maximum net social payoff has no normative implication beyond that of identifying the regional market equilibrium for a sector described in terms of regional supply and demand curves, and transportation costs between and within these regions. The justification for its use is its consistency with economic theory about market behavior and the mathematical efficiency by which it can simulate the market equilibrium under different conditions or assumptions (McCarl and Spreen 1980):

[I]ts behavioral implications are consistent with theoretical economic behavior of the sectional participants. Thus a model with this objective function can be used to simulate producer response to policy.

4.3.3 Price-endogenous linear programming

A linear programming method for solving spatial equilibrium problems (price-endogenous linear programming) was developed by Duloy and Norton (1975). It consists essentially of approximating Samuelson's social surplus, the area under demand curves minus the area under the supply curves, by piecewise linear functions. Variants of this method were used to model a number of diverse agricultural and energy-related sectors prior to development of the NAPAP model or PELPS (Kennedy 1974; McCarl and Spreen 1980).

The most important feature of the price-endogenous linear programming approach (and similar approaches based on quadratic, or more general mathematical programming), is its ability to integrate economic relationships that are sketched with econometric relations (such as demand or supply functions) with economic relationships described in much detail with activity analysis (input/output coefficients and attendant costs describing a specific technique of production). Takayama and Judge (1964a, 1970, 1971) are credited for introducing this kind of "activity analysis" in a spatial equilibrium model. They provided the means of finding the competitive market equilibrium not only among regions but also among manufacturing

processes, each one described by inputs required per unit of output, unit cost of manufacturing net of inputs, and production capacity.

The original PELPS provided a general framework for constructing spatial equilibrium models, with activity analysis (Gilles and Buongiorno 1985). However, it lacked capacity constraints by process, which allowed an unrealistic free substitution of one process for another within the constraint of production capacity for each product. We introduced capacity constraints by process in NAPAP and later versions of PELPS because in reality pulp and paper mills are differentiated both by product and by manufacturing process, such as the type of pulping process, or the reliance on recycled fiber or virgin fiber (Guthrie 1972 or Strange 1977). Different processes have different inputs and costs, and the conversion of mill capacity from one process to another requires capital investment. Thus, in NAPAP, existing capacity acts as a short-run constraint on substitution among production inputs, but capacity may change in the long run by process, product, and region.

4.3.4 Techno-spatial equilibrium modeling

Distinguishing production capacity by process as well as by product and region was a natural extension of Samuelson's spatial equilibrium with Takayama and Judge's activity analysis. This "techno-spatial equilibrium modeling" addressed a technology forecasting problem simultaneously with the spatial multi-commodity equilibrium problem. The FPL Pulpwood model was the first PELPS application in which activity analysis was extended in this way to find competitive equilibria among competing manufacturing processes, with capacity constraints at the process level. The NAPAP model followed the same approach (Ince 1994b)) and PELPS was modified accordingly, along with other improvements leading to PELPS III (Zhang et al. 1993). The adaptability of the classic spatial equilibrium framework to the problem of technology forecasting was a primary consideration in the decision to use this approach.

The latest version of the NAPAP model utilized FPL-PELPS (Lebow et al. 2003). FPL-PELPS incorporated all of the features of PELPS III, along with some additions to the range of outputs, capacity growth parameters, and production constraints, designed to serve the needs of the NAPAP model and other FPL models.

As explained below, in addition to the linear program that describes the static equilibrium in a given year, the NAPAP model

is made dynamic by a set of recursive relationships that update the linear program from year to year according to endogenous and exogenous changes. These recursive equations include exogenously specified shifts in supply and demand as well as endogenous changes in production capacity by process, product, and region. Change in production capacity by process is a function of the marginal value and cost of new capacity, favoring the growth of processes that are more competitive. Thus, change in capacity and technology (including shifts in wood and recycled fiber use associated with competitive process substitution) is influenced by market conditions.

4.4 MATHEMATICAL STRUCTURE OF NAPAP MODEL

The mathematical structure of the model includes the linear programming problem (objective function and constraints) that is solved to derive the spatial market equilibrium for each year in the model, and various recursive relationships used to update the linear program from year to year over the projection period (Zhang et al. 1993, 1996).

4.4.1 Objective function

Maximization of Samuelson's net social payoff (consumer and producer surplus minus transportation and manufacturing costs) defines the linear programming objective function:

$$\text{Max } Z = Z_d - Z_s - Z_t - Z_m \quad (4.1)$$

where:

$$Z_d = \sum_k \sum_j \int_0^{D_{jk}} P_{jk}(D_{jk}) dD_{jk} \quad (4.2)$$

is the area under all demand curves for commodities k and demand regions j , the aggregate value of the products to consumers. The inverse demand function, $P(D)$ links price, P , and quantity demanded, D . Such demand functions are used typically for end products (newsprint, linerboard, etc.).

$$Z_s = \sum_k \sum_i \int_0^{S_{ik}} P_{ik}(S_{ik}) dS_{ik} \quad (4.3)$$

is the area under all supply curves for commodities k and supply regions i , the aggregate cost of production for suppliers. The inverse supply function, $P(S)$ links price, P , and quantity supplied, S . Such supply functions are used to describe raw material supply (pulpwood, recovered paper).

$$Z_t = \sum_k \sum_i \sum_j T_{ijk} d_{ijk} \quad (4.4)$$

is the sum of net transportation costs (quantity transported T times net transport costs d) for all commodities (k) transported between all supply and demand regions (i and j), and

$$Z_m = \sum_i \sum_k \sum_p \sum_x Y_{ikpx} m_{ikpx} \quad (4.5)$$

is the sum of net manufacturing costs, or production quantity Y times unit manufacturing cost (m) for all commodities (k) in all manufacturing regions (i) and for all production processes (p) and fiber input mix (x). The manufacturing cost includes the transportation within the region and the exogenous cost of labor, capital, energy, and other inputs, but excludes the cost of endogenous inputs (wood inputs in the manufacture of pulp, and wood, pulp or recovered paper inputs in the manufacture of paper). Manufacturing activities are used to describe in detail a technique of production, for example, costs and inputs required to transform wood and pulp into paper using a particular process. The range of production possibilities in terms of fiber inputs for a given production process is defined by a set of feasible input combinations or “fiber input mix” alternatives for a given process.

4.4.2 Demand

The NAPAP model covers the demand for 12 categories of paper and paperboard that encompass the full spectrum of paper and paperboard commodities produced in North America.¹ The model also has demand curves for dissolving pulp (a category of pulp used for synthetic polymers, such as production of rayon fiber), and it covers the

¹ These are aggregates of product categories in the production statistics published annually by AF&PA. They consist of newsprint, four categories of printing and writing paper (uncoated free sheet, coated free sheet, uncoated groundwood paper, coated groundwood paper), tissue and sanitary products, unbleached kraft packaging paper, other packaging and industrial paper. linerboard (including unbleached kraft paperboard and recycled linerboard), corrugating medium (including semi-chemical and recycled corrugating medium), solid bleached kraft paperboard, and other recycled paperboard.

demand for roundwood pulpwood used by wood panel mills (such as OSB mills) as projected by TAMM.

For each category of paper, paperboard, and dissolving pulp, demand curves describe the demands within the USA and Canada, and the foreign demand for US and Canadian exports. The model also represents the foreign demand for US and Canadian exports of pulpwood, recovered paper, and market pulp.

In PELPS III, the most general form of the demand equation of commodity k in demand region j for year t is:

$$D_{jk,t} = a_{ik} P_{jk,t}^{\sigma_{jk}} e_{j,t}^{\sigma_{jk}} X_{1jk,t}^{\delta_{jk}} X_{2jk,t}^{\tau_{jk}} X_{3jk,t}^{\alpha_{jk}} D_{jk,t-1}^{\eta_{jk}} \quad (4.6)$$

where e is the currency exchange rate (with respect to the US dollar) in demand region j , σ is elasticity of demand with respect to price, X_1 , X_2 , and X_3 are exogenous shifters of demand over time, δ , τ , and α are elasticities with respect to change in the exogenous shifters over time, and η is a partial adjustment coefficient (elasticity with respect to quantity demanded in the preceding year). While the price is endogenous, the demand shifters and the exchange rate are exogenous. In addition to the general form of demand equation (4.6) PELPS III allows the specification of “L-shaped” demand curves, consisting of a lower bound or minimum demand quantity and a fixed demand price above the lower bound (lower bounds can be shifted over time to reflect exogenous projections of minimum demand quantities).

In the NAPAP model, the general price-responsive form of demand equation (4.6) was used for all US and Canadian domestic paper and paperboard demands, while the L-shaped demand was used to specify global export demands from outside of the USA and Canada. Thus, domestic demands for paper and paperboard in the USA and Canada are determined endogenously in the NAPAP model, using price-elastic demand curves, while trends in exports to other regions are specified exogenously. Trade flows between the USA and Canada (the largest element of US trade in pulp, paper, and paperboard) are also determined endogenously. However, exports to countries outside of the USA and Canada are predetermined via exogenously specified shifts of the lower bounds on export demand.²

² An earlier version of the NAPAP Model developed in the early 1990s included price-elastic demand and supply curves to represent trade between North America and other world regions, but the projected trade flows were unstable and difficult to calibrate, and therefore replaced by simple exogenous trade projections. The GFPM (Buongiorno et al. 2003) predicts multicountry trade flows endogenously, with a PELPS-like structure, but with a much less detailed description of the pulp

Table 4-1 summarizes the base-year (1986) prices and demand quantities of the NAPAP model, and the own-price elasticities, and elasticities with respect to GDP and population for the US and Canadian demand equations by commodity. The assumed future growth rates of US population and GDP are discussed in Chapter 7. For pulp, paper, and paperboard, all quantities are in thousands of tonnes, and all prices in 1986 US dollars per tonne. Demand elasticities may be adjusted over time, but the latest version of the model keeps them constant. Also, the partial adjustment coefficients, referring to the influence of past demand on current demand (4.6) were not used in the latest version of the model. Note that demands for all paper and paperboard commodities are generally inelastic with respect to price in the short run (with absolute values of elasticities less than 1.0) because there are few direct substitutes for paper or paperboard materials in the short run. Substitution does occur over the long run, however, such as with newsprint demand declining with gradual substitution of print media by electronic media.

The US demand equations were based on the results of Zhang (1995). Canadian demand equations were estimated in the early 1990s by collaborators from Forestry Canada (see acknowledgments). The Canadian demand equations used only Canadian GDP as an exogenous independent variable. Table 4-2 summarizes the elasticities of US demand with respect to the other exogenous shifters besides GDP and population. The assumed annual percentage changes of these shifters, from 1986 to 2050, were price of printed material, 3.8%, price of capital, 1%, price of TV/radios, 5.2%, price of computers, -4.5%, price of paper packaging, 1%, price of plastics packaging, -1% PPI, 2.6%. The Canadian GDP was assumed to grow at 2.4% per year initially, declining steadily to 1.2% by 2050. The “technical change (t)” column in Table 4-2 refers to the constant yearly rate of shift of demand over time (Zhang 1995). The “long-run shifter” adjusts future demand growth beyond 2005, on the assumption that paper and paperboard demands will be dampened by further substitution of electronic media for print media and by substitution of plastics for paperboard in packaging. Projected demand growth each year is obtained by multiplying the long-run shifter by the overall shift in demand determined by the projected annual changes in the exogenous variables and their demand elasticities. The dampening effect on demand of the long-run shifter

and paper sector. The GFPM and its planned future application in RPA Timber Assessments are discussed in Chapter 13.

Table 4-1. Demand commodities, regions, base-period (1986) prices (US dollars), base-period regional demand quantities, price elasticities, and elasticities of demand with respect to exogenous variables (For other variables see Table 4-2.)

Demand region and commodity	Base Price	Base quantity	Price elasticity	Exogenous variable elasticities	
				GDP	Population
	<i>1986 dollars/ tonnes</i>	<i>Thousand tonnes</i>			
USA:					
Newsprint	525.00	11,873	-0.220	1.23	1.0
Uncoated free sheet	772.00	11,205	-0.470	1.23	1.0
Coated free sheet	929.00	2,669	-0.400	1.23	1.0
Uncoated groundwood	630.00	2,806	-0.540	1.23	1.0
Coated groundwood	830.00	3,395	-0.400	1.23	1.0
Tissue and sanitary	900.00	4,662	-0.260	0.85	1.0
Specialty packaging paper	700.00	1,771	-0.230	0.65	1.0
Kraft packaging paper	375.00	2,860	-0.540	0.5	1.0
Linerboard	360.00	14,459	-0.290	0.65	1.0
Corrugating medium	340.00	6,158	-0.430	0.65	1.0
Solid bleached board	684.00	3,301	-0.290	0.65	1.0
Recycled board	340.00	5,604	-0.400	0.65	1.0
Construction paper and board	275.00	711	-0.580	-0.26	1.31
Dissolving pulp	575.00	686	-0.260	-0.73	1.0
Canada:					
Newsprint	525.00	1,085	-0.200	0.5	-
Uncoated free sheet	772.00	657	-0.200	0.5	-
Coated free sheet	929.00	252	-0.200	0.6	-
Uncoated groundwood	630.00	212	-0.200	0.6	-
Coated groundwood	830.00	263	-0.200	0.6	-
Tissue and sanitary	900.00	385	-0.600	0.4	-
Specialty packaging paper	700.00	27	-0.600	-0.1	-
Kraft packaging paper	375.00	324	-0.600	-0.2	-
Linerboard	360.00	913	-0.700	0.8	-
Corrugating medium	355.00	422	-0.700	0.8	-
Solid bleached board	684.00	262	-0.700	-0.1	-
Recycled board	320.00	612	-0.700	-0.1	-
Construction paper and board	275.00	126	-0.700	0.2	-
Dissolving pulp	575.00	55	-0.700	-0.1	-

Table 4-2. Elasticities of US demands with respect to other exogenous variables

Demand region and commodity	Exogenous variable elasticities					
	Technical change (t)	Price of printed material	Price of capital	Price of TV/radios	Price of computers	Long-run shifter
USA:						
Newsprint	-0.019	-0.95	0.28	-0.07	-0.06	1.0
Uncoated free sheet	0.01	-0.5	0.28	-0.07	-0.06	0.6
Coated free sheet	0.002	-0.25	0.28	-0.07	-0.06	0.5
Uncoated ground-wood	-0.01	-0.2	0.28	-0.07	-0.06	0.5
Coated ground-wood	0.002	-0.3	0.28	-0.07	-0.06	0.65
Tissue and sanitary	—	—	—	—	—	0.7
	Technical change (t)	Price of capital	Price of paper packaging	Price of plastics packaging	PPI	Long-run shifter
Specialty packaging paper	0.012	0.25	—	0.16	-0.27	0.95
Kraft packaging paper	-0.058	—	-0.59	0.16	-0.27	1.0
Linerboard	0.012	0.25	—	0.16	—	0.8
Corrugating medium	0.012	0.25	—	0.16	-0.1	0.8
Solid bleached board	0.012	0.25	-0.3	0.16	-0.27	0.8
Recycled board	0.012	0.25	—	0.16	-0.27	0.6

also reflects a general maturation of US markets and slower growth in domestic demands for paper and paperboard products due to impacts of economic globalization.

A linear approximation was used to measure the area under the demand curves described by equation (4.6) (Zhang et al. 1993; Lebow et al. 2003). The same method was applied to approximate the area

under the supply curves, and thus obtain a linear approximation of the objective function (4.1). Because all the constraints were also linear, the model was then solved by linear programming.

4.4.3 Supply

The NAPAP model has supply curves for the total supply of pulpwood used in pulp, paper, and paperboard mills and in certain panel mills (OSB mills that use pulpwood roundwood), and also supply curves for recovered paper used in paper and paperboard mills. For each US and Canadian supply region there are separate supply curves for hardwood and softwood pulpwood, and for each species group there are separate supply curves for roundwood pulpwood (representing wood harvested and delivered as roundwood or chips directly to pulp, paper, and paperboard mills or OSB mills) and for wood residues (coarse woody residues such as chips supplied to pulp mills from sawmills and plywood mills).

For each region NAPAP also has separate supply curves for five categories of recovered paper: old newspapers, old corrugated containers, pulp substitutes, high-grade deinking, and mixed paper.³ Furthermore, in the US supply regions each category of recovered paper supply is disaggregated into a price-elastic “spot market” supply representing transactions that occur in the open market, and an inelastic “long-term contract” supply representing transactions governed by long-term contracts (typical of supply from municipal recycling programs). Disaggregating recovered paper supply into spot market and long-term contracts improved the model’s accuracy in tracking the volatile recovered paper prices in the 1990s (Howard et al. 2002).

In PELPS III, the most general form of the supply equation of commodity k in region i for year t is:

$$S_{ik,t} = b_{ik} P_{ik,t}^{\lambda_{ik}} e_{ik,t}^{\lambda_{ik}} X_{1ik,t}^{\rho_{ik}} X_{2ik,t}^{\mu_{ik}} X_{3ik,t}^{\varphi_{ik}} S_{ik,t-1}^{\xi_{ik}} \quad (4.7)$$

where the variables and parameters are analogous to those of the demand equation (4.6). PELPS III also allows L-shaped supply curves, consisting of a reservation price and an upper bound on supply (upper bounds can be shifted over time based on exogenous projections of upper limits on supply quantities). The general form (4.7) was used

³ These five categories are aggregates of more detailed commercial grades of recovered paper defined in the *Guidelines for Paper Stock Transactions* by the Institute of Scrap Recycling Industries (ISRI).

in NAPAP for roundwood pulpwood supply and for the spot market portion of recovered paper supply. The L-shaped form was used for wood residues supply, pulpwood supply from public forests, and for the long-term contract portion of recovered paper supply.

4.4.3.1 Pulpwood supply

Table 4-3 shows the NAPAP model base-year (1986) regional supply prices and quantities of pulpwood, the own-price supply elasticities, and the elasticities of supply with respect to exogenous and lagged variables for US supply regions. Base prices for pulpwood from FI and NIPF timberlands were estimated with data on 1986 pulpwood stumpage prices from various sources. Base prices for pulpwood from public forests, for residues, and for pulpwood supplies in the West are reservation prices for L-shaped supply curves. Upper bounds for pulpwood supplies from public lands and for roundwood in the West were equal in the base year to the base-year supply quantities, and then projected exogenously for subsequent years. The projection usually assumed no significant increase in roundwood pulpwood supply from US public lands in the decades ahead, but this assumption was modified in scenarios that explored impacts of alternative trends in pulpwood supply from public lands. Historically, much of the roundwood pulpwood supply in the West has come from public lands (state and federal).

The upper bound on pulpwood residue supply quantities for all regions are shifted on the basis of projected regional supplies of coarse wood residues from sawmills and plywood mills, as computed by the TAMM model. Regional pulpwood supply functions for FI and NIPF timberlands were estimated together with sawtimber supply relations (see Chap. 3). They featured elasticities with respect to regional pulpwood and sawtimber stumpage prices, real interest rate, per capita disposable personal income (DPI), regional timber inventory (projected by the TAMM/ATLAS model), and lagged timber cut/inventory ratio (also projected by TAMM/ATLAS). Projected trends in macroeconomic variables such as interest rate and DPI are discussed in Chapter 7.

Table 4-4 shows the NAPAP model base-year (1986) regional supply prices and quantities of pulpwood for Canada, along with price elasticities and elasticities of supply with respect to exogenous variables. Unlike the US pulpwood supply equations, which deal with stumpage, the Canadian equations represent delivered-to-mill supply.

Table 4.3. Pulpwood supply commodities among US supply regions, based-period (1986) prices (US dollars), based-period supply quantities, price elasticities, and elasticities of supply with respect to exogenous and lagged variables

Supply region and commodity	Base price	Base quantity	Price elasticity	Exogenous variable elasticities				Lagged timber cut/ inventory
				Sawtimber stumpage	Interest rate	Per capita DPI	Timber inventory	
	1986 dollars/ cubic meter	Thousand cubic meters						
Northeastern USA:								
Hardwood—forest industry	2.90	1,334	0.199	—	0.0092	-0.343	1.0	1.166
Hardwood—other private	2.90	7,656	0.356	0.2485	—	—	1.0	0.4523
Hardwood—public forest	1.00	497	0	—	—	—	—	—
Hardwood residues	4.00	1,781	0	—	—	—	—	—
Softwood—forest industry	3.30	4,449	0.221	—	—	-0.4589	1.0	0.5539
Softwood—other private	3.30	3,695	0.608	—	—	—	1.0	0.9821
Softwood—public forest	2.00	356	0	—	—	—	—	—
Softwood residues	4.00	2,180	0	—	—	—	—	—
North Central USA:								
Hardwood—forest industry	2.90	1,562	0.431	0.4689	0.1211	—	1.0	0.4188
Hardwood—other private	2.90	10,280	0.279	-0.4322	—	—	1.0	0.4464
Hardwood—public forest	1.00	1,622	0	—	—	—	—	—
Hardwood residues	4.00	2,041	0	—	—	—	—	—
Softwood—forest industry	3.30	565	0.600	-0.6881	—	—	1.0	—
Softwood—other private	3.30	1,684	0.407	—	0.0104	-1.1664	1.0	—
Softwood—public forest	2.00	1,208	0	—	—	—	—	—
Softwood residues	4.00	491	0	—	—	—	—	—

Southeastern USA:									
Hardwood—forest industry	1.55	1,725	0.368	0.2322	0.0957	—	1.0	—	—
Hardwood—other private	1.55	10,196	0.122	—	0.0614	—	1.0	0.6415	—
Hardwood—public forest	1.00	465	0	—	—	—	—	—	—
Hardwood residues	5.00	3,243	0	—	—	—	—	—	—
Softwood—forest industry	6.25	8,699	0.463	—	—	—	1.0	0.5117	—
Softwood—other private	6.25	19,287	0.284	-0.2767	0.0304	-0.1183	1.0	—	—
Softwood—public forest	3.00	2,048	0	—	—	—	—	—	—
Softwood residues	5.00	15,087	0	—	—	—	—	—	—
South Central USA:									
Hardwood—forest industry	1.55	3,923	0.437	—	0.1488	—	1.0	—	—
Hardwood—other private	1.55	14,713	0.259	—	—	—	1.0	0.5560	—
Hardwood—public forest	1.00	1,169	0	—	—	—	—	—	—
Hardwood residues	5.00	6,939	0	—	—	—	—	—	—
Softwood—forest industry	6.25	11,583	0.213	—	—	—	1.0	0.3456	—
Softwood—other private	6.25	16,700	0.299	—	—	—	1.0	0.6494	—
Softwood—public forest	3.00	2,638	0	—	—	—	—	—	—
Softwood residues	5.00	19,326	0	—	—	—	—	—	—
West USA:									
Hardwood roundwood	1.00	2,766	0	—	—	—	—	—	—
Hardwood residues	1.00	800	0	—	—	—	—	—	—
Softwood roundwood	1.00	11,233	0	—	—	—	—	—	—
Softwood residues	1.00	27,993	0	—	—	—	—	—	—

Hence the base-year prices are noticeably higher. Harvest and transport costs from stump to mill were added to stumpage prices in US regions to account for this difference. The Canadian pulpwood supply equations are estimated in the early 1990s by collaborators from Forestry Canada. The equations feature elasticities with respect to pulpwood price, sawtimber stumpage price, and real labor cost. The sawtimber price was derived from TAMM projections of sawtimber price for the North. Labor cost for logging in Canada was projected to increase at an annual rate of 2.4%, based on estimates from Forestry Canada. Wood residues are substantial part of the Canadian pulpwood supply. This residues supply was modeled with the L-shaped supply curves of PELP, with a reservation price and upper bound

Table 4-4. Pulpwood supply commodities among Canadian supply regions, base-period (1986) prices (US dollars), base-period supply quantities, price elasticities, and elasticities of supply with respect to exogenous variables

Supply region and commodity	Base price	Base quantity	Price elasticity	Exogenous variable elasticities	
				Sawtimber stumpage	Labor cost
	<i>1986 dollars/cubic meter</i>	<i>Thousands cubic meter</i>			
Canada East:					
Hardwood roundwood	20.00	6,892	0.160	-0.02	-0.29
Hardwood residues	19.00	2,201	0	-	-
Softwood roundwood	27.00	30,324	0.160	-0.02	-0.29
Softwood residues	29.00	19,806	0	-	-
Canada West:					
Hardwood roundwood	20.00	860	0.160	-0.27	-0.2
Hardwood residues	25.00	1	0	-	-
Softwood roundwood	20.00	8,973	0.330	-0.27	-0.2
Softwood residues	17.00	26,858	0	-	-

on supply quantity. The upper bounds were shifted on the basis of projected supplies of coarse wood residues from Canadian sawmills and plywood mills, as determined by the TAMM model.

4.4.3.2 Recovered paper supply

Table 4-5 shows NAPAP model base-year regional supply prices and quantities of recovered paper, the own-price supply elasticities, and the elasticities of supply with respect to other variables for US supply regions. Within each US supply region for recovered paper (North, South, and West) there are two sources of supply, short-term or “spot” market supply and long-term contract supply (LTC in Table 4-5). Howard et al. (2002) observed that overall supply expanded rapidly during the 1990s with increased collection and recycling of paper to divert wastepaper from landfills. Prices were at first depressed with excess supply, but there was a sharp spike in prices in 1994 and 1995, followed by a price collapse. It was postulated that this price volatility reflected the fact that supplies of recovered paper to domestic paper and paperboard mills derived primarily from long-term contracts, while a smaller portion of supply was provided by a volatile spot market. The spot market is volatile because it tends to be the source of recovered paper exports (long-term supply contract arrangements are less common with foreign mills, so exporters of recovered paper operate mainly in the spot market).

Accordingly, Howard et al. (2002) estimated spot market supply equations for recovered paper using export quantity data and spot market price data. For econometric purposes it was assumed that shifts in export quantities were representative of shifts in spot market supply quantities. Spot market supply equations were estimated with own-price and landfill tipping fees as independent variables, along with a fixed unit elasticity relationship (1:1) to “parent commodity” consumption. The parent commodity is the paper or paperboard commodity (or commodities) from which a given recovered paper commodity is derived; for example newsprint is the parent commodity for old newspapers. In the NAPAP projections, landfill tipping fees were assumed to continue increasing to 2050 at a rate of 4% per year. This is about one-third the average rate of increase for tipping fees from the late 1980s to mid-1990s. Development of larger more efficient landfills since then has resulted in more modest increases in tipping fees.

Table 4-5. Recovered paper supply commodities among US supply regions, base-period (1986) prices (US dollars), base-period supply quantities, price elasticities, and elasticities of supply with respect to other variables

Supply region and commodity	Base price	Base quantity	Price elasticity	Other variable elasticities	
				Landfill tipping fees	"Parent" commodity consumption
	1986 dollars/ tonnes	Thousand tonnes			
US North:					
Old newspapers—spot	40.00	138	0.222	0.559	1.0
Old corrugated—spot	55.00	760	0.182	0.383	1.0
Mixed wastepaper—spot	40.00	213	0.384	0.299	1.0
Pulp substitutes—spot	100.00	104	0.805	0.215	1.0
High-grade deinking—spot	180.00	127	0.466	0.724	1.0
Old newspapers—LTC	20.00	1,414	0	—	—
Old corrugated—LTC	20.00	3,252	0	—	—
Mixed wastepaper—LTC	10.00	1,069	0	—	—
Pulp substitutes—LTC	50.00	1,481	0	—	—
High-grade deinking—LTC	50.00	1,151	0	—	—
US South:					
Old newspapers—spot	40.00	240	0.515	1.036	1.0
Old corrugated—spot	55.00	388	0.211	0.524	1.0
Mixed wastepaper—spot	45.00	152	0.256	0.522	1.0
Pulp substitutes—spot	100.00	154	0.672	0.861	1.0
High-grade deinking—spot	200.00	94	0.962	1.090	1.0

Old newspapers—LTC	20.00	607	0	—	—
Old corrugated—LTC	20.00	2,928	0	—	—
Mixed wastepaper—LTC	10.00	596	0	—	—
Pulp substitutes—LTC	50.00	757	0	—	—
High-grade deinking—LTC	50.00	205	0	—	—
US West:					
Old newspapers—spot	60.00	424	0.100	0.615	1.0
Old corrugated—spot	80.00	590	0.204	0.363	1.0
Mixed wastepaper—spot	45.00	316	0.270	0.000	1.0
Pulp substitutes—spot	110.00	132	0.476	0.000	1.0
High-grade deinking—spot	180.00	261	0.484	0.349	1.0
Old newspapers—LTC	20.00	731	0	—	—
Old corrugated—LTC	20.00	1,488	0	—	—
Mixed wastepaper—LTC	10.00	126	0	—	—
Pulp substitutes—LTC	60.00	231	0	—	—
High-grade deinking—LTC	60.00	24	0	—	—

Abbreviations: Spot = Spot market supply; LTC = Long-term contract supply.

The long-term contract supply of recovered paper was represented with L-shaped supply curves, with a reservation price at the low end of the spot market price history, and an upper bound on supply quantity. Upper bounds on long-term contract supply quantities were projected exogenously to follow a gradual upward logistic trend toward assumed maximum feasible recovery rates, which varied by grade of recovered paper and by parent commodity. The combination of spot market and long-term contract supply helped to track the US-recovered paper supply, prices, and recycling rates over historical period, and particularly through the volatile and changing market conditions of the 1990s when US-recovered paper consumption increased by nearly 70%.

Table 4-6 shows the NAPAP model base-year (1986) regional supply prices and quantities for the Canadian-recovered paper supply equations, the own-price elasticities, the elasticity with respect to the parent commodity consumption, and a time trend reflecting a drift of supply over time. These equations were estimated by researchers at Forestry Canada in the early 1990s.

Table 4-6. Recovered paper supply commodities among Canadian supply regions, base-period (1986) price (US dollars), base-period supply quantities, price elasticities, and elasticities of supply with respect to other variables

Supply region and commodity	Base price	Base quantity	Price elasticity	Other variable elasticities	
				Time parameter (t)	"Parent" commodity consumption
	<i>1986 dollars/ tonnes</i>	<i>Thousand tonnes</i>			
Canada East:					
Old newspapers	40.00	121	0.150	0.07	1.5
Old corrugated	55.00	413	0.470	0.05	0.9
Mixed wastepaper	40.00	126	0.200	0.02	0.5
Pulp substitutes	100.00	100	0.390	1.17	0.9
High-grade deinking	180.00	49	0.390	1.17	0.9
Canada West:					
Old newspapers	60.00	40	0.150	0.07	1.43
Old corrugated	80.00	137	0.470	0.05	0.63
Mixed wastepaper	45.00	42	0.200	0.02	0.5
Pulp substitutes	110.00	30	0.390	1.17	0.9
High-grade deinking	180.00	19	0.390	1.17	0.9

4.4.3.3 Other fiber supply

In addition to the supply equations for pulpwood and recovered paper, the NAPAP model also recognized a potential future supply of fibers from agricultural short-rotation woody crops (SRWC), such as hybrid poplars, which have been grown in plantations on agricultural land. Thus far, the extent of agricultural SRWC is relatively small, and is estimated to be less than 1% of pulpwood supply in North America, but such crops could expand in the future, especially if hardwood pulpwood prices increase.

The NAPAP model accounts for the potential agricultural SRWC supply in the USA using L-shaped supply curves, with the reservation price set at the estimated regional costs of agricultural SRWC production. The supply estimates are based on yields and cost estimates for 1990s technology, at delivered-to-mill costs for wood chips from agricultural SRWC of \$46 per dry tonne in the South, \$59 in the North, and \$73 in the West (in 1986 dollars). These costs are generally higher than historical real pulpwood prices. Agricultural SRWC supply can occur only in scenarios that result in higher future hardwood pulpwood prices than the estimated agricultural SRWC costs. There are millions of hectares of agricultural land that could be used for agricultural SRWC cultivation if it became economical, so high upper bounds were set on the agricultural SRWC supply quantities, but these upper bounds were never reached in any scenario that we produced.

4.4.4 Material balance constraints and prices

In each region, the amount of a commodity supplied, produced, and imported must be greater than or equal to the quantity exported plus the quantity consumed in demand and production. This constraint is represented by the following material balance formula:

$$S_{ik} + \sum_p Y_{ikp} + \sum_j T_{jik} - \sum_j T_{ijk} - D_{jk} - \sum_l \sum_p \sum_x a_{iklpx} Y_{ilpx} \geq 0 \quad (4.8)$$

for all commodities IC, supply regions i , and demand regions j . The manufacturing coefficient a_{iklpx} is the amount of input commodity IC needed to manufacture one unit of output commodity l , in region i , by process p , using fiber input mix x . For an optimum solution reflecting an economic equilibrium, the material balance constraints are strict equalities. At this optimum, the shadow price of a material

constraint, the dual variable of the linear program, is the equilibrium price of commodity k in region i .

4.4.5 Manufacturing capacity constraints

In each region (i) and for each commodity (k), production volume (Y) by process (p) in year t is constrained by existing capacity for that type of process (k), as follows:

$$\sum_x Y_{ikpx,t} \leq K_{ikp,t} \quad (4.9)$$

where production volume (Y) by process is the sum of production for each possible input combination or fiber input mix (x) available for a given process, and where $K_{ikp,t}$ is the existing capacity of process p for commodity k in region i and year t . Thus, production volume by process is constrained by its existing capacity, but each process may utilize alternative combinations or “mixes” of fiber inputs. This allows the model to simulate economic substitution among technically feasible alternative combinations of inputs and costs within the limits of overall capacity for each manufacturing process.

Table 4-7 shows the pulp, paper, and paperboard production processes in the latest NAPAP model, along with their estimated 1986 production capacities by region. The categorization and description of these production processes along with historical capacity trends by process and region from 1970 to 2000 were explained and illustrated in Ince et al. (2002). The NAPAP model projections of capacity by process were compared to those actual historical trends in capacity by process, and the model was calibrated to the historical capacity trends by making marginal adjustments in net manufacturing costs by process. In the NAPAP model, changes in production capacity are entirely endogenous, and depend on the projected profitability of new capacity, and on its cost (see Sect. 4.4.7.2).

4.4.6 Net manufacturing costs and input/output coefficients

Net manufacturing costs are defined in the NAPAP model as production costs above the cost of wood or other fiber inputs (dollars per tonne of product). The fiber input cost is determined endogenously as the price of input times the estimated input requirement per tonne of product output. The fiber input cost is also equal to the price of

Table 4-7. Pulp, paper and paperboard production processes in the NAPAP model, along with estimated 1986 production capacities by process and region

Products and production processes	Production capacity by process and region				
	US North	US Southeast	US South Central	US West	Canada East West
<i>Thousands of tonnes per year</i>					
Newsprint					
1. Integrated to groundwood and chemical pulp	285	158	1,403	69	4,510 980
2. Integrated to TMP pulp, using some market pulp	0	684	700	1,061	1,664 0
3. Integrated to deinked pulp (100% recycled)	338	120	0	496	98 0
4. Integrated to CTMP pulp	0	0	0	0	1,764 784
Uncoated free sheet					
1. Integrated to sulfite pulp	792	0	0	236	0 0
2. Integrated to kraft pulp	1,420	703	2,636	703	568 0
3. Based on market pulp	3,094	0	72	295	52 174
4. Integrated to deinked pulp (100% recycled)	675	388	325	73	98 0
Coated free sheet					
1. Integrated to kraft pulp	1,131	0	302	58	0 0
2. Based on market pulp	958	0	39	76	140 0
3. Integrated to deinked pulp (100% recycled)	113	0	0	0	0 0

Table 4-7. Continued

Products and production processes	Production capacity by process and region				
	US North	US Southeast	US South Central	US West	Canada East Canada West
Uncoated groundwood					
1. Integrated to mechanical and chemical pulp	525	0	162	50	525 307
2. Integrated to mechanical pulp, using some market pulp	574	0	0	229	515 0
3. Integrated to deinked pulp (100% recycled)	41	0	0	0	0 0
Coated groundwood					
1. Integrated to mechanical and chemical pulp	868	228	189	0	120 0
2. Integrated to mechanical pulp, using market pulp	1,874	0	180	116	350 0
Tissue and sanitary					
1. Based on market pulp (and some recycled fiber)	1,262	155	0	152	267 83
2. Integrated to deinked pulp (100% recycled)	1,390	124	391	97	102 0
3. Integrated to chemical pulp (and some recycled fiber)	262	133	558	451	34 0
Specialty packaging and industrial paper	1,088	143	456	235	23 0

Kraft packaging paper									
1. Integrated to unbleached kraft pulp	0	1,416	927	766	208	371			
2. Based on recycled fiber	113	0	32	0	0	0			
Linerboard									
1. Older press technology integrated to kraft pulp	0	5,217	6,356	2,354	259	371			
2. New press technology integrated to kraft pulp	0	1,539	796	518	412	0			
3. Based on recycled fiber (test liner; 100% recycled)	216	32	32	294	290	0			
Corrugating medium									
1. Integrated to semichemical pulp	1,280	793	1,158	434	309	24			
2. Based on recycled fiber (100% recycled)	1,417	498	449	458	346	50			
Solid bleached board	0	1,582	2,138	439	73	0			
Recycled board	4,354	790	593	591	801	57			
Building paper	312	205	205	36	472	174			
Dissolving pulp	386	519	250	233	110	155			
Softwood kraft market pulp	220	2,132	1,179	1,519	2,886	4,531			
Hardwood kraft market pulp	802	627	1,141	0	1,770	0			
Recycled (deinked) market pulp	94	32	32	32	33	0			
CTMP market pulp	70	0	50	0	750	750			

Abbreviations: CTMP = chemithermomechanical pulp, TMP = thermomechanical pulp.

the product output minus the net manufacturing cost. Denoted by m_{ikpx} in the objective function (Z_m in (4.5)), the net manufacturing cost includes both variable and fixed costs, including the cost of labor, energy, and other adjusted fixed costs needed to produce and deliver one tonne of output commodity (k) in supply region (i), using process (p) and fiber input mix (x).

The input/output coefficients are the estimated quantities of wood or other fiber inputs (pulp or recovered paper) required to produce one tonne of product, denoted a_{iklpx} in equation (4.8). Each production process has a set of manufacturing costs and a range of input/output coefficients, representing technically feasible combinations of fiber inputs and costs. Like the manufacturing costs, the input/output coefficients vary by region, commodity, process, and fiber input mix. The input/output coefficients were based on product yield estimates gleaned from a wide range of sources, including mill surveys and engineering studies, and they are judged to represent average input requirements for each process and region. The model also takes into account data on specific gravity (density) of wood species among regions for both hardwood and softwood, which influences the volume of wood (cubic meters of wood input) required per tonne of product output.

Table 4-8 summarizes the net manufacturing cost assumptions in the most recent version of the NAPAP model. The final set of net manufacturing cost estimates were established as part of the model Calibration process. Starting with averages of production cost estimates from various sources, the costs were adjusted marginally to obtain NAPAP model projections over the historical period that were close to actual historical data on production volumes, production capacities by process, and wood fiber consumption from 1986 to 2001.

Table 4-9 shows for the most recent version of the NAPAP model the input/output coefficients for pulp, paper, and paperboard processes where pulpwood is an input, Table 4-10 shows those where wood pulp (market pulp) is an input to paper, and Table 4-11 shows those where recovered paper is an input to paper or paperboard. Some processes rely on a mix of pulpwood or wood pulp and recovered paper, representing mills that utilize both virgin wood fiber and recycled paper; while other processes use exclusively virgin fiber or recovered paper (including processes that are based on 100% recycled fiber). (Text continues on page 162).

Table 4-8. Net manufacturing cost assumptions by region for products, processes, and input mix options

Products, processes, and input mix options	Net manufacturing costs by process and region					
	US North	US Southeast	US South Central	US West	Canada East	Canada West
<i>1986 dollars per tonne of product output</i>						
Newsprint						
1. Integrated to groundwood and chemical pulp						
Maximum softwood (100%)	382.80	382.80	382.80	359.60	349.44	349.44
Minimum softwood (90% in GW; 50% in chemical pulp)	379.32	379.32	379.32	359.60	347.20	347.20
2. Integrated to TMP pulp, using some market pulp						
Maximum softwood (100%)	336.40	336.40	336.40	336.40	304.20	304.20
Minimum softwood (90% in TMP; 50% in chemical pulp)	336.40	336.40	336.40	336.40	304.20	304.20
3. Integrated to deinked pulp (100% recycled)						
Using ONP only	348.00	348.00	348.00	348.00	342.20	342.20
Using ONP and mixed recovered paper	348.00	348.00	348.00	348.00	342.20	342.20
4. Integrated to CTMP pulp						
Maximum softwood (100%)	359.60	359.60	359.60	348.00	316.40	327.70
Minimum softwood (90%)	359.60	359.60	359.60	348.00	316.40	327.70
Uncoated free sheet						
1. Integrated to sulfite pulp						
Maximum softwood (75%)	649.60	649.60	638.00	603.20	549.90	549.90
Maximum hardwood (75%)	643.80	643.80	632.20	597.40	544.05	544.05

Table 4-8. Continued

Products, processes, and input mix options	Net manufacturing costs by process and region					
	US North	US Southeast	US South Central	US West	Canada East	Canada West
2. Integrated to kraft pulp						
Maximum softwood (65%) and no recycled	597.40	597.40	591.60	574.20	520.65	526.50
Maximum softwood and maximum recycled (15% pulp substitutes)	603.20	603.20	597.40	580.00	526.50	532.35
Maximum hardwood (75%) and no recycled	591.60	591.60	585.80	574.20	520.65	526.50
Maximum hardwood and max recycled (15% pulp substitutes)	597.40	597.40	591.60	580.00	526.50	532.35
3. Based on market pulp						
Maximum softwood market pulp (60%)	400.20	400.20	400.20	400.20	368.55	374.40
Maximum softwood market pulp and maximum recycled (15% pulp substitutes)	403.68	403.68	403.68	403.68	365.04	370.89
Maximum hardwood market pulp (70%)	400.20	400.20	400.20	400.20	368.55	374.40
Maximum hardwood market pulp and maximum recycled (15% pulp substitutes)	403.68	403.68	403.68	403.68	365.04	370.89
Maximum deinked market pulp	403.68	403.68	403.68	403.68	383.76	389.61
Maximum bleached CTMP market pulp	406.00	406.00	406.00	406.00	374.40	380.25

4. Integrated to deinked pulp (100% recycled)									
Using high-grade deinking grades	539.40	539.40	539.40	539.40	539.40	539.40	516.20	516.20	516.20
Maximum use of lower grades (15% mixed paper)	551.00	551.00	551.00	551.00	551.00	551.00	527.80	527.80	527.80
Coated free sheet									
1. Integrated to kraft pulp									
Maximum softwood (40%) and no recycled	580.00	585.80	580.00	580.00	580.00	580.00	516.00	516.00	516.00
Maximum softwood and maximum recycled (10% pulp substitutes)	583.48	585.80	583.48	583.48	583.48	583.48	519.60	519.60	519.60
Maximum hardwood (90%) and no recycled	574.20	580.00	574.20	574.20	574.20	574.20	522.00	522.00	522.00
Maximum hardwood and maximum recycled (10% pulp substitutes)	577.68	583.48	577.68	577.68	577.68	577.68	525.60	525.60	525.60
2. Based on market pulp									
Maximum softwood market pulp (100%)	469.80	469.80	469.80	469.80	469.80	469.80	432.00	432.00	432.00
Maximum softwood market pulp and maximum recycled (pulp substitutes)	473.28	473.28	473.28	473.28	473.28	473.28	432.00	432.00	432.00
Maximum hardwood market pulp (80%)	469.80	469.80	469.80	469.80	469.80	469.80	432.00	432.00	432.00
Maximum hardwood market pulp and maximum recycled (pulp substitutes)	473.28	473.28	473.28	473.28	473.28	473.28	435.60	435.60	435.60
Maximum deinked market pulp	475.60	475.60	475.60	475.60	475.60	475.60	438.00	438.00	438.00
3. Integrated to deinked pulp (100% recycled)									
Using high-grade deinking grades	562.60	562.60	562.60	562.60	562.60	562.60	539.40	539.40	539.40

Table 4-8. Continued

Products, processes, and input mix options	Net manufacturing costs by process and region				
	US North	US Southeast	US South Central	US West	Canada East West
<i>1986 dollars per tonne of product output</i>					
Uncoated groundwood					
1. Integrated to mechanical and chemical pulp					
Maximum softwood (100% in TMP and chemical pulp)	469.80	469.80	469.80	464.00	378.55
Minimum softwood (75% in TMP; 10% in chemical pulp)	467.48	467.48	467.48	461.68	378.55
2. Integrated to mechanical pulp, using some market pulp					
Maximum softwood (100%) and no recycled	406.00	406.00	406.00	394.40	333.35
Maximum softwood and maximum recycled (10% pulp substitutes)	409.48	409.48	409.48	397.88	336.74
Maximum hardwood (15%) and no recycled	406.00	406.00	406.00	394.40	333.35
Maximum hardwood and maximum recycled (10% pulp substitutes)	409.48	409.48	409.48	397.88	336.74
3. Integrated to deinked pulp (100% recycled)					
Using mixed and high-grade deinking (50/50)	377.00	377.00	377.00	377.00	355.95
Using ONP and high-grade deinking (50/50)	377.00	377.00	377.00	377.00	355.95

Table 4-8. Continued

Products, processes, and input mix options	Net manufacturing costs by process and region					
	US North	US Southeast	US South Central	US West	Canada East	Canada West
Maximum softwood and maximum recycled (30% pulp substitutes)	730.80	730.80	719.20	696.00	738.00	738.00
Maximum hardwood (60%) and no recycled	742.40	742.40	730.80	707.60	750.00	750.00
Maximum hardwood and maximum recycled (20% pulp substitutes)	730.80	730.80	719.20	696.00	738.00	738.00
Specialty packaging and industrial paper						
Maximum softwood (80%) and minimum recycled	527.80	527.80	527.80	493.00	474.60	474.60
Maximum softwood and maximum recycled (7% pulp substitutes)	527.80	527.80	527.80	493.00	474.60	474.60
Minimum softwood (50%) and minimum recycled	527.80	527.80	527.80	493.00	474.60	474.60
Minimum softwood and maximum recycled (7% pulp substitutes)	527.80	527.80	527.80	493.00	474.60	474.60

Kraft packaging paper						
1. Integrated to unbleached kraft pulp						
Maximum softwood (100%)	319.00	301.60	301.60	301.60	259.90	282.50
Minimum softwood (95%)	317.84	300.44	300.44	300.44	263.29	280.24
2. Based on recycled fiber						
Using old corrugated (80% yield)	243.60	243.60	243.60	243.60	243.60	243.60
Linerboard						
1. Older press technology integrated to kraft pulp						
Maximum softwood (100%) and no recycled	232.00	226.20	214.60	197.20	207.40	213.50
Maximum softwood and maximum recycled (10% OCC)	232.00	226.20	214.60	197.20	207.40	213.50
Maximum hardwood (5%) and no recycled	230.84	223.88	212.28	197.20	207.40	213.50
2. New press technology integrated to kraft pulp						
Maximum softwood (100%) and no recycled	220.40	208.80	197.20	191.40	201.30	207.40
Maximum softwood and maximum recycled (25% OCC)	220.40	208.80	197.20	191.40	201.30	207.40
Maximum hardwood (30%) and no recycled	220.40	199.52	193.72	187.92	201.30	207.40
3. Based on recycled fiber (test liner; 100% recycled)						
Using 100% old corrugated	191.40	191.40	191.40	191.40	195.20	195.20

Table 4-8. Continued

Products, processes, and input mix options	Net manufacturing costs by process and region					
	US North	US Southeast	US Central	US West	Canada East	Canada West
Maximum use of lower grades (20% ONP) Corrugating medium	197.20	197.20	197.20	197.20	201.30	201.30
1. Integrated to semichemical pulp Maximum softwood (100%) and no recycled	214.60	214.60	214.60	197.20	182.56	182.56
Maximum softwood and maximum recycled (30% OCC)	214.60	214.60	214.60	197.20	182.56	182.56
Maximum hardwood (100%) and no recycled	208.80	208.80	208.80	197.20	182.56	182.56
Maximum hardwood and maximum recycled (30% OCC)	208.80	208.80	208.80	197.20	182.56	182.56
2. Based on recycled fiber (100% recycled) Using 100% old corrugated Maximum use of lower grades (30% ONP) Solid bleached board	176.32	176.32	176.32	176.32	168.00	168.00
Maximum softwood (75%)	458.20	452.40	446.60	394.40	339.00	339.00
Maximum hardwood (65%)	452.40	452.40	440.80	394.40	339.00	339.00
Recycled board						
Generic mix of recycled furnish	307.40	307.40	307.40	295.80	282.50	282.50

Table 4-9. Input/output coefficients for pulpwood for production that utilize pulpwood

Products, processes, and input mix options	Pulpwood inputs		
	Softwood ^a		Hardwood ^a
<i>Dry tonnes pulpwood per tonnes of product</i>			
Newsprint			
1. Integrated to groundwood and chemical pulp			
Maximum softwood (100%)	1.319	—	—
Minimum softwood (90% in GW; 50% in chemical pulp)	0.979	0.335	—
2. Integrated to TMP pulp, using some market pulp			
Maximum softwood (100%)	1.000	—	—
Minimum softwood (90% in TMP; 50% in chemical pulp)	0.900	0.100	—
3. Integrated to deinked pulp (100% recycled)			
Using ONP only	—	—	—
Using ONP and mixed recovered paper	—	—	—
4. Integrated to CTMP pulp			
Maximum softwood (100%)	1.111	—	—
Minimum softwood (90%)	1.000	0.111	—
Uncoated free sheet			
1. Integrated to sulfite pulp		(West 90%)	(West 90%)
Maximum softwood (75%)	1.484	1.780	0.495
Maximum hardwood (75%)	0.495	—	1.484

2. Integrated to kraft pulp				(West 80%)		(West 80%)
Maximum softwood (65%) and no recycled	1.232			1.517	0.650	0.371
Maximum softwood and maximum recycled (15% pulp substitutes)	1.047			1.289	0.553	0.316
Maximum hardwood (75%) and no recycled	0.474			-	1.393	-
Maximum hardwood and maximum recycled (15% pulp substitutes)	0.483			-	1.105	-
3. Based on market pulp						
Maximum softwood market pulp (60%)	-			-	-	-
Maximum softwood market pulp and maximum recycled (15% pulp substitutes)	-			-	-	-
Maximum hardwood market pulp (70%)	-			-	-	-
Maximum hardwood market pulp and maximum recycled (15% pulp substitutes)	-			-	-	-
Maximum deinked market pulp	-			-	-	-
Maximum bleached CTMP market pulp	-			-	-	-
4. Integrated to deinked pulp (100% recycled)						
Using high-grade deinking grades	-			-	-	-
Maximum use of lower grades (15% mixed paper)	-			-	-	-
Coated free sheet						
1. Integrated to kraft pulp				(West 70%)		(West 70%)
Maximum softwood (40%) and no recycled	0.517			0.904	0.759	0.380
Maximum softwood and maximum recycled (10% pulp substitutes)	0.523			0.814	0.626	0.342
Maximum hardwood (90%) and no recycled	0.129			-	1.139	-
Maximum hardwood and maximum recycled (10% pulp substitutes)	0.174			-	0.968	-

Table 4-9. Continued

Products, processes, and input mix options	Pulpwood inputs		
	Softwood ^a		Hardwood ^a
2. Based on market pulp			
Maximum softwood market pulp (100%)	-	-	-
Maximum softwood mkt. pulp and maximum recycled (pulp substitutes)	-	-	-
Maximum hardwood market pulp (80%)	-	-	-
Maximum hardwood market pulp and maximum recycled (pulp substitutes)	-	-	-
Maximum deinked market pulp	-	-	-
3. Integrated to deinked pulp (100% recycled)			
Using high-grade deinking grades	-	-	-
Uncoated groundwood			
1. Integrated to mechanical and chemical pulp			
Maximum softwood (100% in TMP and chemical pulp)	1.321	-	-
Minimum softwood (75% in TMP; 10% in chemical pulp)	0.559	-	0.749
2. Integrated to mechanical pulp, using some market pulp			
Maximum softwood (100%) and no recycled	0.657	-	-
Maximum softwood and maximum recycled (10% pulp substitutes)	0.592	-	-
Maximum hardwood (15%) and no recycled	0.493	-	0.164
Maximum hardwood and maximum recycled (10% pulp substitutes)	0.503	-	0.089

3. Integrated to deinked pulp (100% recycled)	—	—	—
Using mixed and high-grade deinking (50/50)	—	—	—
Using ONP and high-grade deinking (50/50)	—	—	—
Coated groundwood			
1. Integrated to mechanical and chemical pulp			
Maximum softwood (100% in TMP and chemical pulp)	1.055	—	—
Minimum softwood (65% in TMP; 50% in chemical pulp)	0.572	—	0.476
2. Integrated to mechanical pulp, using market pulp			
Maximum softwood (100%)	0.294	—	—
Maximum hardwood (15%)	0.191	—	0.103
Tissue and sanitary			
1. Based on market pulp (and some recycled fiber)			
Maximum softwood market pulp (70%)	—	—	—
Maximum softwood market pulp and maximum recycled (30% pulp substitutes)	—	—	—
Maximum hardwood market pulp (60%)	—	—	—
Maximum hardwood market pulp and maximum recycled (20% pulp substitutes)	—	—	—
Maximum bleached CTMP market pulp	—	—	—
2. Integrated to deinked pulp (100% recycled)			
Using high-grade deinking grades	—	—	—
Maximum use of lower grades	—	—	—
3. Integrated to chemical pulp (and some recycled fiber)		(West 90%)	(West 90%)

Table 4-9. Continued

Products, processes, and input mix options	Pulpwood inputs		
	Softwood ^a		Hardwood ^a
Maximum softwood (70%) and no recycled	1.444	1.856	0.606
Maximum softwood and maximum recycled (30% pulp substitutes)	1.227	1.299	0.515
Maximum hardwood (60%) and no recycled	0.825	—	1.212
Maximum hardwood and maximum recycled (20% pulp substitutes)	0.660	—	0.970
Specialty packaging and industrial paper			
Maximum softwood (80%) and minimum recycled	1.551	—	0.388
Maximum softwood and maximum recycled (7% pulp substitutes)	1.442	—	0.361
Minimum softwood (50%) and minimum recycled	0.969	—	0.969
Minimum softwood and maximum recycled (7% pulp substitutes)	0.902	—	0.902
Kraft packaging paper			
1. Integrated to unbleached kraft pulp			
Maximum softwood (100%)	1.923	—	—
Minimum softwood (95%)	1.827	—	0.096
2. Based on recycled fiber			
Using old corrugated (80% yield)	—	—	—
Linerboard			
1. Older press technology integrated to kraft pulp			
Maximum softwood (100%) and no recycled	1.904	—	—

Maximum softwood and maximum recycled (10% OCC)	1.713	—	—	—
Maximum hardwood (5%) and no recycled	1.809	—	0.095	—
2. New press technology integrated to kraft pulp				
Maximum softwood (100%) and no recycled	1.768	—	—	—
Maximum softwood and maximum recycled (25% OCC)	1.326	—	—	—
Maximum hardwood (30%) and no recycled	1.238	—	0.530	—
3. Based on recycled fiber (test liner; 100% recycled)				
Using 100% old corrugated	—	—	—	—
Maximum use of lower grades (20% ONP)	—	—	—	—
Corrugating medium				
1. Integrated to semichemical pulp		(North 80%)		(North 80%)
Maximum softwood (100%)	1.282	1.026	—	0.256
and no recycled				
Maximum softwood and maximum recycled (30% OCC)	0.897	0.718	—	0.179
Maximum hardwood (100%)	—	—	1.282	—
and no recycled				
Maximum hardwood and maximum recycled (30% OCC)	—	—	0.897	—
2. Based on recycled fiber (100% recycled)				
Using 100% old corrugated	—	—	—	—
Maximum use of lower grades (30% ONP)	—	—	—	—
Solid bleached board				
Maximum softwood (75%)	1.422	—	0.464	—
Maximum hardwood (65%)	0.664	—	1.207	—
Recycled board				
Generic mix of recycled furnish	—	—	—	—

Table 4-9. Continued

Products, processes, and input mix options	Pulpwood inputs	
	Softwood ^a	Hardwood ^a
Building paper		
Maximum softwood and no recycled	0.990	—
Maximum softwood and maximum recycled furnish (40%)	0.594	—
Maximum hardwood and no recycled	—	0.990
Maximum hardwood and maximum recycled furnish (40%)	—	0.594
Dissolving pulp		
Maximum softwood (100%)	2.632	—
Maximum hardwood (40%)	1.579	1.053
Softwood kraft market pulp		
Maximum softwood	2.083	—
Minimum softwood (90%)	1.875	0.204
Hardwood kraft market pulp		
Maximum hardwood	—	2.041
Minimum hardwood (90%)	0.208	1.837
Recycled (deinked) market pulp		
Using high-grade deinking	—	—
Maximum use of lower grades	—	—
CTMP market pulp		
Maximum softwood (100%)	1.149	—
Maximum hardwood (10%)	1.034	0.115

^a Wood and input coefficients are assumed to be the same among all regions for a given process except where noted in the columns to the right. Abbreviations: TMP = thermomechanical pulp, CTMP = chemithermomechanical pulp, OCC = old corrugated containers.

Table 4-10. Input/output coefficients for wood pulp (tonnes of market pulp required per tonnes of product output) for production processes that utilize purchased market pulp

Products, processes, and input mix options	Market pulp input requirements			
	Softwood kraft market pulp	Hardwood kraft market pulp	Recycled market pulp	CTMP market pulp
<i>Tonnes pulp per tonnes of product</i>				
Newsprint				
1. Integrated to groundwood and chemical pulp				
Maximum softwood (100%)	—	—	—	—
Minimum softwood (90% in GW; 50% in chemical pulp)	—	—	—	—
2. Integrated to TMP pulp, using some market pulp				
Maximum softwood (100%)	0.11	—	—	—
Minimum softwood (90% in TMP; 50% in chemical pulp)	0.06	0.06	—	—
3. Integrated to deinked pulp (100% recycled) Using ONP only	—	—	—	—
Using ONP and mixed recovered paper	—	—	—	—
4. Integrated to CTMP pulp				
Maximum softwood (100%)	—	—	—	—
Minimum softwood (90%)	—	—	—	—

Table 4-10. Continued

Products, processes, and input mix options	Market pulp input requirements			
	Softwood kraft market pulp	Hardwood kraft market pulp	Recycled market pulp	CTMP market pulp
Uncoated free sheet				
1. Integrated to sulfite pulp				
Maximum softwood (75%)	—	—	—	—
Maximum hardwood (75%)	—	—	—	—
2. Integrated to kraft pulp				
Maximum softwood (65%) and no recycled	—	—	—	—
Maximum softwood and maximum recycled (15% pulp substitutes)	—	—	—	—
Maximum hardwood (75%) and no recycled	—	—	—	—
Maximum hardwood and maximum recycled (15% pulp substitutes)	—	—	—	—
3. Based on market pulp				
Maximum softwood market pulp (60%)	0.61	0.40	—	—
Maximum softwood market pulp and maximum recycled (15% pulp substitutes)	0.60	0.26	—	—
Maximum hardwood market pulp (70%)	0.30	0.71	—	—
Maximum hardwood market pulp and maximum recycled (15% pulp substitutes)	0.36	0.55	—	—
Maximum deinked market pulp	0.40	0.00	0.61	—
Maximum bleached CTMP market pulp	0.20	0.40	—	0.40
4. Integrated to deinked pulp (100% recycled)				
Using high-grade deinking grades	—	—	—	—

Maximum use of lower grades (15% mixed paper)	-	-	-	-
Coated free sheet				
1. Integrated to kraft pulp				
Maximum softwood (40%) and no recycled	-	-	-	-
Maximum softwood and maximum recycled (10% pulp substitutes)	-	-	-	-
Maximum hardwood (90%) and no recycled	-	-	-	-
Maximum hardwood and maximum recycled (10% pulp substitutes)	-	-	-	-
2. Based on market pulp				
Maximum softwood market pulp (100%)	0.69	-	-	-
Maximum softwood market pulp and maximum recycled (pulp substitutes)	0.55	-	-	-
Maximum hardwood market pulp (80%)	0.14	0.55	-	-
Maximum hardwood market pulp and maximum recycled (pulp substitutes)	0.12	0.50	-	-
Maximum deinked market pulp	0.34	0.24	0.10	-
3. Integrated to deinked pulp (100% recycled)				
Using high-grade deinking grades	-	-	-	-

Table 4-10. Continued

Products, processes, and input mix options	Market pulp input requirements			
	Softwood kraft market pulp	Hardwood kraft market pulp	Recycled market pulp	CTMP market pulp
Uncoated groundwood				
1. Integrated to mechanical and chemical pulp				
Maximum softwood (100% in TMP and chemical pulp)	—	—	—	—
Minimum softwood (75% in TMP; 10% in chemical pulp)	—	—	—	—
2. Integrated to mechanical pulp, using some market pulp				
Maximum softwood (100%) and no recycled	0.33	—	—	—
Maximum softwood and maximum recycled (10% pulp substitutes)	0.30	—	—	—
Maximum hardwood (15%) and no recycled	0.11	0.22	—	—
Maximum hardwood and maximum recycled (10% pulp substitutes)	0.15	0.15	—	—
3. Integrated to deinked pulp (100% recycled)				
Using mixed and high-grade deinking (50/50)	—	—	—	—
Using ONP and high grade deinking (50/50)	—	—	—	—
Coated groundwood				
1. Integrated to mechanical and chemical pulp				
Maximum softwood (100% in TMP and chemical pulp)	—	—	—	—

Minimum softwood (65% in TMP; 50% in chemical pulp)	-	-	-	-
2. Integrated to mechanical pulp, using market pulp				
Maximum softwood (100%)	0.41	-	-	-
Maximum hardwood (15%)	0.26	0.14	-	-
Tissue and sanitary				
1. Based on market pulp (and some recycled fiber)				
Maximum softwood market pulp (70%)	0.77	0.33	-	-
Maximum softwood market pulp and maximum recycled (30% pulp substitutes)	0.54	0.23	-	-
Maximum hardwood market pulp (60%)	0.44	0.66	-	-
Maximum hardwood market pulp and maximum recycled (20% pulp substitutes)	0.44	0.44	-	-
Maximum bleached CTMP market pulp	0.28	0.28	-	0.55

Table 4-10. Continued

Products, processes, and input mix options	Market pulp input requirements			
	Softwood kraft market pulp	Hardwood kraft market pulp	Recycled market pulp	CTMP market pulp
2. Integrated to deinked pulp (100% recycled) Using high-grade deinking grades Maximum use of lower grades	- - -	- -	- -	- -
3. Integrated to chemical pulp (and some recycled fiber) Maximum softwood (70%) and no recycled Maximum softwood and maximum recycled (30% pulp substitutes) Maximum hardwood (60%) and no recycled Maximum hardwood and maximum recycled (20% pulp substitutes)	- - - - - -	- - - - - -	- - - - - -	- - - - - -

Note: Paperboard products and market pulp products generally do not utilize market pulp as an input.

Abbreviations: ONP = old newspapers, GW = groundwood, chemithermomechanical pulp, TMP = thermomechanical pulp, CTMP = chemithermomechanical pulp.

Table 4-11. Input/output coefficients for recovered paper (tonnes of recovered paper required per tonne of product output) for production processes that utilize recycled fiber

	Recovered paper inputs				High-grade deinking
	ONP	OCC	Mixed paper	Pulp substitutes	
Metric tons per metric ton of product output					
Newsprint					
1 - Integrated to groundwood & chemical pulp					
Maximum Softwood (100%)	-	-	-	-	-
Minimum Softwood (90% in GW; 50% in Chem. Pulp)	-	-	-	-	-
2 - Integrated to TMP pulp, using some mkt. pulp					
Maximum softwood (100%)	-	-	-	-	-
Minimum softwood (90% in TMP; 50% in chem. pulp)	-	-	-	-	-
3 - Integrated to deinked pulp (100% recycled)					
Using ONP only	1.176	-	-	-	-
Using ONP & mixed recovered paper	0.882	-	0.385	-	-
4 - Integrated to CTMP pulp					
Maximum softwood (100%)	-	-	-	-	-
Minimum softwood (90%)	-	-	-	-	-
Uncoated free sheet					
1 - Integrated to dulfite pulp	-	-	-	-	-
Maximum softwood (75%)	-	-	-	-	-
Maximum hardwood (75%)	-	-	-	-	-
2 - Integrated to kraft pulp	-	-	-	-	-
Maximum softwood (65%) & no recycled	-	-	-	0.152	-
Maximum softwood & max recycled (15% pulp subs.)	-	-	-	-	-
Maximum hardwood (75%) & no recycled	-	-	-	-	-
Maximum hardwood & max recycled (15% pulp subs.)	-	-	-	0.152	-

Table 4-11. Continued

Products, processes, and input mix options	Recovered paper inputs			High-grade deinking	
	ONP	OCC	Mixed paper		Pulp substitutes
Metric tons per metric ton of product output					
3 - Based on Market pulp	-	-	-	-	-
Maximum SW market pulp (60%)	-	-	-	0.152	-
Max. SW mkt. pulp & max. recycled (15% pulp subs.)	-	-	-	-	-
Maximum HW market pulp (70%)	-	-	-	0.100	-
Max. HW mkt. pulp & max. recycled (15% pulp subs.)	-	-	-	-	-
Maximum deinked market pulp	-	-	-	-	-
Max. bleached CTMP market pulp	-	-	-	-	-
4 - Integrated to deinked pulp (100% recycled)	-	-	-	-	1.071
Using high grade deinking grades	-	-	0.171	-	0.910
Maximum use of lower grades (15% Mixed paper)	-	-	-	-	-
Coated free sheet					
1 - Integrated to kraft pulp	-	-	-	-	-
Maximum softwood (40%) & no recycled	-	-	-	-	-
Max. softwood & max recycled (10% pulp subs.)	-	-	-	0.069	-
Maximum hardwood (90%) & no recycled	-	-	-	-	-
Max. hardwood & max recycled (10% pulp subs.)	-	-	-	0.069	-
2 - Based on market pulp					
Maximum SW market pulp (100%)	-	-	-	-	-
Max. SW mkt. pulp & max. recycled (pulp subs.)	-	-	-	0.140	-
Maximum HW market pulp (80%)	-	-	-	-	-
Max. HW mkt. pulp & max. recycled (pulp subs.)	-	-	-	0.069	-
Max. deinked market pulp	-	-	-	-	-
3 - Integrated to deinked pulp (100% recycled)	-	-	-	-	-
Using high grade deinking grades	-	-	-	0.365	0.365
Using old corrugated (80% yield)	-	-	-	-	-
Uncoated groundwood					
1 - Integrated to mechanical & chemical pulp	-	-	-	-	-
Maximum softwood (100% in TMP and chem. pulp)	-	-	-	-	-
Minimum softwood (75% in TMP; 10% in chem. pulp)	-	-	-	-	-

Table 4-11. Continued

Products, processes, and input mix options	Recovered paper inputs				High-grade deinking
	ONP	OCC	Mixed paper	Pulp substitutes	
					<i>Metric tons per metric ton of product output</i>
Specialty packaging and industrial paper					
Maximum softwood (80%) & min. recycled	-	-	-	-	-
Maximum softwood & max. recycled (7% pulp subs.)	-	-	-	0.074	-
Minimum softwood (50%) & min. recycled	-	-	-	-	-
Minimum softwood & max. recycled (7% pulp subs.)	-	-	-	0.074	-
Kraft packaging paper					
1 - Integrated to unbleached kraft pulp					
Maximum softwood (100%)	-	-	-	-	-
Minimum softwood (95%)	-	-	-	-	-
2 - Based on recycled fiber					
Using old corrugated (80% yield)	-	1.250	-	-	-
Linerboard					
1 - Older press technology integrated to kraft pulp					
Maximum softwood (100%) & no recycled	-	-	-	-	-
Max. softwood & max. recycled (10% OCC)	-	0.104	-	-	-
Maximum hardwood (5%) & no recycled	-	-	-	-	-
2 - New press technology integrated to kraft pulp					
Maximum softwood (100%) & no recycled	-	-	-	-	-
Max. softwood & max. recycled (25% OCC)	-	0.261	-	-	-
Maximum hardwood (30%) & no recycled	-	-	-	-	-
3 - Based on recycled fiber (test liner; 100% recycled)					
Using 100% old corrugated	-	1.042	-	-	-
Maximum use of lower grades (20% ONP)	0.248	0.834	-	-	-
Corrugating medium					
1 - Integrated to semichemical pulp					
Maximum softwood (100%) & no recycled	-	-	-	-	-
Max. softwood & max. recycled (30% OCC)	-	0.315	-	-	-

Maximum hardwood (100%) & no recycled	-	-	-	-	-
Max. hardwood & max. recycled (30% OCC)	-	-	0.315	-	-
2 - Based on recycled fiber (100% recycled)	-	-	-	-	-
Using 100% old corrugated	-	-	1.053	-	-
Maximum use of lower grades (30% ONP)	0.375	-	0.737	-	-
Solid bleached board	-	-	-	-	-
Maximum softwood (75%)	-	-	-	-	-
Maximum hardwood (65%)	-	-	-	-	-
Recycled board	-	-	-	-	-
U.S. North & Canada	0.118	0.579	0.313	-	0.118
U.S. South	0.118	0.421	0.500	-	0.118
U.S. West	0.000	0.632	0.500	-	0.000
Building paper	-	-	-	-	-
Maximum softwood & no recycled	-	-	-	-	-
Max. softwood & max. recycled furnish (40%)	0.118	0.158	0.188	-	0.056
Maximum hardwood & no recycled	-	-	-	-	-
Max. hardwood & max. recycled furnish (40%)	0.118	0.158	0.188	-	0.056
Dissolving pulp	-	-	-	-	-
Softwood kraft market pulp	-	-	-	-	-
Hardwood kraft market pulp	-	-	-	-	-
Recycled (deinked) market pulp	-	-	-	-	-
Using high grade deinking	-	-	-	0.588	0.588
Maximum use of lower grades	-	-	0.125	0.529	0.529
CTMP market pulp	-	-	-	-	-

Note: ONP = old newspapers; OCC = old corrugated containers; pulp substitutes and high-grade deinking refer to higher grades of unprinted or sorted recovered paper, and mixed paper refers to lower grades of mixed recovered paper. These grade categories are aggregates of more detailed commercial categories of recovered paper specified by the Institute of Scrap Recycling Industries.

Processes that have wood pulp input coefficients represent papermaking capacity that relies on purchased market pulp. It can be noted also that in the West (western USA and Canada) a higher proportion of softwood fiber was assumed to be utilized than in other regions (Table 4-9).

4.4.7 Recursive relationships

Recursive relationships establish the conditions for the market equilibrium in the following year, $t + 1$, given the market equilibrium in the current year, t . The conditions of the market in year $t + 1$ are determined by exogenous variables, such as changes in shifters of product demand (GDP, population, etc.), fiber supply (timber inventory, land-fill tipping fees, etc.) and currency exchange rates, and by endogenous variables, such as shifts in production capacity, revealed by the equilibrium solution at year t .

4.4.7.1 Shifts in supply and demand

Supply and demand curves are updated via exogenously specified annual shifts in independent variables, shifts in currency exchange rates, or exogenous changes in supply or demand quantities for L-shaped supply or demand curves.

For example, population and per capita GDP which appear as independent variables in most of the US paper and paperboard demand equations (Table 4-1), reflect the strong influence of demographic and economic growth on paper and paperboard demand. Other independent variables include the prices of printed material, TV and radio advertising, and computers (shifters that are unique to publication paper demand), and prices of plastic packaging materials, and the overall producer price index, which shift paperboard demand. In NAPAP projections, RPA Timber Assessment assumptions about US population and GDP serve as drivers, while past trends are used for the exogenous price variables. In addition, the upper bounds on import supply and lower bounds on export demand are adjusted exogenously to control the trade of the USA and Canada with the rest of the world. The PELPS system allows also for exogenous changes in net manufacturing costs and manufacturing coefficients. Although useful to simulate disembodied technical progress, productivity gains, or other changes in costs or input, this feature was not used extensively in the most recent version of the NAPAP model.

4.4.7.2 Capacity change

Projected change in production capacity by process from year to year is the principal means by which the NAPAP model simulates technical change, including shifts in wood or fiber input requirements over time. Annual capacity changes by process are generally determined endogenously within the model as a function of projected economic conditions.⁴

The model predicts net changes in capacity, the difference between the gross change in capacity due to new investments, and the depreciation or retirement of old capacity. Gross changes in capacity are computed with a “q model,” based on Tobin’s q theory of investment, which suggests that (Tobin 1969): 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.

Accordingly, in the NAPAP model, the gross change in capacity by process is an increasing function of the q ratio, the ratio between the value of current capacity and the cost of new capacity (Zhang and Buongiorno 1993):

$$\Delta K_{ikp,t}^g = \left(b_0 + b_1 q_{ikp,t} + b_2 q_{ikp,t-1} + b_3 \frac{\Delta K_{ikp,t-1}^g}{K_{ikp,t-1}} \right) K_{ikp,t} \quad (4.10)$$

where $K_{ikp,t}$ is the capacity level of process p in region i and year t , $q_{ikp,t}$ and $q_{ikp,t-1}$ are the q ratios, b_0 , b_1 , b_2 , and b_3 are coefficients or “expansion parameters” of the q model formula, and $\Delta K_{ikp,t}^g$ is the change in gross capacity due to new investments. The q ratio is computed as the ratio of the shadow price of current capacity to the cost of new capacity. The shadow price of current capacity is determined by the dual of the linear programming solution that describes the current market equilibrium. Thus, the shadow price measures the economic value of one additional unit of capacity for a given production process, commodity, and region under current market conditions. The cost of new capacity is an exogenous estimate of the capital investment required for expansion of capacity, per unit of product output, for each process. Table 4-12 shows the estimated costs of new capacity by process. The expansion parameters used in the NAPAP model for

⁴The PELPS system offers alternative formulas to predict capacity changes in response to current market conditions. Capacity can also be set exogenously for part of, or all the projection period (Zhang et al. 1993).

Table 4-12. Estimated costs of new/expanded capacity by process, used in q formula for projecting capacity change

Products and production processes	Costs of new capacity by process
Newsprint	<i>1986 dollars per tonne of product output</i>
1. Integrated to groundwood and chemical pulp	212.00
2. Integrated to TMP pulp, using some market pulp	170.00
3. Integrated to deinked pulp (100% recycled)	164.00
4. Integrated to CTMP pulp	175.00
Uncoated free sheet	
1. Integrated to sulfite pulp	350.00
2. Integrated to kraft pulp	240.00
3. Based on market pulp	160.00
4. Integrated to deinked pulp (100% recycled)	210.00
Coated free sheet	
1. Integrated to kraft pulp	275.00
2. Based on market pulp	180.00
3. Integrated to deinked pulp (100% recycled)	300.00
Uncoated groundwood	
1. Integrated to mechanical and chemical pulp	210.00
2. Integrated to mechanical pulp, using some market pulp	165.00
3. Integrated to deinked pulp (100% recycled)	200.00
Coated groundwood	
1. Integrated to mechanical and chemical pulp	240.00
2. Integrated to mechanical pulp, using market pulp	210.00
Tissue and sanitary	
1. Based on market pulp (and some recycled fiber)	185.00
2. Integrated to deinked pulp (100% recycled)	225.00
3. Integrated to chemical pulp (and some recycled fiber)	255.00
Specialty packaging and industrial paper	260.00
Kraft packaging paper	
1. Integrated to unbleached kraft pulp	150.00
2. Based on recycled fiber	130.00
Linerboard	
1. Older press technology integrated to kraft pulp	135.00
2. New press technology integrated to kraft pulp	130.00
3. Based on recycled fiber (test liner; 100% recycled)	110.00

Corrugating medium	
1. Integrated to semichemical pulp	110.00
2. Based on recycled fiber (100% recycled)	90.00
Solid bleached board	250.00
Recycled board	90.00
Building paper	100.00
Dissolving pulp	250.00
Softwood kraft market pulp (other supply regions excluding South and West)	250.00
Softwood kraft market pulp (South and West)	230.00
Hardwood kraft market pulp (other supply regions excluding South and West)	250.00
Hardwood kraft market pulp (South and West)	230.00
Recycled (deinked) market pulp	130.00
CTMP market pulp	125.00

Abbreviations: TMP = thermomechanical pulp, CTMP = chemithermomechanical pulp.

all processes and regions were $b_0 = 0.01$, $b_1 = 0.20$, $b_2 = -0.11$ and $b_3 = -1.00$ (Zhang and Buongiorno 1993).

The net yearly change in capacity is the gross change in capacity, predicted by equation (4.10), minus the amount of capacity depreciation. The capacity depreciation rates were set at 3% per year for paper and paperboard capacity, and 1% per year for wood pulp capacity. Yearly depreciation rates can be adjusted exogenously over time, but they were generally held constant in the NAPAP projections. With the q model, capacity grows most rapidly in regions, and for products and processes that are the most profitable under projected market conditions, while capacity declines for processes that are unprofitable. Thus, capacity change and process substitution are simulated as a competitive behavior that responds to market conditions.

4.4.8 Selected outputs

This concluding section illustrates selected NAPAP model projections for the US pulp and paper sector from the base case (see Chap.9)) illustrating the kinds of output that the model produces, and also showing comparisons of model solutions to actual historical data trends. Comparison of model solution values to historical data trends has served as a principal means of model calibration as well as model validation.

Figure 4-2 shows historical and projected trends in total US paper and paperboard consumption. Historically, up to the year 1999, US paper and paperboard consumption was rising on a per capita basis but declining per million dollars of real GDP. Consumption per capita is projected to remain essentially flat in the decades ahead, while consumption per million dollars of real GDP is projected to continue declining.

Figure 4-3 shows US paper and paperboard production and wood pulp production from 1970 to 2005, along with NAPAP projections from 2006 to 2050. Projected growth in US pulp, paper, and paperboard output to 2050 is much lower than growth in the decades prior to the year 2000, reflecting recent impacts of economic globalization on demand and trade, and projected electronic media substitution for print media.

Figure 4-4 shows total US paper and paperboard production capacity along with US wood pulp production capacity, showing actual historical capacity data from 1970 to 2005 and overlapping NAPAP model projections of capacity from 1986 to 2050. NAPAP provides

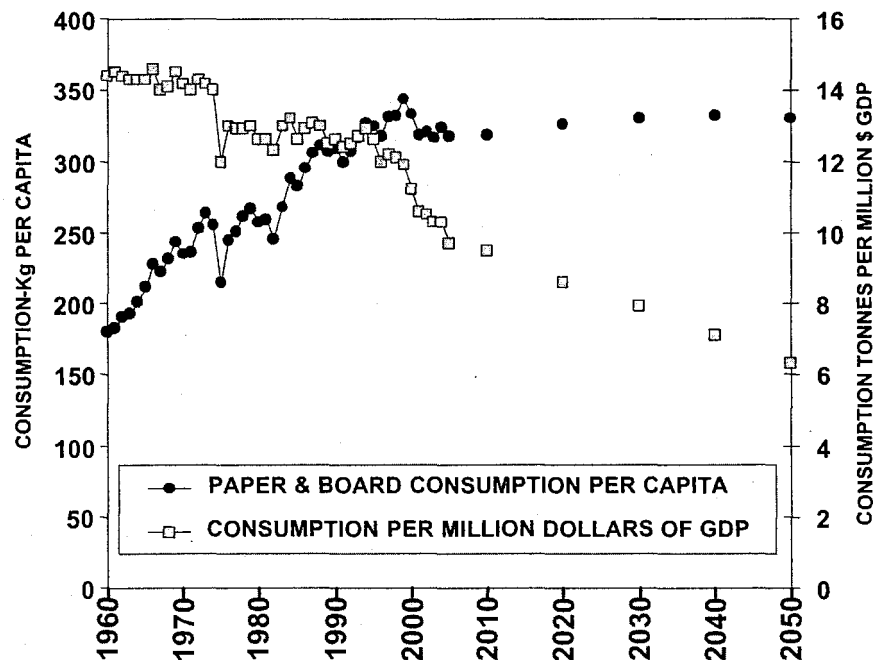


Figure 4-2. US paper and paperboard consumption per capita and per million dollars of real GDP (chained 1992 dollars) from 1960 to 2005, with NAPAP projections 2010 to 2050.

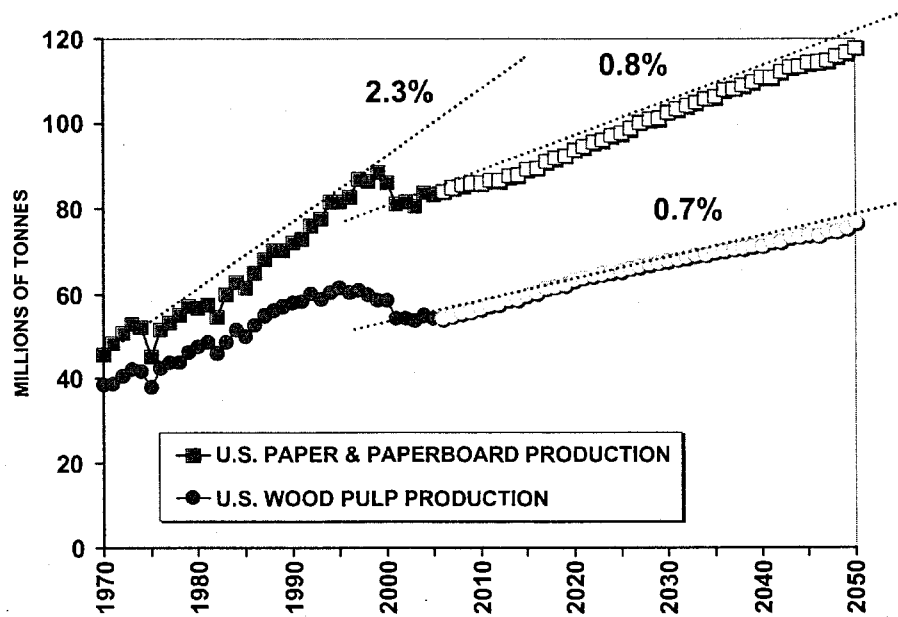


Figure 4-3. US paper and paperboard production, and wood pulp production, 1970 to 2005 (AF&PA, API), with NAPAP model projections from 2006 to 2050, showing growth rates before 2000 and projected after 2000.

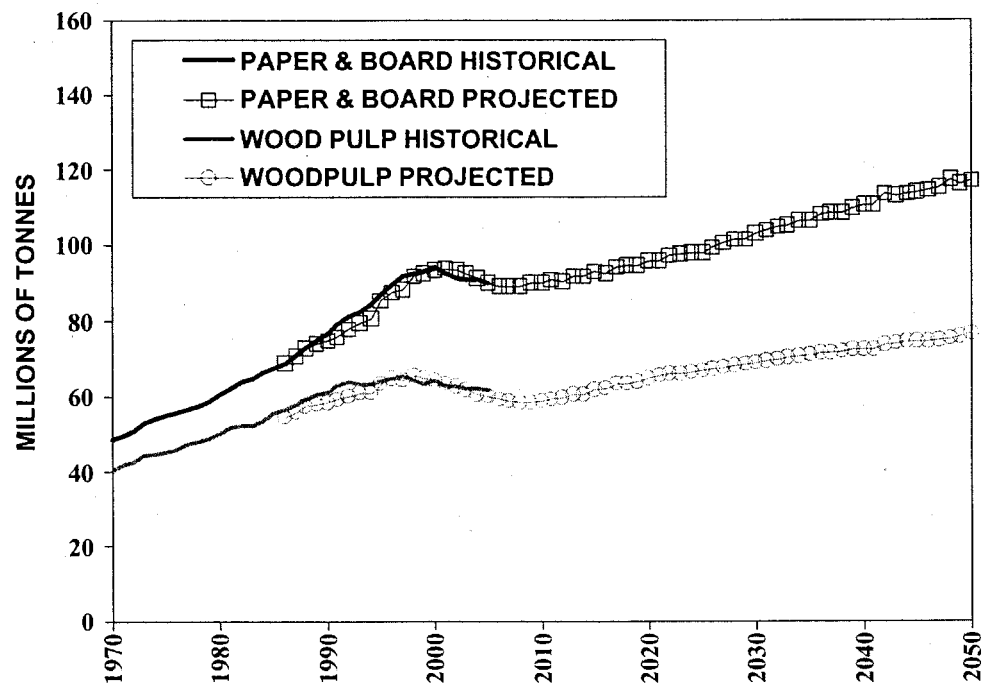


Figure 4-4. US paper and paperboard production capacity along with wood pulp production capacity, 1970 to 2005 (AF&PA, API); and NAPAP model projections from 1986 to 2050.

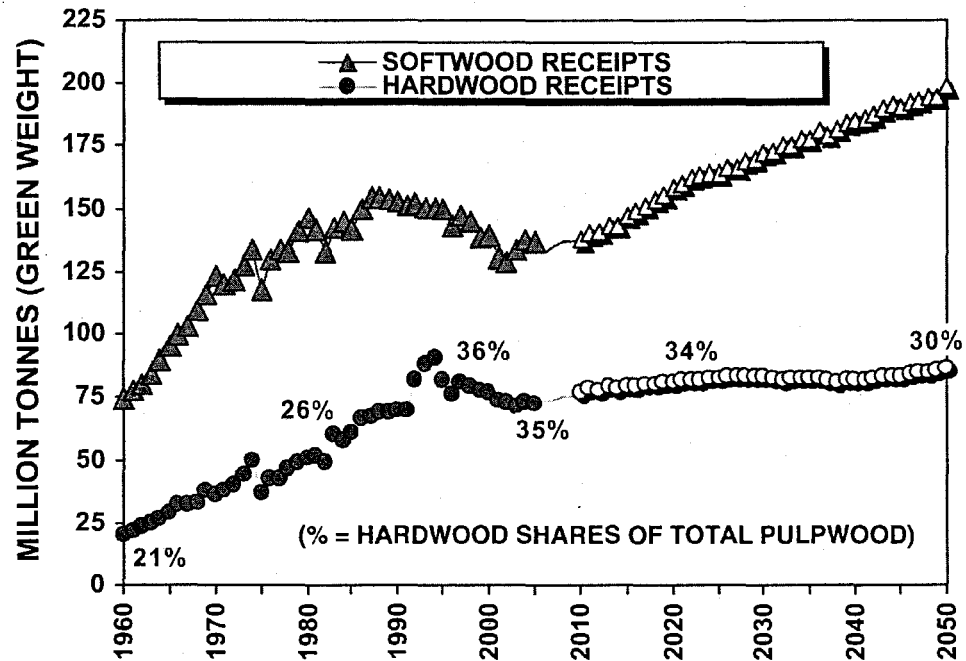


Figure 4-5. Softwood and hardwood pulpwood receipts at US wood pulp mills, 1960 to 2005 (Forest Resources Association 2006), and NAPAP projections 2010 to 2050, showing hardwood shares of total receipts.

fairly accurate endogenous projections of capacity trends using the q model.

Figure 4-5 shows historical and projected trends in hardwood and softwood pulpwood receipts at US pulp mills (base case NAPAP projections). Recycling had a big impact on softwood use in the 1980s (via expanded recycling in newsprint and containerboard). Future hardwood use is limited by very little projected growth in US printing and writing paper output.

Model validation consisted in part of graphical and statistical comparison of model projections to actual historical data trends since 1986, as illustrated by examples in Figures 4-1 and 4-4. A broader view is that “validation means that a model is acceptable for its intended use because it meets specified performance requirements” (Rykiel 1996). Accordingly, within the RPA Timber Assessment context, the long-range NAPAP model projections were subjected to reviews and subjective judgments by various industry experts who provided their opinions and feedback on reasonableness of the projections. The model sustained generally positive reviews in that context, and to some extent the exogenous assumptions about trade and long-run shifters of demand reflect the expert opinions.

4.4.9 Conclusions

Models are never perfect representations of reality, nor can any model match expectations universally, but the NAPAP model was a reasonably accurate tool to analyze and project important structural changes and dynamic evolution of pulpwood requirements in the US pulp and paper sector. The NAPAP model and earlier PELPS-based models of the North American pulp and paper sector helped provide better understanding of the timber resource implications of broad developments in the pulp and paper sector, such as the substitution of hardwood for softwood pulpwood, increased paper recycling, and economic globalization. Understanding broad implications of economic globalization and structural change in the US pulp and paper sector has led also to an appreciation of need for broader global perspectives and a global economic model in future US forest assessment studies (globalization and implications are discussed further in Chap. 13).

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