Working Paper

MATHEMATICAL FORMULATION OF A FOREST SECTOR PROTOTYPE MODEL

Lars Lönnstedt

July 1983
WP-83-69

International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria

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FOREWORD

The objective of the Forest Sector Project at IIASA is to study long-term development alternatives for the forest sector on a global basis. The emphasis in the Project is on issues of major relevance to industrial and governmental policy makers in different regions of the world who are responsible for forestry policy, forest industrial strategy, and related trade policies.

The key elements of structural change in the forest industry are related to a variety of issues concerning demand, supply, and international trade of wood products. Such issues include the development of the global economy and population, new wood products and substitution for wood products, future supply of roundwood and alternative fiber sources, technology development for forestry and industry, pollution regulations, cost competitiveness, tariffs and non-tariff trade barriers, etc. The aim of the Project is to analyze the consequences of future expectations and assumptions concerning such substantive issues.

The research program of the Project includes an aggregated analysis of long-term development of international trade in wood products, and thereby analysis of the development of wood resources, forest industrial production and demand in different world regions. The other main research activity is a detailed analysis of the forest sector in individual countries. Research on these mutually supporting topics is carried out simultaneously in collaboration between IIASA and the collaborating institutions of the Project.

The purpose of this paper is to serve as a background paper both for detailed national forest sector analysis as well as for the analysis of the global development. The paper discusses substantive issues related to the evaluation of the forest sector. A set of policy alternatives for coping various problems (in particular those related to dynamics) have been discussed as well.

Markku Kallio
Project Leader
Forest Sector Project

ABSTRACT

This paper gives a mathematical description of a long-term prototype model developed as a part of IIASA's Forest Sector Project. The model is developed for analyzing in a 20-30 years perspective, the impact of cost competitiveness and wood availability on the structural change of the forest sector under investigation. The model is intended to be used by decision makers at strategic discussions about possible futures of the forest sector.

The model consists of two symmetric competing forest sectors -- one for the national forest sector under investigation; and one for competing forest sectors of other countries. Each forest sector covers all activities ranging from timber growth to the consumption of forest industrial products such as paper (pulp), sawnwood and panels. This is represented in the model through eight modules: Demand of products, product market, forest industry, roundwood market, forest management, inventory of standing volume, construction sector and regulation of the forest sector. In this paper each of the modules is described and the mathematical equations are presented.

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MATHEMATICAL FORMULATION OF A FOREST SECTOR PROTOTYPE MODEL

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1. INTRODUCTION

This paper gives a mathematical description of a long-term prototype model developed as a part of IIASA's Forest Sector Project (Adams et al, 1982). The model is developed for analyzing in a 20-30 years perspective, the impact of cost competitiveness and wood availability on the structural change of the forest sector under investigation (Grossmann and Lönnstedt, 1983a). The model is able to produce scenarios for the forest sector (1) under different assumptions about the economic environment of the forest sector or (2) when different policies are applied. The model is intended for interactive use at strategic discussions in ministries, companies, and other organizations concerned with the future of the forest sector (Grossmann and Lönnstedt, 1983b).

Given the assumptions that the sector under study is able to compete, that wood is available, and that no better investment opportunities exist outside the sector, the model produces a scenario where the sector will keep its long-term market share. The long-term price will follow the long-term development of processing costs. However, the market share and price will fluctuate around these trends due to, for example, information delays, planning time, and building time which will cause excess demand or excess supply (Figure 1). Unfavorable cost development, limited wood resources or opportunities for better investment outside the sector will alter this scenario in the sense that the market share for the sector under investigation will decrease. If this share already is small and the sector under investigation is not the price leader, the price will remain unchanged. Actions taken by the sector will, however, change the scenario.

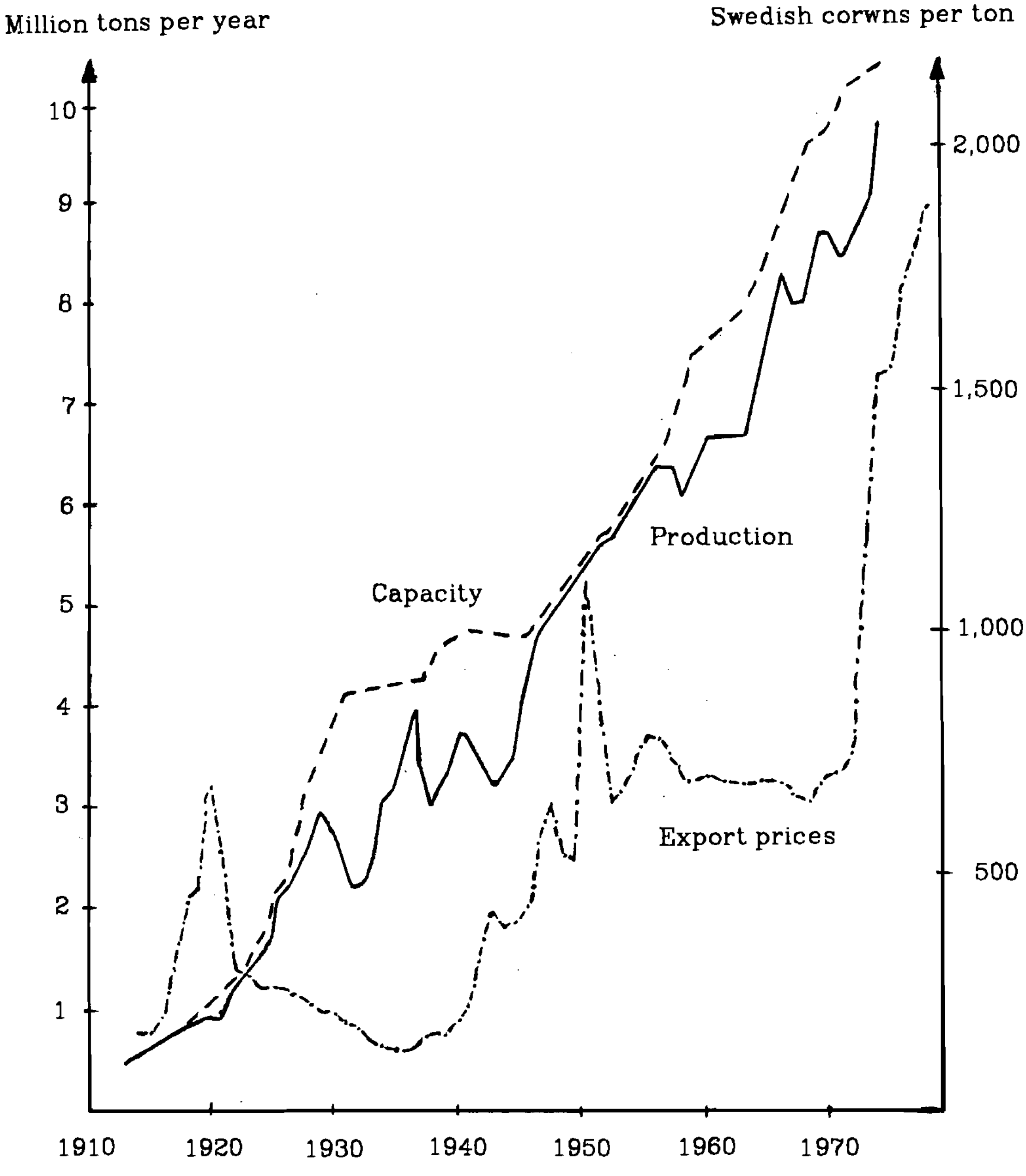

Figure 1. The capacity and production levels of Canadian newsprint paper industry 1914-1974 and export prices for Swedish newsprint paper. (Source: Kalgraf and Lönnstedt 1981).

Existing forest sector models (Lonnstedt and Randers 1979, Adams and Haynes 1980, Kalgraf and Lönnstedt 1981 Kallio et al. 1982, Kuuluvainen and Seppälä 1982) as well as the general economic theory lie behind the construction of the model (e.g., Douglas 1979, Gold 1971, Layard and Walters 1978, Cohen and Cyert 1965). The demand and supply curves are indirectly represented. One main assumption is that the system is all the time trying to equalize potential demand and supply, but never succeeds due to delays (Grossmann and Lönnstedt, 1983b). A simulation approach will be used where the solution is found recursively over time.

The model consists of two symmetric competing forest sectors -- one for the national forest sector under investigation; and the other represents competing forest sectors of other countries (see Figure 2)*. Each forest sector covers all activities ranging from timber growth to the consumption of forest industrial products such as paper (pulp), sawnwood, and panels.

In the text to follow, the general structure of the model system is described starting from an aggregated level, i.e., the linkage between demand and supply will be described (1). Then comes the description of the modules making up supply (2). At the end, these modules will be presented in a somewhat more detailed form (3).

(1) In principle, each sector is thus defined by domestic long-term ***demand*** and ***supply*** of forest industry products and by a product market. ***Trade*** is introduced by linking the two sectors. This means that imports of forest industrial products and roundwood are introduced on the domestic markets. At the same time, the forest sector under investigation has the possibility to export its products. Exogenous variables are GDP, size of population, price of substitutes, exchange rate, price of input factors and technological change.

The price of the bulk products studied, which is essential for the feed-back mechanisms that exist in the model, is defined by the aggregated long-term demand and long-term supply for the two sectors. For example increasing relative price of forest products will after some time decrease the demand of forest industry products which in its turn will affect the price. Price also affects supply via profits and investments. Decreasing price means, everything else unchanged, reduced profit per product unit, and less money for investments. Less investments in new capacity will after some years reduce long-term supply of forest industry products, which in turn will increase the price.

(2) ***Supply*** of forest industry products from each forest sector is in the model made up of five submodels or modules representing: 1) forest industry; 2) roundwood market; 3) forest management; 4) inventory of standing volume; and 5) regulation. The linkage of these modules to the rest of the system are carried out through the forest industry module. Potential supply and processing costs are given to the product market module, from which product price, actual demand and market imbalance are received.

* A more detailed verbal description of the model structure is to be found in Lönnstedt (1983).

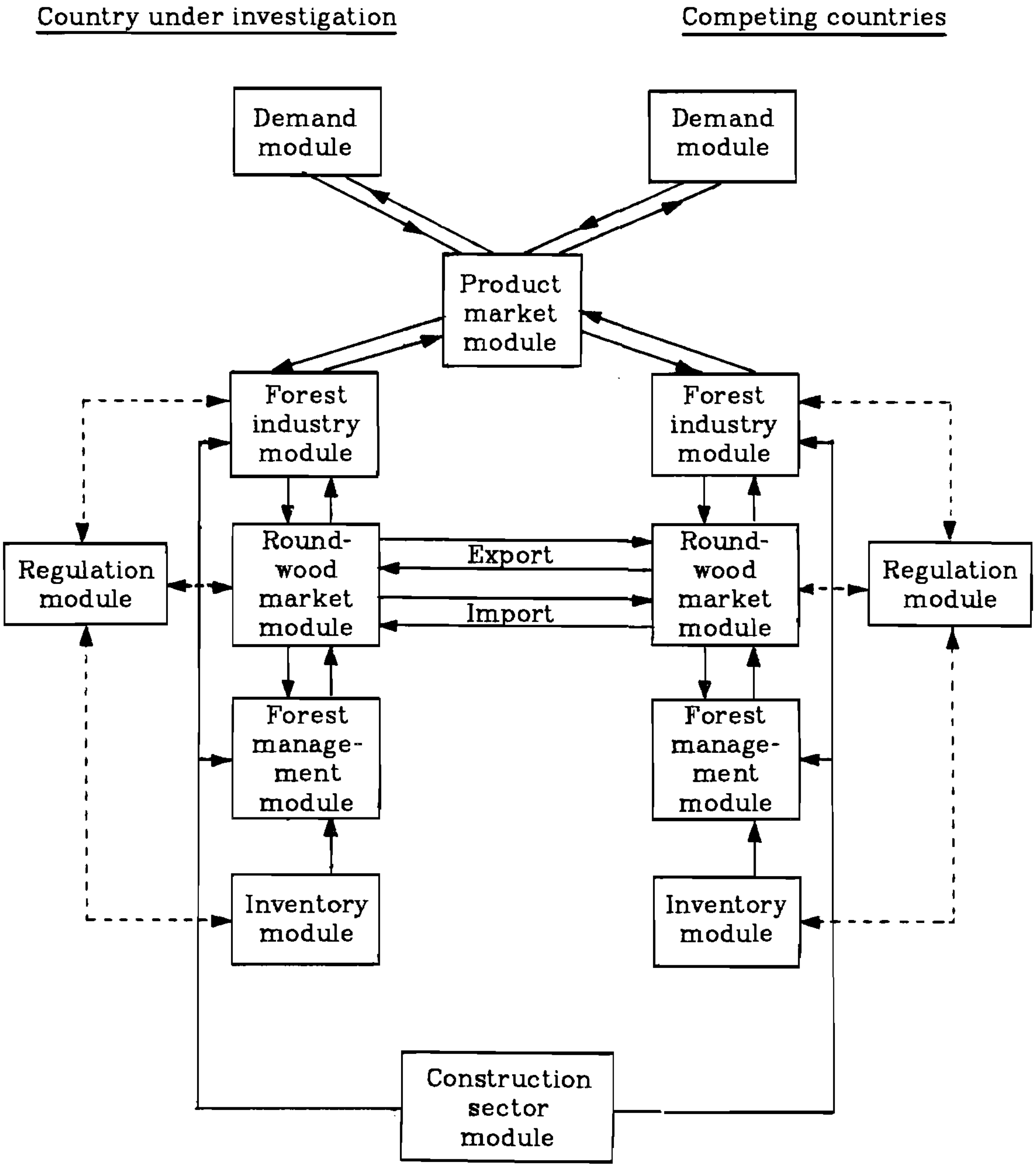

Figure 2. Outline of the prototype model used on the forest sector under investigation and competing forest sectors. The linkage between the modules consists essentially of price and quantity information. From the construction sector module new capacity is received. The regulation module specifies quantitative restrictions (marked by dotted lines). As exogenous variables are GDP, size of population, prices of substitutes, exchange rates, and prices of input factors other than wood and technological development treated.

The forest industry module defines production capacity and processing costs. The wood raw material base for the industry is the domestic forest resources and import of wood. Gross felling, import of wood, and delivery price are defined in the roundwood market module. Potential supply based on existing forest resources and harvesting capacity, as well as the harvesting costs are calculated in the forest management module. The regulation module allows regulation of investments in new industry capacity and gross felling.

(3) The linkage between the "supply modules" is important for the definitions of different variables as well as the feed-back mechanisms. A detailed specification of the linkage between the modules can be found in Figure 3.

The ***forest industry*** module gives potential demand for wood and maximum stumpage price to the wood market and receives delivery price and actual supply of wood. Production capacity and potential demand also is given to the forest management module. This is another example of a feed-back mechanism -- the higher the demand of wood, the higher the supply and thus the delivery price. Everything else unchanged the increase of price will affect demand. What will actually happen depends on the development of actual demand, product prices, harvesting costs, and wood availability.

Another feedback mechanism, which is actual for those countries where regulation of the forest sector exist, is between the forest industry module and the regulation module. Production capacity is given to the regulation module which gives back recommended investments in new capacity. Recommended investments are defined from production capacity, increment and standing volume.

From the capital sector module investment cost of new capacity and required use of input factors per produced output unit (for simplicity called "efficiency") is received.

An important feed-back mechanism inside the forest industry module is described in the following. An increase of the price will, everything else unchanged, increase the profit and the cash flow. More money will be available for investments. Investments in new capacity will increase the total production volume and also reduce the production cost per unit due to higher efficiency for new equipment. The result will be an increase in the profit, and so on.

The linkage between the ***roundwood market*** and industry modules have been described above. From the forest management module, the roundwood market module receives potential supply and harvesting cost. It gives back actual demand and delivery price. This is the same type of feedback mechanism as the one between forest industry and roundwood market which is also true when it comes to the linkage between the roundwood market and regulation module. The latter module receives standing volume and increment from the inventory module and actual supply from the roundwood module. It gives back allowable cut.

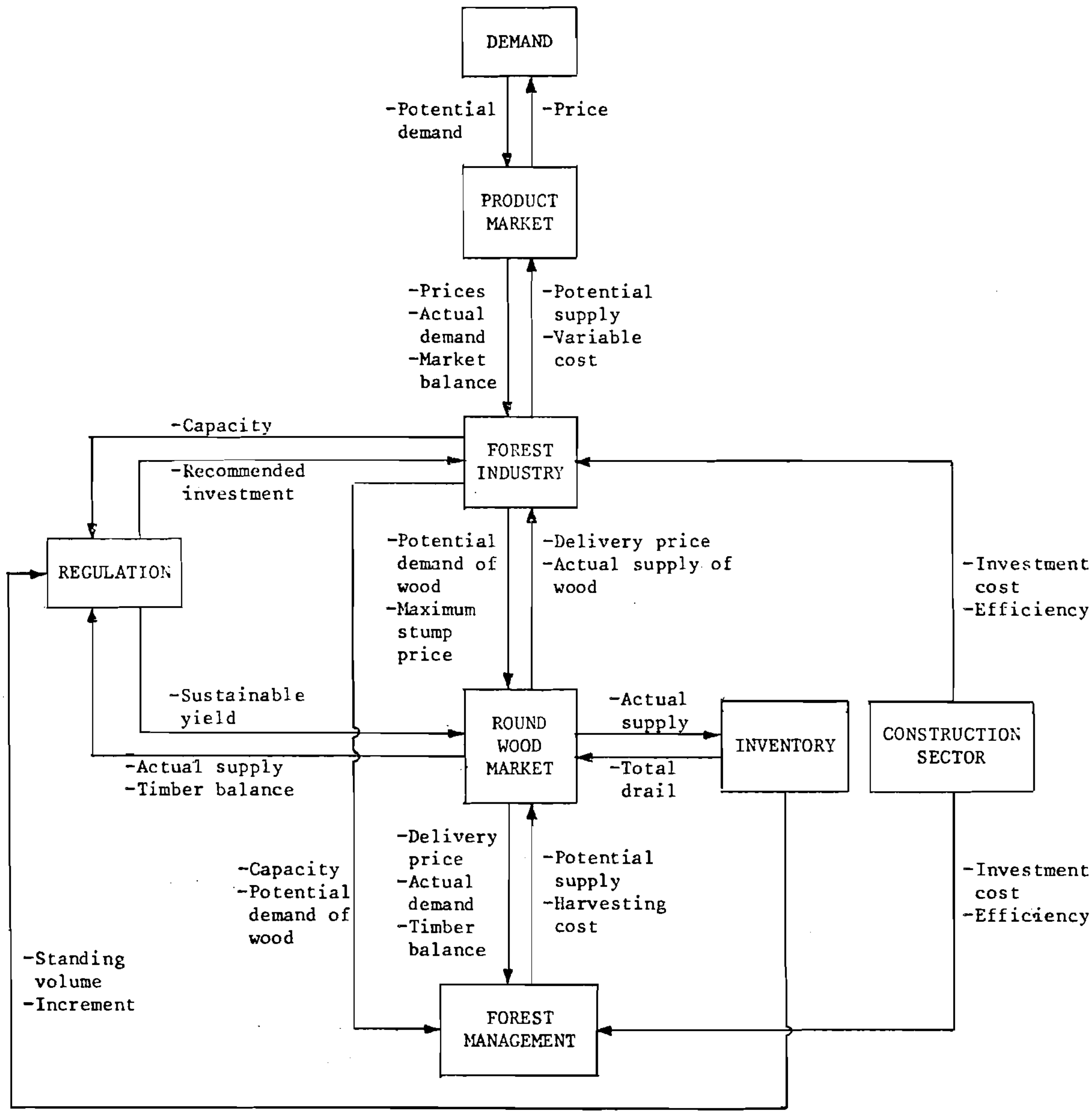

Figure 3. Linkages between the modules of one forest sector.

In the roundwood market module, timber balance is defined as the ratio between potential demand of wood and total drain. (Total drain is defined as actual supply of wood plus mortality.) Timber balance is given to the regulation module where it affects the "regulation power" of the forest industry and the roundwood market. The tighter the timber balance, the harder the regulation.

The linkages between the *forest management* module and the roundwood market and forest industry modules have already been described. Increased utilization of the forest resources, as it is measured by the timber balance, means longer transport distances and when the resource really are limited, probably utilization of even low quality stands. This will increase the cost of wood for the industry which, if all other things are unchanged, will reduce demand. As for the forest industry module, investment cost for new capacity and new equipment, required use of input factors per harvested cubic meter (called efficiency) are received from the capital sector module. The internal feedback mechanism is the same as for the forest industry module – increased profit due, for example, to increased delivery price; increases when everything else is unchanged, the harvesting capacity; reduces cost per harvested cubic meter which increases the total profit, and so on.

The *inventory* module keeps track on the standing volume. From the wood market module the actual cut is received. Standing volume and increment are given to the regulation module and total drain to the roundwood market module. The linkages between the regulation and the capital sector modules and the rest of the system have already been described.

Each of the eight modules is described in the following text. Each section contains a description of how each module is constructed, and the mathematical equations are also presented. Possible future extensions of the model is also pointed out.

2. DEMAND OF FOREST INDUSTRIAL PRODUCTS

Demand per capita for paper (pulp), sawnwood, and panels, can for example be defined by a logistic function of GDP per capita, and product price relative to price of substitutes* (Figures 4 and 5). Total demand is calculated by multiplying demand per capita with size of population. Demand for fuelwood relative to total demand of wood, $\varepsilon(t)$, can be calculated along the same principles, but in this model version, in order to simplify, is defined as a constant shares of demand for wood raw material.

$$d_{1i}(t) = 2a_1 \cdot \left[G(t) + a_2\right] \qquad (1.1)$$

$$d_{2i}(t) = 1 / \left\{p_i(t) / p_l(t) \cdot \left[1 + a_3 \cdot p_i(t) / p_l(t)\right]\right\} \qquad (1.2)$$

* The chosen function is just one of several candidates here as well as later on in the paper. The function is an *example* for giving structure to the model. The final choice must be made after looking at the data for the forest sector under investigation. In order to simplify some equations will be divided into two or several parts and denoted with a numerical index attached to the symbol for the main function.

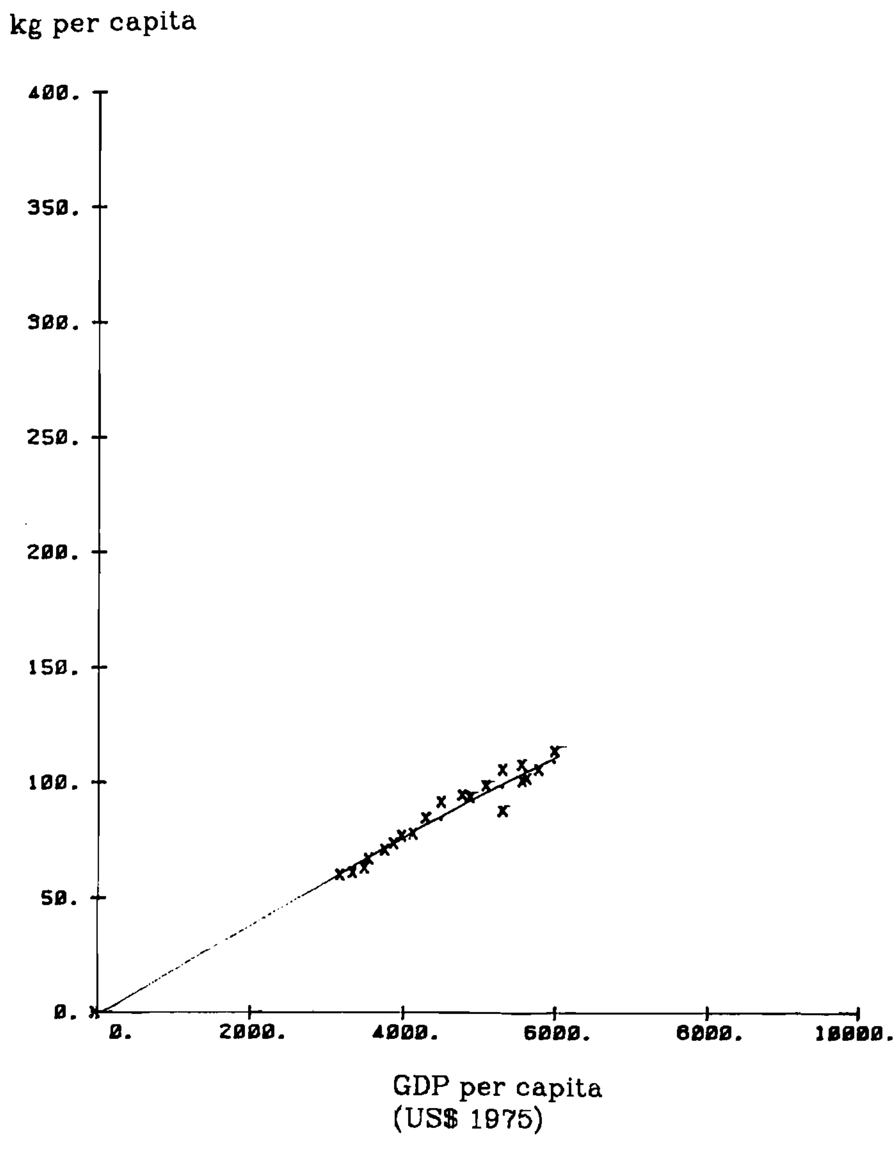

Figure 4. Example of a demand function (1.3) for paper and paperboard in Western Europe. Estimated parameter values are a_1 = 0.14d-03, a_2 = -2243.6, a_4 = 41.8, and a_5 = 142.8. No substitution to or from other products is assumed to have taken place, i.e., a_3 = 0 (Figure 5). (Sources: UN Statistical Yearbook, Yearbook of National Accounts Statistics and FAO Yearbook of Forest Products).

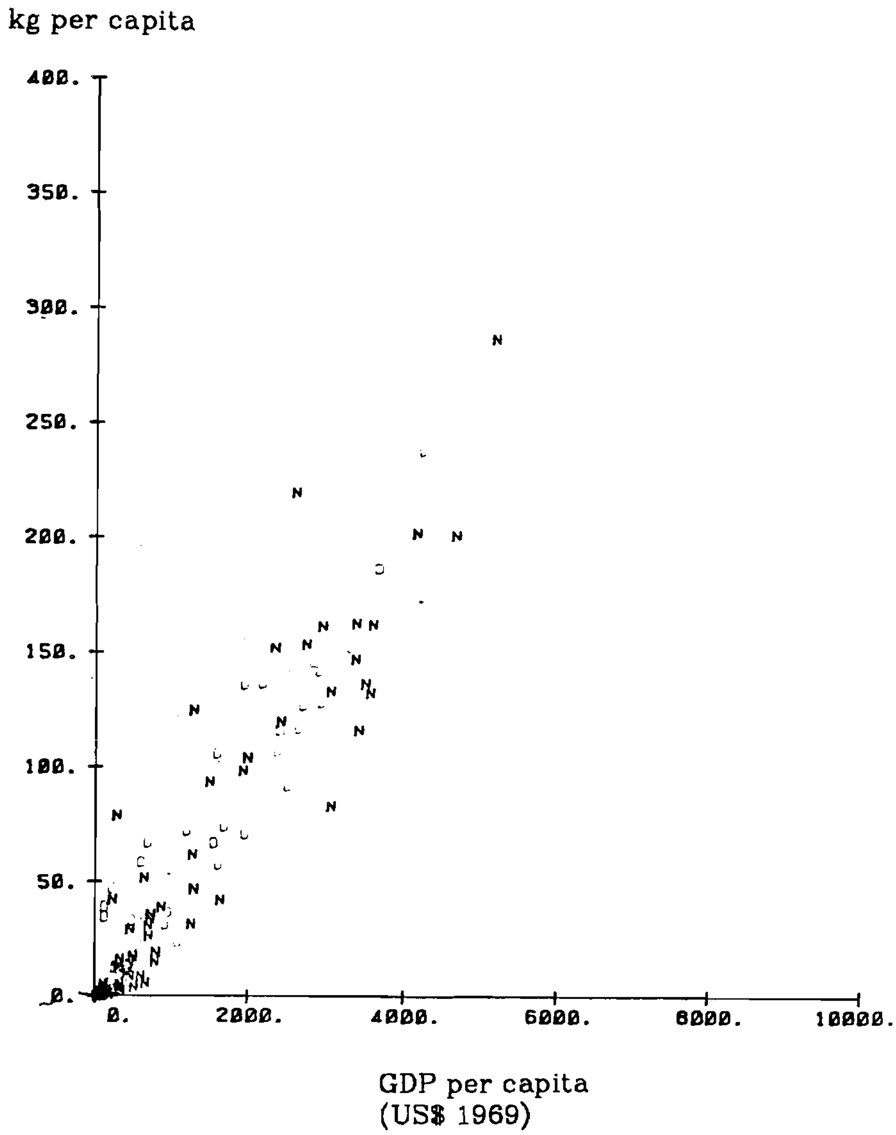

Figure 5. Consumption of paper and paperboard per capita in 62 countries 1969 (marked by "o" and 1979 (marked by "n"). It is difficult to observe any general substitution effect. By experimenting with different parameter values of a_3, possible substitution effects in the future for example between paper and telematic can be illustrated. (Sources as for Figure 4 and Wibe 1983).

$$d_i(t) = \left\{a_4 + a_5 \cdot \left[1 - e^{-d_{1i}(t)}\right] / \left[1 + e^{-d_{1i}(t)}\right]\right\} \cdot d_{2i}(t) \cdot P(t) \qquad (1.3)$$

where*

- i = refers to forest industry
- t = time (year)
- d_{1i} = equation used for calculating potential demand, affects how quickly changes in potential demand per capita takes place
- a = constant parameter **
- G = gross domestic production in real terms (₤/capita and year)***
- d_{2i} = equation used for calculating substitution effect on potential demand
- p = price (US$/ton)
- l = refers to substitutes
- d_i = potential demand (ton/year)
- P = size of population (number of inhabitants)

Demand for paper (pulp), sawnwood, and panels will, in this version of the model, be aggregated in the market module into just one demand curve. The output of the forest industry is thus only one product. The industrial demand for wood together with the demand for fuelwood meet the supply of wood in the roundwood market. The principles outlined in this paper can easily be followed in future versions of the model when the number of products are increased. Another important aim in future model versions is to relate the demand functions to the end use of wood based products.

3. PRODUCT MARKET

Sawnwood, panels, and pulp can be considered as bulk products the prices of which are determined by the conditions of an international market -- in this case defined by the two forest sectors under study. Thus, after getting total potential demand from the demand modules and total potential supply from the industry modules, the market module determines:

a) the product price (in US$) which is the same for the two sectors under investigation

b) the ratio between aggregated potential demand and aggregated potential supply, which is called market imbalance.

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* The verbal definitions of variables will after presenting the equations be repeated until the variable has been defined by an equation. The verbal definitions of exogenous variables and constant parameter will always be repeated. A list of all variables with explanation is in appendix 2.

** The indices refers to one equation at time and thus start from the beginning for the next equation.

*** ₤ will be used for notifying the local currency for the forest sector under investigation.

Market Price

The principle for formulating the price in the product market is to calculate what long-term price is needed in order to cover both variable and fixed costs. The price is calculated as the long-term average variable cost for those producers supplying the market plus a mark up for required long term return on capital. As a weight when calculating the average variable cost the quantity produced by each producer has been used. Mark up can for example be defined by an exponential function of the market imbalance (Figure 6). Excess supply implies a lower mark-up than a market with excess demand. Market imbalance information is somewhat delayed in the model. Therefore, it will take some time for the price to change when the market situation changes.

$$b_i(t) = \left[d_i(t-\tau) + d_i^j(t-\tau)\right] / \left[s_i(t-\tau) + s_i^j(t-\tau)\right] \tag{2}$$

$$o_i(t) = a_1 + a_2 \cdot e^{a_3 CB b_i(t) + a_4 CE} \tag{3}$$

$$p_i(t) = \left\{\left[v_i(t) / z(t) \cdot C_i(t) + v_i^j(t) \cdot C_i^j(t)\right] / \left[C_i(t) + C_i^j(t)\right]\right\} / \left[1 - o_i(t)\right] \tag{4}$$

where

b_i = market imbalance

τ = indicates a time difference compared with actual time, t (year)

j = refers to competing forest sector

s_i = potential supply (ton/year)

o_i = mark up

p_i = market price (US$/ton)

v_i = variable cost (£/ton)

z = exchange rate (£/US$)

C_i = capacity (ton)

Import and Export

Import is determined as a delayed share of potential demand. The share can for example be defined by a logistic function of relative processing cost, taking transportation cost into consideration (Figure 7) (Considine et al 1983, see also Andersson and Persson 1982). Export is calculated in the same way but using the conditions in the competing forest sector for which potential demand is calculated following the same principles as for the forest sector under investigation. Depending on the actual case it can be necessary to introduce trade with one more market. The same principle as those outlined can be followed.

$$h_i(t) = \left\{v_i(t-\tau) / \left[v_i^j(t-\tau) \cdot z(t-\tau) \cdot (1 + k_i^j)\right]\right\} \tag{5.1}$$

$$m_i(t) = 1 / \left\{1 + a_1 \cdot \left[h_i(t) - a_2\right]^{-a_3}\right\} \tag{5.2}$$

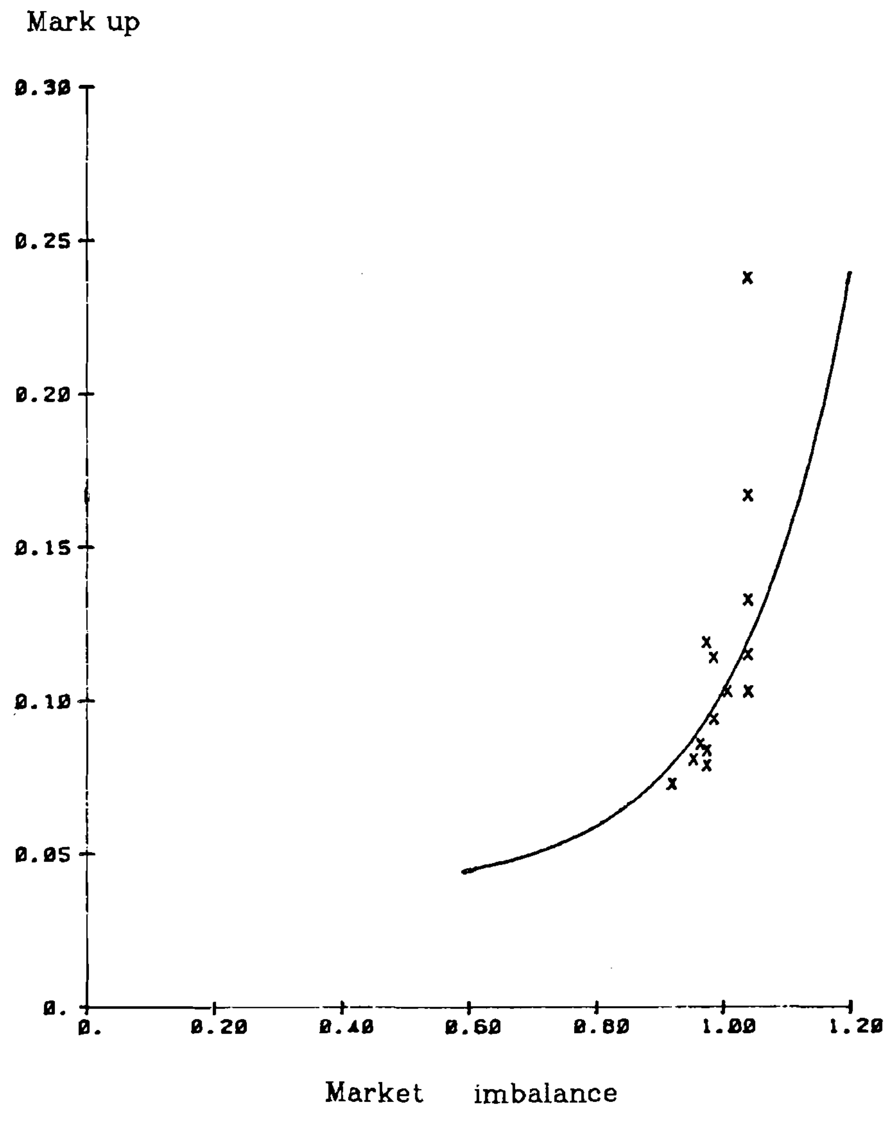

Figure 6. Example of mark up defined as an exponential function (3) of market imbalance. The parameter values for the function are a_1 = 0.038, a_2 = 7.12, a_3 = 0.559 and a_4 = -1.838. As an alternative to the exponential function a linear function could be used within a limited range, for example $0.9 \leq b_i(t) \leq 1.1$. Plotted in the figure is gross profit for the Swedish forest industry related to a calculated value of capacity utilization. The capacity utilization when production is peaking is assumed to be 0.95 of the capacity. The values thus calculated have been related to the average capacity utilization. (Sources: Yearbook of Forest Product, Yearbook of Swedish Forest Statistics and SOS Industry).

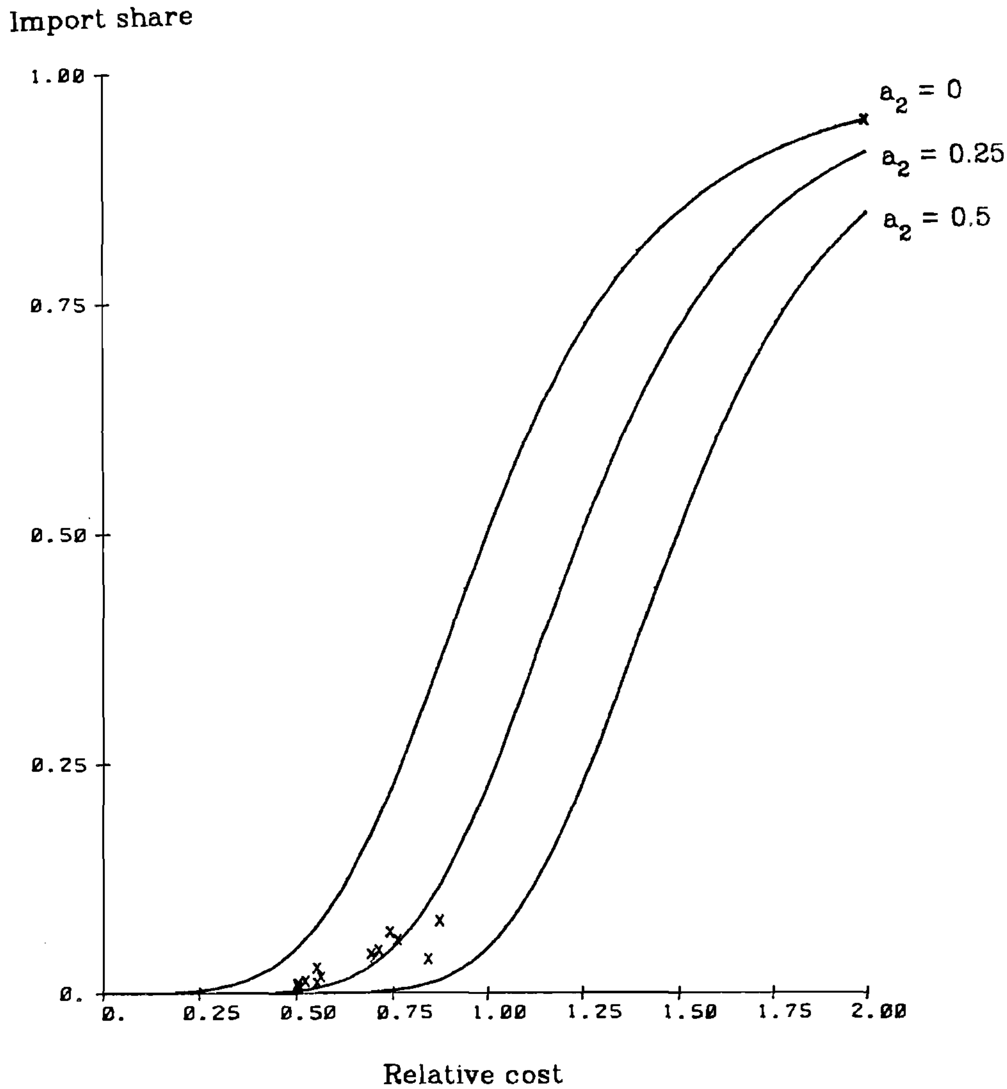

Figure 7. Examples of import relative to potential domestic demand of forest industry products defined as a logistic function (5.2) of domestic production cost related to production cost and transportation cost for imported goods. The parameter values for the functions are $a_1 = 1.0$, $a_2 = 0$, 0.25 respectively 0.5, and $a_3 = 4.25$. From a theoretical point of view one could expect half of the domestic consumption to be imported when relative cost equals one, i.e. $a_2 = 0$. Politics, economic communities, and traditions are some reasons for a deviation (Nagy 1983). Plotted in the figure is Austrian import share of sawlogs related to domestic price as a share of import price of sawlogs.

$$M_i(t) = m_i(t) \cdot d_i(t) \tag{6}$$

$$h^j(t) = v_i^j(t-\tau) / \left[v_i(t-\tau) \cdot (1 + k_i^j) / z(t-\tau)\right] \tag{7.1}$$

$$x_i^j(t) = 1 / \left\{1 + a_4 \cdot \left[h^j(t) - a_5\right]^{-a_6}\right\} \tag{7.2}$$

$$X_i^j(t) = x_i^j(t) \cdot d^j(t) \tag{8}$$

where

h_i = domestic production cost related to production and transportation cost for imported products.

v_i = variable cost (US$/ton)

z_i = exchange rate (£/US$)

m_i = import relative to potential domestic demand

k_1 = transportation cost between mill and market and custom duties as a share of variable cost

M_i = import (ton/year)

x_i = export relative to potential demand of forest products in competing forest sectors

X_i = export (ton/year)

Actual Demand and Supply

The price that is fixed for a specific time period generates potential demand and supply. If potential demand is greater than potential supply then the actual demand and supply will be equal to potential supply. If it is the other way around the actual demand and supply will be equal to potential demand. In the long run demand and forest industry capacity will follow each other. This means that inventory fluctuations can be neglected. There will of course be periods when potential demand exceeds potential supply, triggering price increases that increase production capacity and decrease the potential demand — and vice versa if there is an excess supply (compare Figure 1). At the same time demand and supply change due to income changes and changes in technology. If everything remains unchanged or develops in the same way the market shares of the two forest sectors in the model will also be unchanged. If the competitive conditions are getting worse for one of the sectors or if it faces limited wood resources the market share of this sector will decrease (if not actions are taken for offsetting those disadvantages).

Actual demand and supply is in the module calculated as the minimum value of potential demand and potential supply taking export and import into consideration.

$$S_i(t) = \min\left[s_i(t), d_i(t) - M_i(t) + X_i(t)\right] \tag{9}$$

where

S_i = actual supply (ton/year)

s_i = potential supply (ton/year)

4. FOREST INDUSTRY

In the forest industry module the long-term potential supply is determined taking an eventual shortage of wood deliveries into consideration. The module consists of three submodels: a) gross profit module, b) cash flow module, and c) production capacity module.

4.1 Gross Profit

Gross profit is defined by subtracting total variable costs from total income. Gross margin is gross profit as a share of total income. Gross profit for the forest sector under investigation is in the model calculated through adding profit for domestically sold products to profit for exported products. The difference in profit between these two types of sales is explained by differences in transportation costs. The market price, expressed in US dollars, is transferred into the national currency.

The long term development of variable costs is in the model dependent on the development of input factor costs and efficiency in utilization of the input factors (output-input-ration). The intention of the model is, as was described in Section 1, to study long term structural changes due to changed cost competitiveness or limited wood resources. Short term changes in the marginal cost due to changed capacity utilization will be neglected. Furthermore, the model will be operating with an average variable cost for all those mills included in that industrial branch under investigation.

The variable costs are in this version of the model calculated from two groups of input factors: wood and other input factors. The formulation assumes fixed coefficients for labor and capital usage. This means that the relative cost of labor and capital is constant. The transportation cost from mill to market is calculated as a share of total variable processing cost.

The cost of wood is calculated by adding the transportation cost to the delivery price, which is defined in the roundwood market (see Section 5). Transportation cost is assumed to be a constant share of the roundwood price. For calculating the wood raw material cost per product unit, cost of wood at mill is multiplied by wood volume needed per product unit; this transformation quotiant in the model is a constant parameter.

The principle for calculating the production cost related to input factors other than wood is the same. The price of the input factors is divided by the quantity of forest industry products produced per unit input factor (shortly called average efficiency). If we take labor as an example the calculation is as follows: the wage cost per hour is divided by the number of units produced per hour — a number that changes with the technological development, investments, and shutdowns — and the result is wage cost per produced unit (see also Section 4.3). Compared with the calculation of the cost of wood, the price of the other input factors than wood is treated as an exogenous variables and the efficiency in utilization of the factors as a variable.

$$v_{1i}(t) = c_i(t) / \bar{e}_i(t) \tag{10.1}$$

$$v_{2i}(t) = p_f(t) \cdot \left[1 + k_2^i\right] \cdot \left[S_f(t) - X_f(t)\right] \cdot \left[1 - \varepsilon(t)\right] \tag{10.2}$$

$$v_{3i}(t) = p_f^j(t) \cdot z(t) \cdot \left[1 + k_2^j\right] \cdot M_f(t) \cdot \left[1 - \varepsilon(t)\right] \tag{10.3}$$

$$v_i(t) = v_{1i}(t) + \left[v_{2i}(t) + v_{3i}(t)\right] / \left\{\left[S_f(t) - Xsbf(t) + Msbf(t)\right] \cdot \left[1 - \varepsilon(t)\right]\right\} \tag{10.4}$$

$$\pi_{1i}(t) = \left[p_i(t) \cdot z_i(t) - v_i(t) \cdot (1 + k_1^i)\right] \left[S_i(t) - X_i(t)\right] \tag{11.1}$$

$$\pi_{2i}(t) = \left[p_i(t) \cdot z_i(t) - v_i(t) \cdot (1 + k_1^j)\right] \cdot X_i(t) \tag{11.2}$$

$$\pi_i = \pi_{1i}(t) + \pi_{2i}(t) \tag{11.3}$$

$$\rho_i(t) = \pi_i(t) / \left[p_i(t) \cdot z_i(t) \cdot S_i(t)\right] \tag{12}$$

where

v_{1i} = variable unit processing cost excluding cost for wood (£/ton)

c_i = prices of input factors (£/unit)

$\bar{e}_i$ = average production efficiency (ton/unit)

v_{2i} = total cost for domestic wood (£/year)

p_f = delivery price (£/m^3)

f = refers to forestry

k_2 = transportation cost between place of delivery and mill and custom duties as a share of delivery price

S_f = gross felling (m^3/year)

X_f = export of wood to competing regions (m^3/year)

ε = consumption of fuelwood relative consumption of roundwood

v_{3i} = total cost for imported wood (£/year)

M_f = import of wood (m^3/year)

z = exchange rate (£/US$)

v_i = variable unit processing cost (£/ton)

k_1 = transportation cost between mill and market (and custom duties) as a share of variable costs

π_{1i} = gross profit from domestic sale (£/year)

π_{2i} = gross profit from export (£/year) as a share of variable costs

π_i = gross profit (£/year)

ρ_i = gross margin

The present formulation can be criticized

- for using a production function with fixed input coefficients for labor and capital
- for combining different costs with different dynamic behaviors into just one cost factor
- for treating transportation costs and efficiency in wood utilization as constant.
- for using the same fuelwood share for import as for of domestic harvest

4.2 Cash Flow

In this version of the model we are operating with two inflows and one outflow of cash. One inflow is earnings before depreciation after subtracting a constant share representing interest payments, dividends, and taxes. Another financial source is net inflow of external money such as new loans after repayment of old ones. The external financing is expressed as a share of the first mentioned inflow — a share that can for example be a linear function of the gross margin for new investments* relative to a gross margin reference value for alternative investment opportunities. The financial resources that these two cash inflows make up are all, with exception for a certain share that is withheld as working capital, used for investments. One part of this financial outflow is for investments in new forest industry capacity and the other part is for investments outside the sector (see next section).

$$\alpha_i(t) = a_1 + a_2\left[\rho_i^{\gamma}(t) / k_3\right] \quad (13)$$

$$\dot{F}_i = \pi_i(t)\cdot\left[1 - k_5\right]\left[1 + \alpha_i(t)\right] - \left[1 - k_4\right]\cdot F_i(t) \quad (14)$$

where

α_i = loans supplied by the capital market as a share of earnings before depreciation but after taxes, dividends and interests

a = constant parameter

ρ_i^{γ} = gross margin for new capacity

k_3 = reference value for gross margin

F_i = financial resources (£)**

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* Gross margin for new investments, $P_i^{\gamma}(t)$, is defined from gross margin for the whole industry adjusted for the lower variable unit processing cost.

** $\dot{F}$ stands for the changes between two time periods thus $\dot{F} = F(t) - F(t-\tau)$ $F(t) = F_0 + \int_0 (\ldots)dt$

k_4 = share of financial resources used as working capital

k_5 = share of financial net costs, dividends, and taxes, relative to profit before depreciation

The amount of borrowed money and repayments follow, in this version of the model, given a profitability of the forest sector comparable with alternative investment opportunities, the development of the gross profit and financial resources. The model will become more realistic by introducing an accounting system that keeps track on balance of payment and allows the industry to manipulate its profit and taxes by changing the depreciations. This will probably not have any major impact in the dynamic behavior of the model.

4.3 Production Capacity

As mentioned in the previous section when describing the cash flow two types of investments exist. One type is investments in new industry capacity and the other type is investment outside the sector. The share of financial resources available for forest industry investments can for example be a linear function of expected changes in the market situation as measured by a moving average of the imbalance between potential demand and supply. Changes in the market imbalance indirectly reflects what changes that can be expected in the product price and profitability. (Figure 8). If no regulation exists ($r_i(t) = 0$, see Section 9) the "planned" change in capacity, in the model defined by dividing the outflow from the financial resources intended for new industrial capacity with unit investment costs, will be realized. If regulation exists ($r_i(t) > 0$) the change of the industrial capacity will be affected by authorized change and regulation power. Financial resources not used due to regulation are assumed to be used for investments outside the sector.

Between the investment decision and the start of production several years will elapse because it will take some years to build new capacity. The model operates with a shut down rate that for example can be expressed as an exponential function of profit margin (Figure 9).

As pointed out in Section 4.1, it is important to keep track of the production efficiency of the existing capacity as this will affect the variable costs. In the model we handle this by saying that each new capacity unit allows the input factors to be used with a certain efficiency. The average efficiency of the operating capacity is thus affected by the rate of introduction of new capacity and the shutdown of old capacity.

For calculating average efficiency a technical term, called efficiency memory, has been introduced. The efficiency memory is defined as existing capacity times average efficiency for existing capacity. Changes in the efficiency memory depend on new capacity times production efficiency for new capacity respectively shut down of old capacity and the production efficiency for this old capacity. Average capacity is calculated through dividing the efficiency memory by the capacity.

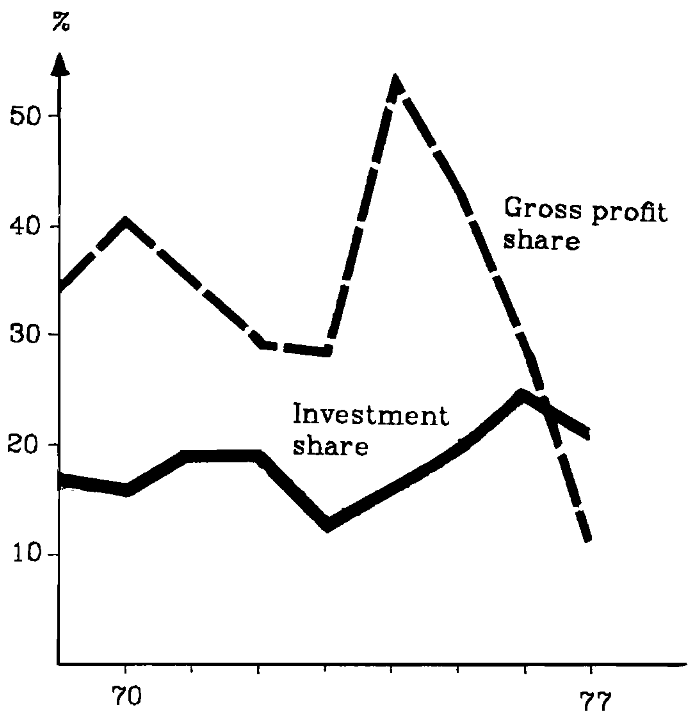

Figure 8. Gross profit and investments as a share of value added for the Swedish pulp and paper industry. (Source: taken from SIND 1980:2).

$$\beta_i(t) = a_1 + a_2 \cdot \left[b_i(t-\tau)\right] \tag{15}$$

$$U_i(t-\tau) = \beta_1(t-\tau) \cdot F_i(t-\tau) / w_i(t-\tau) \tag{16}$$

$$N_i(t) = \min\left[U_i(t-\tau), u_i(t-\tau)\right] \cdot r_i(t-\tau) + U_i(t-\tau) \cdot \left[1 - r_i(t-\tau)\right] \tag{17}$$

$$O_i(t) = a_3 \cdot e^{a_4 \cdot \left[p_i(t) - a_5\right]} \tag{18}$$

$$\dot{C}_i = N_i(t) - O_i(t) \cdot C_i(t) \tag{19}$$

$$\bar{e}_i(t) = E_i(t) / C_i(t) \tag{20}$$

$$\dot{E}_i = e_i(t) \cdot N_i(t) - O_i(t) \cdot C_i(t) \cdot \bar{e}_i(t-\tau) \tag{21}$$

where

β_i = share of financial resources, except working capital, used for investments in new capacity

U_i = planned increase of industrial capacity (ton/year)

w_i = investment cost for new capacity (£/ton)

Figure 9. Example of a shut down function derived for the Swedish pulp and paper industry (18). Estimated parameters a_3 = 1.9, a_4 = 4.7 and a_5 = 0.9. (Source: taken from SIND 1983:1).

N_i = new capacity (ton/year)

u_i = authorized new capacity (ton/year)

r_i = regulation power

O_i = shutdown as a share of capacity

C_i = capacity (ton)

E_i = efficiency memory (ton/unit*ton)

$\bar{e}_i$ = average production efficiency (ton/unit)

In this version of the model we have not distinguished between investments in existing or new capacity. Furthermore, investment costs are not affected by type and size of investment. Neither have we incorporated the effect maintenance investment will have on the lifetime of capacity.

Potential forest industry production is, taking the conversion quotiant into consideration, defined from gross felling, export and import of wood and use of fuelwood. Potential domestic demand of wood is calculated through multiplying the production capacity with the conversion quotiant and adding fuelwood.

$$s_i(t) = \left[S_f(t) - X_f(t) + M_f(t)\right] \cdot \left[1 - \varepsilon(t)\right] / k_6 \tag{22}$$

$$d_f(t) = \left[k_4 \cdot C_i(t)\right] / \left[1 - \varepsilon(t)\right] \tag{23}$$

where

s_i = potential supply of forest industry products (ton/year)

S_f = gross felling (m^3/year)

X_f = export of wood (m^3/year)

M_f = import of wood (m^3/year)

k_6 = conversion quotiant

d_j = potential demand of wood (m^3/year)

5. ROUNDWOOD MARKET

Forest industry and forest owners are looked upon in this module as two independent parties. The roundwood market is characterized by negotiations between the parties about the actual stumpage price.

Price of Roundwood

The actual delivery price is decided upon after negotiations and depends on the demand and supply of wood. In the model all roundwood will be sold as delivered timber. The delivery price is calculated from the sum of the average variable cost for logging and the stumpage price. The stumpage price is depending on negotiation power set somewhere between the maximum stumpage price the buyers are willing to pay and the minimum stumpage price the sellers are willing to accept for doing any cutting. The negotiation power can for example be defined as a linear equation of timber balance. Two extreme possibilities exist. If negotiation power equals one the realized stumpage share equals maximum possible stumpage share that the forest industry can pay. On the other hand if the forest owners have no negotiation power at all the realized stumpage price equals minimum acceptable stumpage share for forest owners. If negotiation power equals one half the stumpage share will be between those two extreme values. What parameter values to use is partly a policy question when experimenting with the model.

$$p_f^i(t) = \left[p_i(t) \cdot z_i(t) \cdot (1 - k_7) - v_{1i}(t)\right] / \left[(1 + k_2) \cdot k_6\right] \tag{24}$$

$$\rho_f^i(t) = \max\left[k_8, 1 - v_f(t) / p_f^i(t)\right] \tag{25}$$

$$b_f(t) = \left[d_f(t - \tau) - M_f(t - \tau) + X_f(t - \tau)\right] / u_f(t - \tau) \tag{26}$$

$$n_f(t) = a_1 + a_2 \cdot b_f(t) \tag{27}$$

$$\rho_f(t) = \rho_f^i(t - \tau) \cdot n_f(t - \tau) + k_8 \cdot \left[1 - n_f(t - \tau)\right] \tag{28}$$

$$p_f(t) = v_f(t) / \left[1 - \rho_f(t)\right] \tag{29}$$

where

p_f^j = maximum possible delivery price for the forest industry

z_i = exchange rate (£/US$)

k_7 = minimum acceptable gross margin for forest industry (as a share of market price)

k_2 = transportation cost between place of delivery and mill as a share of delivery price

k_6 = conversion quotient (m^3/ton)

ρ_f^j = maximum possible stumpage share that the forest industry can pay

k_8 = minimum acceptable stumpage share for forest owners

v_f = variable cutting cost (£/m^3)

b_f = timber balance

X_f = export of wood (m^3/year)

u_f = allowable cut (m^3/year)

n_f = negotiation power

p_f = price at place of delivery (£/m^3)

ρ_f = stumpage share

Depending on the type of market in different countries the structure of this module will be changed. If, instead of negotiations, there is just a fixed price for standing timber that has to be paid to the forest owner (for example the national forest service) this "price" can just be added to the average variable cost instead of the negotiation structure now outlined. If the owner structure of the forest sector is other than the one outlined, for example closer economic links between forestry and industry, the net profit of the forest sector management will go into the financial resources of the forest industry. The outflow of financial resources will in its turn be divided between investment in the industry and in forestry.

Import and Export

Import and export of wood is calculated following the same principles as for import and export of forest industry products (compare Section 3). Import of wood is thus calculated as a s-shape share of potential demand of wood — a share that increases if domestic wood at mill becomes relatively more expensive than imported wood. Export is calculated in the same way but using the conditions in the competing forest sectors.

$$h_f(t) = p_f(t-\tau)\cdot(1+k_2^j) / \left[p_f^j(t-\tau)\cdot z(t-\tau)\cdot(1+k_2^j)\right] \quad (30.1)$$

$$m_f(t) = 1 / \left\{1 + a_1\cdot\left[h_f(t) - a_2\right]^{a_3}\right\} \quad (30.2)$$

$$M_f(t) = m_f(t)\cdot d_f(t) \quad (31)$$

$$h_f^j(t) = p_f^j(t-\tau)\cdot(1+k_2^j) / \left[p_f(t-\tau)\cdot(1+k_2^j) / z(t-\tau)\right] \quad (32.1)$$

$$x_f^j(t) = 1 / \left\{1 + a_4 \cdot \left[h_f^j(t) - a_5\right]^{a_6}\right\} \quad (32.2)$$

$$X_f^j(t) = x_f^j(t)\cdot d_f^j(t) \quad (33)$$

where

h_f = domestic delivery price related to delivery price and transportation cost for imported roundwood

z = exchange rate (₤/US$)

k_2 = transportation cost between domestic place of delivery and the mill, as a share of delivery price

m_f = import relative to potential domestic demand of wood

M = import of wood (m^3/year)

x_f = export relative to potential demand of wood in competing forest sectors

X_f = export of wood to competing regions (m^3/year)

Gross Felling

Gross felling is calculated as the minimum value of demand for wood taking trade into consideration and potential supply of wood. If cutting is regulated the potential supply will be a compromise between the forest owners' willingness to cut and the allowable cut calculated by the regulators. Where between those two extremes the compromise will be depends on the regulation power (see Section 9).

$$S_f(t) = \min\left\{d_f(t) - M_f(t) + X_f(t), \min\left[u_f(t), s_f(t)\right]\cdot r_f(t) + s_f(t)\cdot\left[1 - r_f(t)\right]\right\} \quad (34)$$

where

S_f = gross felling (m^3/year)

u_f = allowable cut (m^3/year)

s_f = potential supply of wood (m^3/year)

r_f = regulation power

6. FOREST MANAGEMENT

The long term goal of the forest managers is assumed to be to adjust the harvesting capacity to the industrial capacity, considering economic and biological restrictions. The effects on the long-term supply due to changed owner structure, inflation, taxes, lack of investment opportunities, recreational and environmental considerations (Grossmann 1983), and lack of forest labor will not be taken into consideration in this version of the model.

The principles behind the structure of the forestry module are the same as for the industrial part — the same mechanisms are functioning.

6.1 Gross Profit

Gross profit is defined by delivery price minus variable harvesting cost times gross felling. The variable harvesting costs in forestry are calculated by dividing the prices of the input factors by the efficiency by which they are used. The production efficiency will change depending on technological development, investments, discarding, and relative cutting level (see Figure 10).

$$v_f(t) = c_f(t) / \overline{e}_f(t) \tag{35}$$

$$\pi_f(t) = \left[p_f(t) - v_f(t)\right] \cdot S_f(t) \tag{36}$$

where

v_f = variable cost (£/m^3)

c_f = prices of input factors (£/unit)

$\overline{e}_f$ = average cutting efficiency (m^3/unit)

π_f = gross profit (£/year)

In more advanced model versions, it will, as for the forest industry, be of interest to distinguish more than two input factors.

6.2 Cash flow

In this version of the model we are operating with only one inflow and one outflow of cash. The inflow, financial resources from operations and the outflow, investments in new capacity, is calculated using the same formulations as for the forest industry.

$$\dot{W}_f(t) = \pi_f(t) \cdot \left[1 - k_9\right] - k_{10} \cdot W_f(t) \tag{37}$$

where

W = financial resources (£)

k_9 = share of financial net costs, personal use or dividends and taxes, relative to gross profit before depreciation

k_{10} =share of financial resources used for investments

The model will become more realistic by the introduction of more detailed in and outflows of cash. It could, in future model versions, be possible for the forest managers to borrow. It can also be of interest to incorporate other investment opportunities and in case of another owner structure of the industry and the forests the transfer of money between forestry and forest industry.

6.3 Harvesting Capacity

We have used the same principle as for the forest industry in formulating the capacity. The adjustment of forestry capacity to the industrial one is modeled by allowing financial resources for investments to be used both for harvesting equipment respectively silvicultural activities. The share used for silvicultural activities can for example be defined as a linear function of total demand of roundwood relative to existing harvesting capacity. If this relationship is bigger than one the share of financial resources used for silvicultural activities will decrease and vise versa (compare Section 4.3).

As for the forest industry an harvesting efficiency memory is introduced that is used for calculating average efficiency through a division with harvesting capacity. However one more factor has been introduced to reflect that the harvesting costs and efficiency depends on the utilization of limited wood resources (Figure 10). When more of the forest resources are utilized the distances of the forest transportation increase. Increased utilization of the forest resources sooner or later reach the situation where, depending on the ability of the industry to pay and price for alternative resources, one starts to evaluate utilization of low quality stands or stands on steep slopes which quite certainly will affect the harvesting costs. This mechanism can in the model system create a comparative disadvantage for a forest sector with limited forest resources.

$$\varphi_f(t) = a_1 - a_2 \cdot \left[d_f(t) + X_f(t)\right] / C_f(t) \tag{38}$$

$$N_f(t) = \left\{k_{10} \cdot W_f(t) \cdot \left[1 - \varphi_f(t)\right]\right\} / w_f(t) \tag{39}$$

$$\dot{C}_f(t) = N_f(t) - k_{11} \cdot C_f(t) \tag{40}$$

$$\lambda_f(t) = a_1 + b_f(t-\tau) \cdot \left[a_2 + a_3 \cdot b_f(t+\tau)\right] \tag{41}$$

$$\bar{e}_f(t) = E_f(t) / \left[C_f(t) \cdot \lambda_f(t)\right] \tag{42}$$

$$\dot{E}_f(t) = e_f(t) \cdot N_f(t) - k_{11} \cdot C_f(t) \cdot e_f(t-\tau) \tag{43}$$

where

φ_f = share of investment used for silvicultural activities

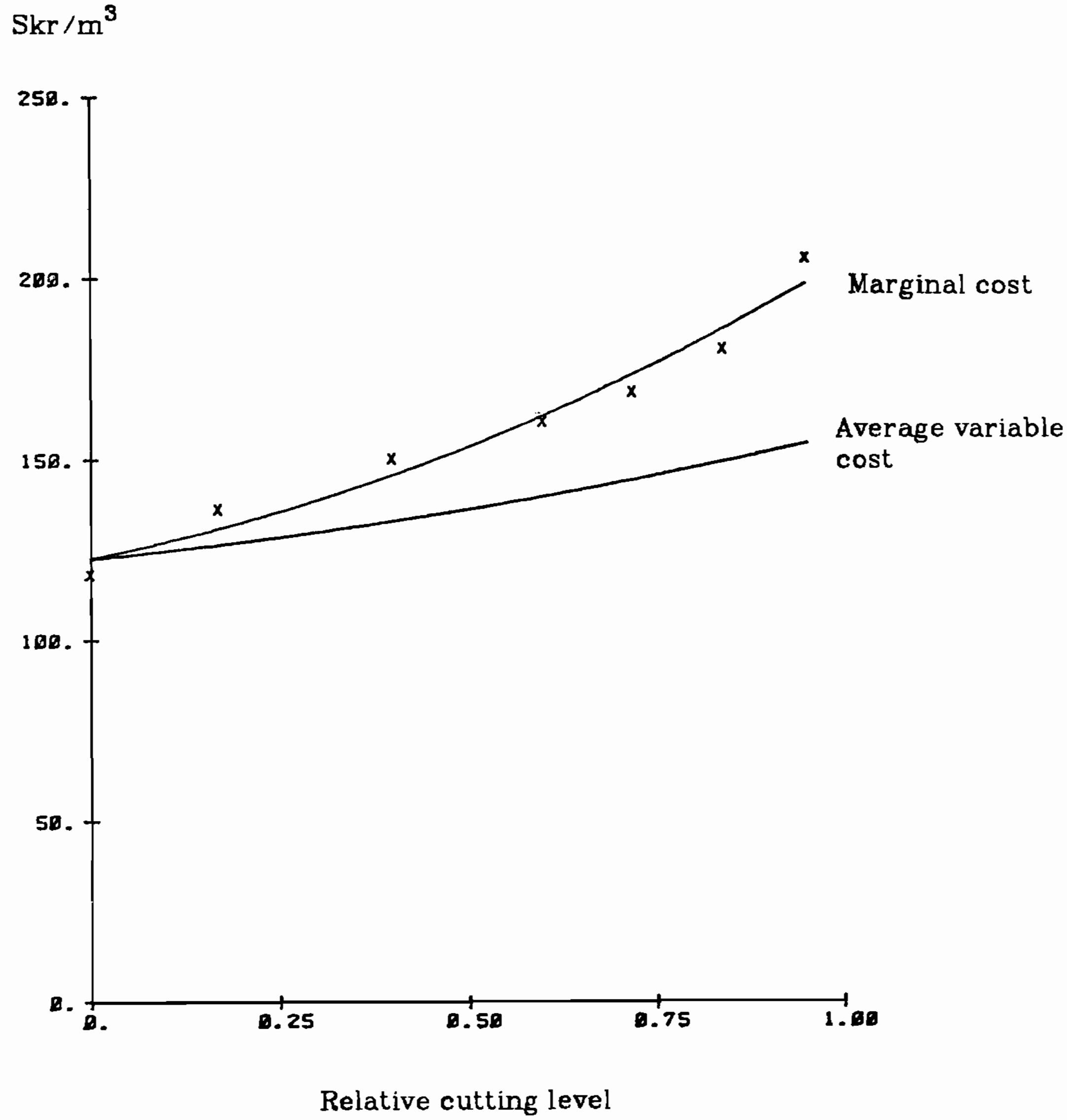

Figure 10. Example of relative cost increase as a function of relative cutting level. Estimated parameter values for the average variable cost function a_1 = 1.225, a_2 = 0.205, and a_3 = 0.135. (Source: Slora Kopporberg —a Swedish forest industry company.)

C_f = forestry capacity (m^3)

N_f = new forestry capacity (m^3/year)

k_{10} =share of financial resources used for investments

w_f = investment cost for new forestry capacity (\$/m^3)

k_{11} =discarding as a share of harvesting capacity

λ_f = effect on efficiency from intensity in utilization of the forest resources

E_f = efficiency memory (m^3/unit * m^3)

$\bar{e}_f$ = average cutting efficiency (m^3/unit)

Gross felling depends on the forestry capacity. The flexibility of the forestry capacity is however much bigger than the utilization of the forest industry capacity. In forestry it is, within certain limits, possible to change utilization during the day and week, to utilize more of the resources for harvesting operations instead of silvicultural activities, or to use farm equipment. In the formulation we have taken this flexibility into consideration by relating the forestry capacity utilization to demand of wood and forestry capacity.

$$\sigma_f(t) = \min\left\{k_{12}, a_1 + a_2 \cdot \left[d_f(t) + X_f(t)\right] / C_f(t)\right\} \tag{44}$$

$$s_f(t) = \sigma_f(t) \cdot C_f(t) \tag{45}$$

where

σ_f = capacity utilization

k_{12} =maximum capacity utilization

s_f = potential supply of wood (m^3/year)

The harvesting capacity module will become more realistic when distinguishing between efficiency for different input factors as well as for different types of capacity, for example felling or off-road extraction capacity. In this version we have assumed that there is enough work force for utilization of the logging capacity. This is not necessarily true for all regions of the world.

8. INVENTORY OF STANDING VOLUME

The structure of the forest industry module is formulated without detail. This is reflected in the modeling of the inventory module. The aim is to give an estimate of the wood raw material base for the forest industry. In this model version we do not distinguish between different species, site quality classes, or age classes. Neither do we distinguish between different types of felling. We have not taken into consideration the future possibility of decreasing residues and losses or of using branches, roots, leaves, and needles. The effects of different silvicultural activities have not been handled.

The standing volume of the forest in the model is increased by increment and decreased by total drain and mortality. The increment is calculated by multiplying an increment percentage by the standing volume. The increment percentage can for example be defined as an exponential function of density. Mortality is calculated in the same way (Figure 11). These relationships are assumed to be a mirror image of the relationship between increment and age. The forest land area has been made a constant. The total drain is calculated as the sum of gross felling and mortality. The latter is a constant factor of standing volume.

$$y_f(t) = a_1 + a_2 \cdot e^{a_3 \cdot [I_f(t) / A_f(t) + a_4]} \tag{46}$$

$$\mu_f(t) = a_5 + a_6 \cdot e^{a_7 [I_f(t) / A_f(t) + a_8]} \tag{47}$$

$$\dot{I}_f(t) = y_f(t) \cdot I_f(t) - S_f(t) - \mu_f(t) \cdot I_f(t) \tag{48}$$

where

y_f = increment percentage (1/year)

I_f = inventory (m^3)

A_f = forest area (ha)

μ_f = mortality percentage (1/year)

In a future version of the model it is possible to incorporate the effects of silvicultural activities. Other possibilities are to introduce different age classes, qualities, and species.

8. CONSTRUCTION SECTOR

The forest industry and management modules get investment cost and efficiency, used when calculating new capacity respectively efficiency memory, from the construction sector module. Investment cost is calculated from cost of input factors divided by the efficiency in using the input factors when producing new machineries. Both factor costs and efficiency are exogenous.

9. REGULATION OF THE FOREST SECTOR

In some countries such as the Nordic countries, there is a long established tradition to utilize the forest in accordance with long-term allowable cut. This was, for a long time, only done through regulations on the cutting. Now, even the investments in new sawmilling, panel, and pulp capacity are regulated.

The allowable cut can for example be defined as a linear adjusted value of the annual increment. If the inventory is above a target value, this represents in the model, a forest with an uneven distribution towards mature stands and the allowable cut calculated from increment will be somewhat increased and vice versa.

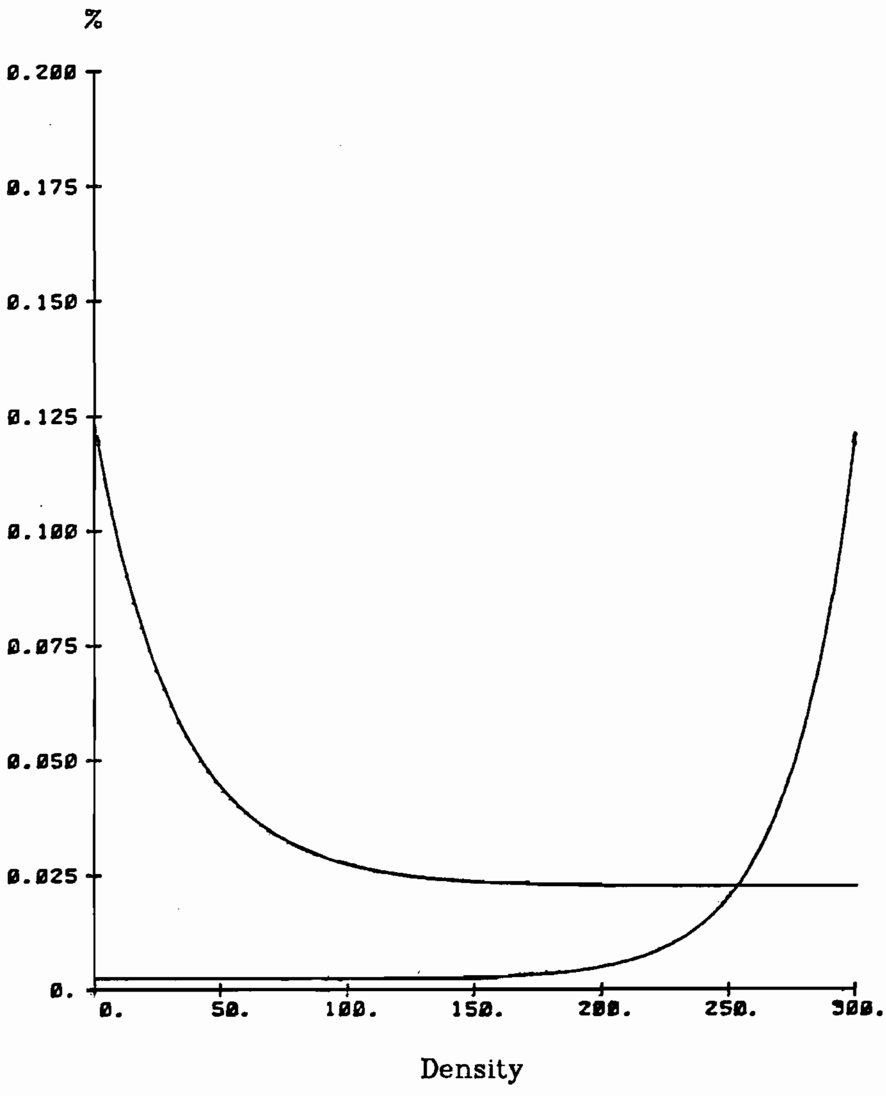

Figure 11. Examples of increment respectively mortality percentage functions. The functions are based on the hypothesy that density in this model with its specific purpose reflects the age structure for the whole forest area. As can be seen the increment and mortality percentages are for most of the range quite stable. The data plotted are calculated from the Swedish forest surveys. Estimated parameter values for the increment function are a_1 = 0.0225, a_2 = 0.096, a_3 = -0.030 and a_4 = -0.101. Estimated parameter values for the mortality function are a_1 = 0.002, a_2 = 0.00006, a_3 = 0.037 and a_4 = -99. (Source: Yearbook of Swedish Forest Statistics).

The regulation power can for example be defined as a linear function of the timber balance. A tight timber balance — total drain exceeds allowable cut — implies a high regulation power, and vice versa. By setting the regulation power to zero the regulating authorities will be put out of play (compare Section 4.3).

$$u_i(t) = \max\left\{0, O_i(t)\cdot C_i(t) + \left[u_f(t) - d_f(t) - X_f(t)\right] / k_6\right\} \tag{49}$$

$$u_f(t) = a_1 + a_2\cdot\left[I_f(t-\tau)k_{15}\right]\cdot y_f(t-\tau) \tag{50}$$

$$r_i(t) = a_3 + a_4\cdot b_f(t) \tag{51}$$

where

u_i = authorized new industry capacity (year ton/year)

u_f = allowable cut (m^3/year)

k_6 = conversion quotiant (m^3/year)

r = regulation power

10. CONCLUDING REMARKS

The prototype model presented is to be looked at as a suggestion or example of how a national forest sector model could be built. Some of the modules will be of more interest than others depending on the conditions for the forest sector under study. For example in some countries the forest resources will be of more importance than in others. For some cases, it will be found that modules are missing, for example, representing land use and pollution (Grossmann 1983). The structure of some modules will probably also need some changes. For example, in countries where the forest area is mainly owned by the state the stumpage price could be decided upon in another way. More detail could be wanted. This is true when it comes to the number of products. However before changing and developing the model too much it is important to implement the model to real cases, and confront the model an its result with decision makers. This will give a good direction for future work.

APPENDIX 1: DEFINITIONS

Actual Supply	Minimum value of potential demand and potential supply.
Allowable cut	Long term cutting volume corresponding to the yield that a forest can produce continuously at a given intensity of management.
Capacity	Capacity is increased through new investments and decreased through shut downs respectively scrapping.
Efficiency	Amount of input factors (for example working hours) necessary for producing one product unit (for example one ton of pulp)
Efficiency Memory	A technical term used for calculating average efficiency through division with capacity. Efficiency memory is defined as existing capacity times efficiency for existing capacity. Changes in the efficiency memory depend on new capacity times efficiency for new capacity respectively shut down of old capacity and the efficiency for this old capacity.
Financial Resources	Money available for investment in new capacity or outside the sector and as working capital. Cash inflows are earnings before depreciation but after interest payments, dividends, and taxes, and net inflow from for example new loans.
Gross Margin	Gross profit as a share of total income.
Gross Profit	Total income minus variable costs.
Inventory of Standing volume	Standing volume available for commercial use. Inventory is increment by increased and decreased by total drain.
Mark Up	Required long-term return on capital.
Market Imbalance	Total potential product demand related to total potential product supply.
Timber Imbalance	Total potential demand of wood related to total potential supply of wood.
Variable Unit Cost	Cost per output unit for wood and other input factors.

APPENDIX 2: VARIABLES IN THE MODEL

A	forest area (ha)
C	capacity (ton respectively m^3)
E	efficiency memory (ton/unit * ton respectively m^3/unit * m^3)
F	financial resources (£)
G	gross domestic production in real terms (£/year)
I	inventory of standing volume (m^3)
M	import (ton respectively m^3/year)
N	new capacity (ton respectively m^3/year)
O	shutdown or scrapping as a share of capacity.
P	size of population (number of inhabitants)
S	actual supply (ton/year)
U	planned increase of capacity (ton/year)
X	export (ton respectively m^3/year)
a	constant parameter
b	market respectively timber imbalance
c	prices of input factors (£/unit)
d	potential demand (ton/year)
d_{1i}	equation used for calculating potential demand, affects how quickly changes in potential demand per capita takes places
d_{2i}	equation used for calculating substitution affect on potential demand
e	efficiency (ton respectively m^3/unit)
f	refers to forestry
h	domestic production cost related to production and transportation cost for imported products
i	refers to industry
j	refers to competing forest sector
k	constant parameter
k_1	transportation cost between mill and market (and custom duties) as a share of variable cost
k_2	transportation cost between place of delivery and mill (and custom duties) as a share of delivery price
k_3	reference value for gross margin
k_4	share of financial resources used as working capital
k_5	share of financial net costs, dividends, and taxes, relative to gross profit before depreciation

k_6 conversion quatiant

k_7 minimum acceptable gross margin for forest industry as a share of market price

k_8 minimum acceptable stumpage share for forest owners

k_9 share of financial net costs, personal use or dividends, and taxes relative to gross profit before depreciation

k_{10} share of financial resources used for investments

k_{11} discarding as a share of harvesting capacity

k_{12} maximum capacity utilization

l refers to substitutes

m import share of potential demand

m_1 equation used for calculating import share, affects how quickly the share will change

n negotiation power

o mark up

p price (US$/ton respectively m^3)

r regulation power

s potential supply (ton/year)

t time (year)

u authorized new capacity respectively allowable cut (ton respectively m^3/year)

v average variable cost (£/ton respectively m^3)

v_{1i} variable unit processing cost excluding cost of wood (£/ton)

v_{2i} total cost for domestic wood (£/year)

v_{3i} total cost for imported wood (£/year)

v_{4i} variable unit processing cost for new capacity excluding cost for wood (£/ton)

w investment cost for new capacity (US$/ton respectively m^3)

x export share of competitors potential demand

x_1 equation used for calculating export share, affects how quickly the share will change

y increment percentage (1/year)

z exchange rate (£/US$)

α share of financial resources supplied by the capital market (1/year)

φ share of financial resources used for investments (1/year)

ε fuel wood share of actual consumption of wood

λ effect on efficiency from industry in utilization of the forest resources

γ refers to new capacity

π gross profit or, for forestry, stumpage (£/year)

π_{1i} gross profit from domestic sale (£/year)

π_{2i} gross profit from export (£/year)

ρ gross margin respectively stumpage share

σ capacity utilization (dimensionless)

τ indicates a time difference compared with actual time (t) —this time difference is different for different variables

μ mortality percentage (1/year)

REFERENCES

Adams, D.M., and R.W. Haynes. 1980. The 1980 Softwood Timber Assessment Market Model: Structure, Projections, and Policy Simulations. Monograph 22. *Supplement to Forest Science*, 26(3).

Adams, D., M. Kallio and R. Seppälä. 1982. Structural Change in the Forest Sector — The Forest Sector Project. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Andersson, Å.E. and H. Persson. 1982. Modelling International Trade Flows and Specialization. WP 1982:1. Umeå: University of Umeå, Swedish College of Forestry.

Considine, T.J., T.D. Mount and T.J. Tyrrell. 1982. Clarifying the Use of Linear Logit Models: An Extension to Input Demand Analysis. Ithaca, New York: Cornell University.

Cohen, K.J. and R.M. Cyert. 1965. *Theory of the Firm: Resource Allocation in a Marke Economy*. Englewood Cliffs, New Jersey: Prenitce-Hall.

Douglas, e.J. 1979. *Managerial Economics: Theory, Practice, and Problems.* Englewood Cliffs, New Jersey: Prentice-Hall.

FAO. Yearbook of forest products. Rome: Food and Agriculture Organization of the United Nations.

Gold, B. 1971. *Explorations in managerial Economics: Productivity, Costs, Technology and Growth.* New York: Basic Books.

Grossmann, W.-D. 1983. A Prototype Model of the Forest Sectors and Their Socioeconomic Environment. WP-83-xxx. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Grossmann, W.-D. and L. Lönnstedt. 1983a. Dynamics of the Forest Sector: Problems and Policies. WP-83-xxx. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Grossmann, W.-D. and L. Lönnstedt. 1983b. Policy Instrument For National Forest Sector Analysis. WP-83-xxx. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Layard, P.R.G. and A.A. Walters. 1978. *Microeconomic Theory*. New York: McGraw-Hill.

Kalgraf, K. and L. Lönnstedt. 1981. The Dynamics of Wood Utilization for Construction Paper and Energy. Report 35. Umeå: Swedish University of Agricultural Sciences, Department of Forest Economics.

Kallio, M., A. Propoi and R. Seppälä. 1982. A Model for the Forest Sector — Revised Version. (Internal Draft). Laxenburg, Austria: International Institute for Applied Systems Analysis.

Kuuluvainen, V.J. and H. Seppälä. 1982. Ein Planungsmodell für den Waldsektor in Finnland. *Forschungs-Ergenbisse der Finnischen Forstlichen forschungsanstalt*, Sonderdruck aus Allgemeine Forst Zeitschrift 1982.

Lönnstedt, L. 1983. The Forest Sector Prototype Model — The Simplified Model Structure. WP-83-68. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Lönnstedt, L. and J. Randers. eds. 1979. *Wood Resource Dynamics in the Scandinavian Forestry Sector*. Uppsala: The Swedish University of Agricultural Sciences. College of Forestry.

Nagy, A. 1983. The Treatment of International Trade in Global Models. WP-83-25. Laxenburg, Austria: International Institute for Applied Systems Analysis.

SIND. 1980. *Vinster och sysselsättning i svensk industri — En strukturanalys av Sveriges industri 1969-77* (Profit and Employment in the Swedish Industry. A structural Analysis of the Swedish Industry 1969-77) (in Swedish). Stockholm: LiberFörlag.

SIND. 1983. *Lönsamhetsstruktur och investeringsmönster. En dynamisk analys av den svenska industrin på arbetsställenivå*. (Profitability Structure and Investment Pattern. A Dynamic Analysis of the Swedish Industry Based on Statistics from Working Places) (in Swedish). Stockholm: LiberFörlag.

United Nations. UN Statistical Yearbook. New York: United Nations.

United Nations. Yearbook of National Accounts Statistics. Volume I and

II. New York: United Nations.

Wibe, S. 1983. Technological Forecasting: A Short Introduction to Models and Methods with Empirical Illustration from the Forest Sector. WP-83-70. Laxenburg, Austria: International Institute for Applied Systems Analysis.