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Systems Analysis for the Forest Sector

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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, supplies, 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 supplies of roundwood and alternative fiber sources, technology development for forestry and industry, pollution regulations, cost competitiveness, tariffs and nontariff trade barriers, etc. The aim of the Project is to analyze the consequences of future expectations and assumptions concerning such issues.

This article serves as an introduction and summary to a forthcoming volume representing the state-of-the-art of systems analysis in the forest sector. This volume is entitled *Systems Analysis in Forestry and Forest Industries* and it is edited by Å. Andersson, M. Kallio, A. Morgan, and R. Seppälä. It contains articles written by scientists from countries, from both East and West. The topics cover economic as well as noneconomic issues of forests and forest industries at the micro and macro scale, including international aspects of the forest sector.

Markku Kallio
Project Leader
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ABSTRACT

This article is an overview of systems analysis in forestry and forest industries. The issues covered range from forest management and forest industrial strategy to international trade in forest products and structural change in the forest sector worldwide. The methodologies discussed include mathematical models of economies, statistics, and operations research.

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SYSTEMS ANALYSIS FOR THE FOREST SECTOR

by

Å.E. Andersson, M. Kallio, and R. Seppälä

1. INTRODUCTION

Applied systems analysis is often oriented toward improving *long-term* policy making. This implies an emphasis on strategic rather than tactical or operational issues. Frequently the work involves generating policies for major changes concerning production and marketing, and the use of capital, labor, and raw materials. This means that the analyst must ensure close cooperation with policy makers and planners – whether they are in industrial firms or in regional or national government.

Such long-term policy analysis of necessity involves some "well-behaved" uncertainties, as well as others that are less conveniently structured. Problems of predicting the available labor force, and the availability of raw materials and energy are notorious in this respect.

The uncertainties are even greater with respect to the prediction of future demand structures. It is hard to make reasonable, quantitative predictions about the technologies and the politics that will predominate over a planning period of two to three decades. It is often necessary for this reason to use scenarios, sensitivity analysis, and other similar approaches to provide insight into probable consequences of the fundamental uncertainties involved in long-term policy making.

Modeling plays an important role in applied systems analysis, so much so that the two are sometimes assumed to be identical. Most systems-analytical studies are based on one or more explicit models. Often, however, models are used throughout the process, but their use is never made explicit to the final user.

When a policy decision is being made, it would be extremely helpful for the decision maker to know what would be the consequences of his choice. Models used for predicting these consequences are often called systems-analytical models. Examples of basic modeling techniques are optimization, simulation, gaming, and game-theoretical models. A given model may employ more than one of these techniques.

The analysis often relates socioeconomic, ecological, and technological systems to each other in an essentially dynamic and regional modeling effort. This implies that frequently a large number of variables have to be interconnected. It is up to the analyst to make a sensible trade-off between realism, simplicity, and possibilities of estimation.

In tactical and operational management analyses using models, the aim is often to generate quantitative recommendations or forecasts. For applied systems analysis oriented toward long-term policy problems, a more moderate goal would be to formulate qualitative policy recommendations or *policy options* as rules of thumb. This formulation involves a certain amount of judgemental information concerning possible substantial changes in the environment of the system modeled.

For very long-term perspectives even this may be too ambitious. In these cases applied systems analysis can only be used to create a better understanding of the long-term policy problems and their interdependence. To use models for such pedagogical purposes, it is very often necessary to generate projections for the future. In order to trace out the consequences of possible assumptions concerning uncertainties, this type of projection is defined as a series of scenarios.

The forest sector comprises two main components: forestry and the forest industry. The forest sector concept integrates all aspects connected with forests and their exploitation, i.e. activities from timber growth to the use of end products. Ecological, environmental, and socioeconomic factors are also included in this definition.

The forest sector has a number of specific features that influence its planning and policy making:

- Although forests are a renewable natural resource, the production time, i.e. the growth period of trees from seeds to logs, is usually very long, in temperate areas close to a hundred years. As a result of the long rotation time, structural changes in forests cannot take place very quickly. In addition, the soil and climatic conditions often restrict the options for timber growing dramatically.

- The growing stock of trees is at the same time both a product and a production machinery in which annual growth accumulates. This gives flexibility in choosing the exact time for the realization of production.

- Wood is one of the most versatile raw materials. Its use for fuel, for housing and other construction, for furniture, for printing, packaging and household paper, for rayon and cellulose derivatives, and as a chemical feedstock gives the forest sector a very diverse potential within the economy.

- The forest industry is a processing industry, the bulk of which is very capital intensive. The normal life-span of machinery is several decades. (Some paper machines built before the first world war are still operating.) This is one reason why the forest industry is rather conservative and not very flexible.

- Production technology in the forest industry is to a large extent based on old and well-known principles. Therefore, the technology is international, and productivity is tightly connected to the age and size of the production plant.

- The life cycle of different forest products is long. Innovations have usually only meant improvements in existing products, and completely innovative goods have appeared on the market very rarely. One of the implications has been that price has become a pronounced factor in market competition. Therefore, world-wide profitability has become relatively low, and the traditional forest industry is often characterized as a mature industry.

- Consumption of forest products results almost entirely from input needs in other areas, such as the construction and information sectors.

In recent years there has been a marked pronounced interest in the introduction of systems-analytical approaches for studying the problems of the forest sector. The International Institute for Applied Systems Analysis (IIASA) has, for instance, launched a large-scale effort in this direction. In this project, scientists from more than twenty countries have been engaged in the development of systems-analytical tools to study development policies for the forest sector.

Although applied systems analysis is oriented toward interdependences between all levels of decision making, the combination of a large number of interrelated variables leads to a practical need for decomposition: different parts of the analysis are separated from each other. Ideally such a decomposition should be made so that interdependences between components are few but strong.

The following decomposition of the forest sector outlines the organization of the different articles in this volume:*

- Global analysis

Throughout the article, * refers to papers included in ***Systems Analysis for Forestry and Forest Industries***, a volume edited by Å. Andersson, M. Kallio, A. Morgan, and R. Seppälä (forthcoming).

- National macroeconomic analysis
- Forest sector analysis
- Forestry management
- Nonindustrial use of forests
- Ecosystem dynamics

We shall discuss each topic in the following sections.

2. A GLOBAL PERSPECTIVE

2.1. International Issues

As the demand for forest products increases, world supply is constrained by the availability of wood raw materials, higher production and transport costs, environmental concerns, and competition between industry and agriculture for land. For example, according to recent estimates of annual wood removals for the period 1970-2000, the Nordic countries, the traditional suppliers of Western European markets, have reached their wood production limit and cannot increase their average production rate. Although there is some growth potential in the forest industries in other Western European countries, scattered ownership patterns and environmental issues limit this potential. Increasingly, Western European forest industries are becoming dependent on imports. To remain competitive, they are concentrating on end products that are easily transported and that do not have cost structures dominated by wood costs. In contrast, parts of North America still have forest resources with potential for the future, as well as a developed industrial infrastructure that would allow industries in this region to become major suppliers of wood products on the world market.

Although most of the forest industry capacity is in the industrialized countries, more than half of the estimated forest land area of the world is located in the developing countries. Besides being raw material for forest product industries, these forests play an important role in providing fuel and land for agriculture. However, temporary relief from food shortage has frequently occurred at the expense of the biological potential of the forests. Forest land once stripped cannot support agriculture for long due to erosion or low soil fertility. The devastation of forests is one of the most serious problems in developing countries. Each minute, some 20 hectare of tropical forest vanish and the relative pace is increasing.

The global forest sector system is an assembly of interacting national systems. The interaction takes place mainly via international trade. At present, such trade in forest products is small relative to total world production -- about 85% of woodpulp, paper and paperboard is consumed in the country where it is produced. Moreover, trade flows in quite circumscribed paths and so is of unequal significance to different countries and regions. However, the foreseeable changes, especially in the availability of wood raw material and the cost structures of products, may cause drastic changes in the patterns of trade, whose total is growing rapidly. The following factors have a fundamental impact on the development of world trade:

- Regional demand
- Regional forest resources
- Relative production costs
- Transportation costs
- Trade policies
- Exchange-rate policies

We shall now discuss each of these factors in detail.

Demand for Forest Products

Future demand for forest products is characterized by changing response patterns in different countries and areas. Over the long term, the impacts of a number of technological changes need to be evaluated. Examples such as advances in electronic information technologies, super absorbent materials, and packaging substitutes will affect the demand for forest products. This will be noticeable earlier and more strongly in some countries than in others. Also the impacts of the changing energy scene on both forest products and on competitive products need consideration.

The large variations between different countries cause considerable prediction problems. The consumption of paper has, for instance, been more than twice as large in the USA than in Switzerland, over the same given time period when the two countries had approximately the same standard of living. It is thus evident that simple econometric analysis of price and income elasticities is not sufficient to permit us to understand and predict the level of demand. It has been argued by industrialists that the use of packaging paper, for instance, is related to the whole structure of production and consumption of commodities, and to the packaging requirements related to spatially dispersed producers and consumers. Modeling long-term demand and consumption development must therefore take into account not only income and price development but also developments in the location patterns of producers and consumers as well as life styles associated with in different parts of the world.

Forest Resources

Problems of future resources can be approached from several different viewpoints. First, the long-term resource potential may be studied. A steady-state analysis of forests demonstrating the ultimate potential could be a starting point (see for example, Kallio and Soismaa*). The advantage of this approach is that it avoids the mental traps of restricting the analysis to minor extensions of current practices.

Second, supply potentials under alternative social and agricultural land-use policies can be examined in conjunction with varying economic incentives for timber production. Provisions for fuel and agricultural uses of wood, taking into consideration the problems of erosion, may also be advisable.

Production and Transportation Costs

Another aspect of the supply of forest products is the restructuring process that forest industries are facing in many countries. A primary issue is the *comparative advantage* of the industry in the country concerned, i.e. how the relative abundance of wood raw material and the cost of inputs affect capital investments in the industry. Also, hypotheses from *product cycle theory* must be included in the analysis.

Key cost factors in the forest industry are wood, energy, labor, transportation, and capital costs. In the Nordic countries wages and capital costs are the most important items and their combined share is about half of the export price to Western Europe. On average, stumpage paid to forest owners, energy costs and transport costs each account for 10-15% of the export price.

In the long term, there should be no significant differences in capital, energy, and chemical costs between countries. In constrast, wages can vary considerably, but often differences in productivity bring the costs per product unit to the same level. The major differences in the production costs of the forest industry are thus found in wood and transportation costs.

Table 1 shows the drastic international disparity in pulpwood prices in 1978. It can be argued that the data, indicate a disequilibrium in world trade in wood and wood products, rather than price differentials consistent with transportation and energy price differences.

Equilibrium in the world market would exist if the price difference between markets were, at most, the marginal cost of transportation for each commodity. The cost of transporting a Finnish forest product to Western Europe constitutes between 10 and 25 percent of the product's sales price. In deliveries to Western Europe, Sweden has a transport cost advantage of 1-4 percent of the product's price compared to Finland, which itself has an advantage of 5-10 percent over US and Canadian suppliers.

Table 1. Typical wood cost at mill by region in 1978 (US$/m^3).

	Southern Sweden	British Columbia (coast)	British Columbia (interior)	Southern USA	Brazil
Sawlogs (pine)	51	27	14		
Pulpwood (pine)	32			19	9
Pulpwood (hardwood)	27			17	8
Pulpwood (chips)		15	13		

Source: Pöyry and Ryti (1979)

A general framework for analyzing the comparative advantage of forest industries is discussed by Kirjasniemi*. The economic comparative advantage of forest plantations in a number of tropical regions and implications for the traditional forest products supply regions are considered by Sedjo*.

Artificial Trade Barriers

Distance can be considered a natural barrier to trade. Tariffs, quota restrictions, subsidies, and trade agreements, on the other hand, are artificial resistance factors. Subsidies in particular have been used heavily in some major forest industry countries since the mid-1970s.

One factor of considerable importance for the 1980s and 90s is the growing tendency to return to protectionist or even mercantilist trade policies. This phenomenon has been observed with increasing frequency since the energy crises, and it may have serious impacts on a number of countries such as Canada, Finland, and Sweden, which are strongly oriented toward the export of forest products.

Noncompetitiveness is not the only reason for the use of subsidies. In some cases subsidies are used to create industries in certain regions, especially in those that are less developed. They have also been used in efforts to influence the production structure of the forest sector.

Exchange Rate Policies

The fluctuations in the relative value of the US dollar have caused disruptions of world trade patterns in forest products. During the last fifteen years, currency relations between some countries exporting forest products have developed as shown in Table 2. We observe that the values of the Swedish and rmall Finnish currencies were relatively high in the mid-seventies. Consequently, problems emerged for these countries in both their international competitive position and their internal profitability. Within the last five years, however, the situation has reversed completely. In 1982-83 the position of these currencies changed markedly in relation to the US and Canadian dollars. For this reason, the Nordic forest industry (especially in Sweden) witnessed a remarkable recapture of its international competitive power, with booming profits and greatly improved possibilities for future expansion.

For industies that strongly depend on international markets, uncertainty about the future values of currencies is a major concern. Such industries could benefit substantially from embarking upon portfolio-

Table 2. Currency exchange rates 1968-1983 (US$/100 units of national currency).

	1968	1972	1975	1978	1979	1980	1981	1982	1983
Canada	93	100	98	88	85	86	83	81	81
Finland	24	24	27	24	26	27	23	21	19
Sweden	19	21	24	22	23	24	20	16	13
Austria	3.8	4.3	5.7	6.9	7.5	7.7	6.3	5.9	5.9
Norway	14	15	19	19	20	20	17	15	14
Brazil	31.6	16.8	12.2	5.5	3.7	1.9	1.1	.6	.3
Indonesia	36	24	24	23	16	16	16	.15	14

Source: International Financial Statistics.

allocation strategies in terms of investments, marketing, and currency holdings.

2.2. Analysis of the Global Forest Sector

According to Ohlin (1933) (see also Heckscher, 1949), the theory of interregional and international trade is nothing other than a theory of interregional and international location of supplies. This follows from the basic assumption that the pattern of location and the pattern of trade are simultaneously determined. According to this view, countries tend to specialize in the production of commodities that contain a relatively large proportion of fairly immobile resources that are relatively abundant in the country concerned.

This implies that, although certain resources are not themselves directly mobile, the export of commodities containing a large amount of such immobile resources would be equivalent to a migration of the resources. From this follows the Heckscher-Ohlin factor-price equalization theorem: The indirect migration of factors would, in the long run, tend to even out the factor prices of different regions. Any absolute factor-price equalization is of course impossible as long as there are transportation and communication costs and other constraints on mobility.

It is evident that free trade is more beneficial to the world economy than an autarkic system. In an autarkic system, welfare in a given region is determined by the resources in that region. Any erasing of this constraint will improve the possibility of achieving a higher level of welfare. Free trade corresponds to a summation of regional resource constraints, and thereby to a relaxation of constraints for the individual regions.

The only constraints that cannot be removed are those associated with the immobility of factors, commodities, and information. The analysis must thus concentrate on the initial distribution of such factors (including resources and technological know-how) and on the communication and transportation systems.

Based on the static theory of comparative advantage, various propositions have been formulated that are relevant for an understanding of the future interregional division of labor in the world (see e.g., Ethier, 1983). The first of these propositions is called the Rybczynski theorem. It states:

> *At constant factor prices, an increase in the endowment of a factor used in at least two sectors, which leaves that factor fully employed, produces a more than proportional rise in the output of some good and a fall in the output of some other good.*

As an application, consider the European and North American situation. Assume that wood resources are constant (over time) for Europe but growing in North America, and that the capital market in North America is tight (allowing no expansion of capacity in this illustration) whereas production capacity in Europe is growing. Then, applying the Rybczynski theorem twice, chemical wood processing in North America is shifting over time toward wood-intensive commodities like pulp, and in Europe toward capital-intensive (and wood-extensive) products like paper. This is in fact the conclusion formulated by Ryti*, a conclusion substantiated by the Rybczynski theorem.

Associated with the Rybczynski theorem, there is the Stolper-Samuelson theorem:

> *An increase in the price of an initially produced good using an assortment of at least two factors necessarily causes some factor price to rise in even greater proportion and some other factor price to fall.*

In a two-factor/two-commodity world, this theorem might be interpreted as follows. Consider an economy producing paper and pulp, and using machinery and land as factor inputs. Let k_1 and l_1, respectively, be the quantities of machinery and land necessary per unit output of paper, and k_2 and l_2 similar coefficients for pulp. We denote the price of paper by p_1, the price of pulp by p_2, the rent of machinery by q, and land rent by w. If sales prices are entirely imputed to factors of production, we have

$$k_1 q + l_1 \omega = p_1$$
$$k_2 q + l_2 \omega = p_2$$

When the commodity prices p_1 or p_2 change, the factor prices q and w must also change. If paper is more machinery intensive than pulp, i.e. if $k_1/l_1 > k_2/l_2$, then the rise in the price of paper will cause a relative rise in the rent of machines that is greater than the relative price increase of paper, and it will also cause a fall in the land rent. For the same reason, a rise in the price of pulp, which uses relatively more land, will cause a relative rise in land rent that is greater than the relative price rise, and a fall in the rent of machines.

These ideas formulated by Ohlin, Rybcyznski, Samuelson, and Stolper can be extremely useful in understanding the simultaneous determination of location of supplies, demands, and trade. The paper by Buongiorno* is an example in this tradition of interregional location and trade analysis, applied to a study of the US pulp and paper market.

For dynamic analysis of these issues, other procedures have been proposed. One prominent concept is the *product cycle theory* (Vernon, 1966). According to this theory, every product tends to follow a *location cycle*. Each product cycle starts in one of the developed economies where research and development leads to the introduction of the product (or product quality). In the primary stage, profitability is high and thus other countries with large research and development capacity will quickly imitate the country that originally introduced the new product. In this stage, the knowledge about the new commodity is diffused among the most developed countries, which become the major world suppliers. Thereafter, the product technology becomes more widely known and ordinary comparative advantage determines the interregional pattern of production according to the availabilities of production factors and constraints on trade. Due to the maturing of the technology the final phase is then reached, during which a collapse of the industry in the original countries of specialization may occur.

The essential difference between the theory of comparative advantage and the product cycle theory is the emphasis placed upon technological change as a driving force. In the traditional theory of comparative advantage, the technology is assumed to be given and in some versions of the theory even known to every participant in international exchange. By contrast, the theory of product cycles regards the research and development process as the essential driving force in the changing pattern of technological knowledge and in the international pattern of supply location.

Irrespective of what determines supplies in the different regions, there are a number of ways of determining trade flows in a model. Two basic approaches are as follows:

- Simultaneous determination of location of supplies, regional demands, and trade between the different regions, e.g., Leontief et al. (1977);
- Stepwise analysis in which supplies and demands are determined for each region separately, after which a procedure of linking is used to predict the trade flows, e.g., the LINK project (Klein, 1976).

Both procedures have their own advantages and disadvantages in terms of analytical consistency and information needs. The simultaneous approach implies a gain in consistency but quite often a loss in the quality of the information on resources and technological conditions for each region. A linking system means that the heavy burden of regional information gathering is decentralized while the coordinating effort can be focused on balancing supplies and demands through trade flows. Furthermore, this procedure puts a greater responsibility for modeling on each of the participating regions.

If a linking procedure is chosen, there still remains the choice of a mechanism for determining the trade flows. When choosing such a mechanism, one is forced to ask whether the system actually behaves rationally (evolving according to some welfare criteria and possibly even in an almost deterministic way) or whether it behaves more or less erratically. If the first assumption is valid, there remains the problem of choosing a *performance criterion.* Among the criteria suggested, the following are prominent:

- Maximize economic surplus (equivalent to generating a constrained competitive equilibrium).
- Maximize the sum of profits (equivalent to a monopolistic equilibrium, with prices set by firms).
- Minimize total cost subject to quantitative constraints (corresponding to a specific oligopolistic equilibrium solution).
- Minimize transport costs (a special case of the preceding criterion).

If rational behavior cannot be assumed or if our knowledge of the behavioral relations is of limited quality, a suitable approach is to determine a *stochastic outcome*. This often amounts to maximizing the likelihood of the outcome subject to the economic and political constraints that can be formulated *a priori*.

3. NATIONAL FOREST SECTOR ANALYSIS

3.1. Macro- and Microeconomic Issues

Supply of Capital

The investment of resources in the forest industries is an issue of primary importance in many of the forest product supply countries. The allocation of capital between the paper and pulp industry and other sectors of the economy is of great concern in countries like Canada, Sweden, and Finland. Particularly in the United States, Canada, and Sweden, there has been a long-term pattern of low savings and investment, as compared to countries like Japan, Finland, and Norway. The general lack of investment resources is especially problematic for the paper and pulp industry, which is extremely capital intensive. The capital: output ratio for the paper and pulp industry is normally larger than 6, which is the same order of magnitude as the ratios for the basic metal industries. Economies of scale in integrated paper and pulp plants only deepen the problem.

Regional Employment

The supply of and demand for labor for the forest sector has in some countries become a question of a trade-off between regional employment goals and the goals of industrial growth and profitability. Therefore, the allocation of labor between different economic sectors cannot always be analyzed at the national level, but must sometimes be performed at the regional level.

Labor demand is often unnecessarily constrained by the wage costs associated with central negotiation schemes for the labor market. In such cases, it can even be nationally efficient to subsidize employment in the forestry regions. With a general employment subsidy, the forestry firms normally located in areas of high unemployment also have the option of hiring otherwise unemployed labor at lower wage costs. Such schemes have been successfully developed for the Scandinavian countries and are now in use.

Microeconomic Issues

The most important decisions affecting the structure of an industry are decisions on investment. Four major interconnected questions must be answered: ***What***, in terms of products? *How*, in terms of production technology and capacity? *For whom*, in terms of markets? ***Where***, in terms of location of production sites?

The main factors affecting product choice in investment in the forest industry are:

- future demand for the products.
- market situation : competition, trade barriers.
- wood availability and price.
- availability and price of other production inputs: energy, chemicals, capital, human resources.

- production technology available.

If neither the markets nor the technology were to pose unavoidable barriers and if the production inputs were available in abundance and at a fixed price, the choice between different products could simply be based on a profitability criterion, i.e. return on investment. But when the procurement of wood is, in fact, a bottleneck and the price of wood is determined on roundwood markets, ordinary profitability criteria are no longer so useful. Instead, the profit maximization is subject to resource and other constraints.

The manufacturing cost per product unit usually decreases with increasing mill size. However, with growing mill size the wood transportation costs increase. This, together with the finite amount of available capital, imposes a limit on how large a mill should be. The optimal mill size is likely to grow with technological development. In most tropical regions with fast growing trees, the lack of infrastructure and skilled labor reduces the advantages of economies of scale. In addition, the lack of capital may prevent the building of big mills, even though the raw material base would in principle provide good opportunities. In general, economies of scale in a sawmill are much more limited than in a pulp or paper mill.

In addition to the size of the mill, there are other mill-related factors that affect the profitability of production. These are the extents of vertical integration (i.e. using the product of one line as a raw material for another line in the same mill) and horizontal integration (i.e. grouping of products into a multiproduct complex that uses different species and assortments of wood and manufactures several end products). The competitiveness of primary production can to some extent be improved by vertical integration. Most standard products of the Nordic paper industry are currently made in integrated mills.

The aim of horizontal integration is to utilize wood species and timber assortments in the same proportions as they occur in the forest. The manufacturing costs, capital charges, and savings in wood harvest costs can be about one-fifth less in a multiproduct complex than for separate mills making the same products.

The forest sector and especially the wood industries have traditionally paid little attention to R & D. In most cases, the wood industries devote less than 1/20th of the share of value-added that gives to R & D investments in other manufacturing industries. This has serious implications for the future of wood as an input in mechanical and chemical processing. Other feedstocks, especially oil and non-ferrons alloys, are the subject of much more intensive research and development which, in the long run, will tend to influence the competitiveness of those feedstocks in relation to wood.

3.2 Macroeconomic Modeling

The problem of analyzing a set of industries like the forest industries is essentially a question of handling ***interdependences*** of a technological and economic nature. The standard method is ***input-output analysis***, where each sector is characterized by a technological input-output coefficient a_{ij} indicating the amount of commodity i that is required to produce one unit of commodity j. The set of such input-output coefficients can be assembled into an input-output matrix

$A = \{a_{ij}\} = \{x_{ij} / x_j\}$, where x_j is the gross production of commodity j and x_{ij} is the required input of commodity i. Forming the simplest possible static balance requirement for the economy we get

$$x = Ax + f$$

where $x = (x_i)$ and $f = (f_i)$ is the final demand (defined to be exogenously determined consumer, government, investment, and net export demand). Solving for the equilibrium structure x^* of production essentially amounts to calculating

$$x^* = (I-A)^{-1}f$$

The prices are determined in this type of national model by the requirement that the price p_i of each commodity i $(i = 1,2,...,n)$ covers the costs of all inputs:

$$p = pA + \omega$$

where $p = (p_i)$ and $\omega = (\omega_l \; a_{li})$ is a vector indicating the cost of labor (and possibly other primary inputs) for each product, with a_{li} being the labor: output coefficient in sector i and ω_l being the wage rate.

As a practical example, assume that the wage rate increases in the sawmill sector. This corresponds to an increase of, say, $\Delta \omega_i$ in the component of ω corresponding to sawmill operations. The resuting change in the price vector is then given by

$$\Delta p = (0,...,\Delta\omega_i,...,0)(I-A)^{-1}$$

The demand for primary inputs (which may not refer to labor alone) can be calculated by premultiplying the production vector x^* by the vector $a_l = (a_{li})$ of primary inputs. In the case of labor, $L^* = a_l(I-A)^{-1}f$

gives the equilibrium employment. If we assume that the final demand is increased by $\Delta f = (0,\ldots,\Delta f_i,\ldots,0)^T$ (say, an increase in the demand for newsprint), the increase in employment is

$$\Delta L^* = a_l (I-A)^{-1} \Delta f$$

Increasing newsprint demand implies an increased demand for pulp, which in its turn implies an increased demand for chemicals. The increased demand for chemicals implies a further increase in the demand for oil, etc., in a diminising series that finally involves the whole economy. Thus the influence of any change in final demand for a forest product – in terms of consumption, government demand, net exports, etc. -- spreads both within the forest sector and onto other sectors, as well as returning eventually to the forest sector itself.

The influence of investment can be analyzed within an extended input-output framework. In this case investments in new machinery, building, etc., are distinguished in the demand f. Let b_{ij} be an investment-output coefficient indicating the input of commodity i needed to achieve unit growth in the production capacity of sector j, and let t denote time. Then the dynamic input-output model is given by the balance requirement

$$x(t) = Ax(t) + B\,\dot{x}(t) + f(t) \ ,$$

where $B = (b_{ij})$ and $\dot{x}(t)$ is the time derivative of production, i.e, the rate of increase in capacity. It can be shown that any decrease in an input-output or investment coefficient will increase the general rate of growth and lead to a structural change in the economy.

This differential-equation system cannot be solved directly because of numerical stability problems (Brody, 1969). Various transformation procedures have, however, been suggested to overcome such problems, and models solved in this way are currently being used in some countries to forecast and plan long-term sectoral development.

It is possible to show that under these assumptions there exists a maximum growth rate with a corresponding balanced composition of industries. Such an equilibrium growth rate corresponds to the ***minimal equilibrium rate of interest*** associated with a balanced set of relative prices of all commodities.

One disadvantage of the class of models described above is the assumed inflexibility of technologies. A number of procedures have been proposed to overcome this weakness. One method is due to von Neumann (1937). He proposed a formulation in which

$Q\,x \geq A\,x + f$	Quantitative equilibrium condition
$p\,Q \leq p\,A + \omega$	Price equilibrium condition
$p\,f = \omega\,x$	General equilibrium conditions

where A is an input matrix, Q is an output matrix, f is the final demand and ω is the cost vector of primary inputs. The approach involves two basic assumptions:

- Each activity can produce ***many*** commodities, including capital goods (joint production).
- Each commodity can be produced by a number of activities (substitution).

These assumptions imply that the matrices Q and A may be rectangular. Otherwise the method follows the assumptions of input-output theory, of which it thus is a generalization. This model is closely related to the theory of linear programming, although it dates back to the 1930s. In fact, it is equivalent to choosing technologies and production levels to satisfy final demand at minimum costs in terms of primary inputs.

A model based on input-output theory but allowing for partial substitution of inputs has been developed by Johansen (1972 and 1974). A variant of this model is described by Sohlberg*. In this approach, labor, capital, and energy are substitutable inputs, while all other inputs are regulated by fixed input-output coefficients.

Mathematical programming methods for handling the interdependences between a sector like the forest sector and the rest of the economy have been proposed by Dantzig (1963). The idea here is to use an optimization model of the forest sector, in which an efficient choice of technologies is calculated assuming various supply functions for resources and demand functions for products. The prices are then determined together with the set of input-output coefficients optimally selected by the model. This approach has been adopted by Kallio, Propoi, and Seppälä* for studying the Finnish forest sector.

3.3 An Approach for Analyzing Economic Structural Change

The development of an industry is determined both by external technological and by consumer demand changes influencing corporations and their plants. An approach for analyzing these processes was introduced by Salter (1960) and further refined by Johansen (1972). In this approach, plants are assumed to be flexible regarding substitution at the investment stage only. After investment, each plant is almost rigid in terms of the energy, labor, and other input requirements per unit of output. At this later stage, substitution can only occur at the industry or corporate level by opening up new plants or closing down units constructed earlier. Another feature of this theory is the *asymmetry* of the closing down and investment criteria. The closure of a plant occurs when the product price decreases below the average variable cost. Investment in a new plant occurs when the expected price exceeds the average variable cost and *a proportion of* the fixed cost, properly discounted.

The analytical procedure can be illustrated by the empirical diagram in Figure 1, where the shaded area gives the gross profit of the paper industry in Sweden in 1978. Similar productivity and cost curves are now produced for the Swedish and Norwegian industry sectors on an annual basis. The structure and potential uses of such a data base are discussed by Johansson*.

Against this background a model of economic structural change can be formulated based on the following assumptions:

- Each industry in each region consists a number of production units of given vintages with given output capacities.
- All production techniques are characterized by coefficients that vary across vintages and sectors only.

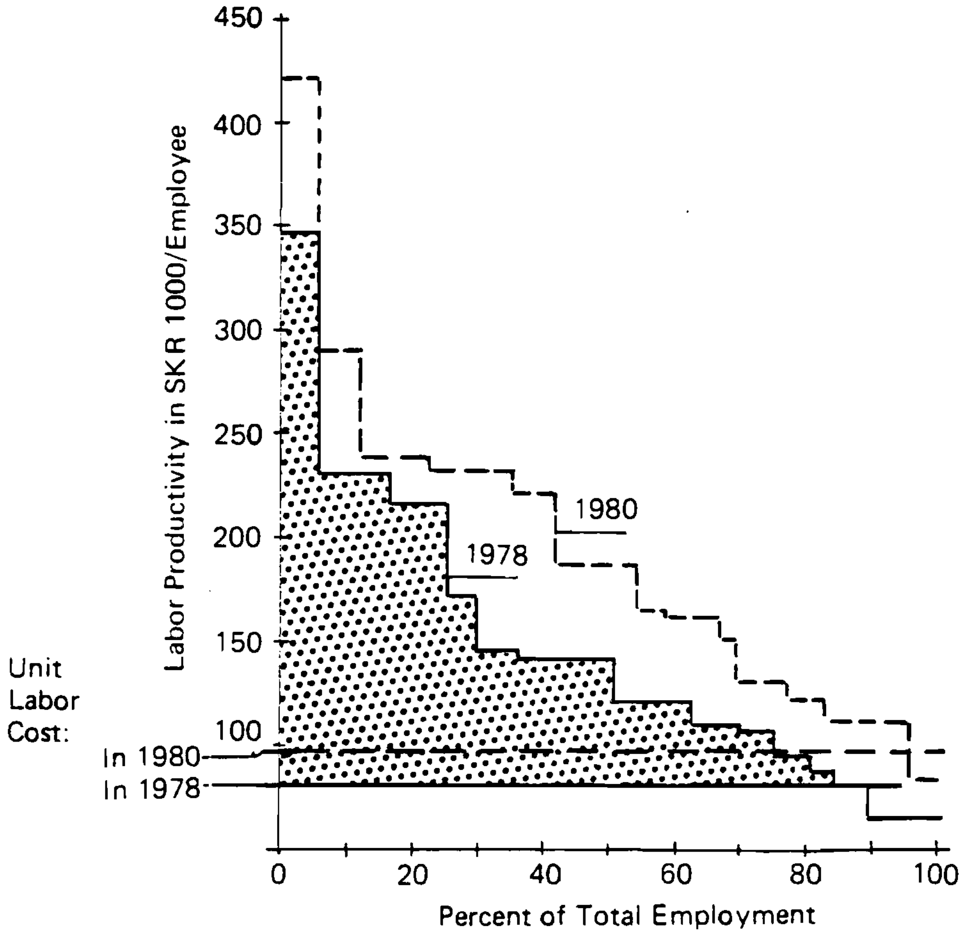

Figure 1. Labor demand of the paper industry in 1978 and 1980 in Sweden.

- Only labor is considered as primary input, though it is feasible to extend the model to cover other inputs such as energy.
- The investment possibility in each industry and region is given by a new vintage with a certain "*best practice technology*".
- Existing capacities are utilized and new capacities created according to an efficiency criterion of maximizing total value added for manufacturing industry as a whole. This is equivalent

to profit maximization under constraints reflecting the costs of production.

Various industrial policy goals can be included either in the objective function or as constraints. The basic formulation employs maximization of total value added. The other policy goals concerning employment and production, by industry and region, are taken into account by means of appropriate constraints. Additional constraints may specify availability of labor by region, availability of capital by industry, and employment in new vintages. The model framework is basically static, but the inclusion of the possibility of investment in new vintages allows some dynamic features to be simulated. The various sectoral and regional economic activities are only related to each other through competition for some resources such as labor and investment.

3.4. Forest Sector Modeling

In the preceding section it was implicitly assumed that a forest sector model exists that is compatible with modeling at higher levels of aggregation. This is not always the case. Forest sector models are often constructed without due consideration for requirements of consistency with macroeconomic models in terms of sectoral disaggregation, time periods to be covered, etc. This is an unfortunate situation in certain respects, but may also have advantages in other aspects: consistency in modeling simplifies cooperation whereas inconsistency can further the free development of new modeling ideas.

Forest sector models may be distinguished in a number of ways: disaggregation of inputs and outputs, treatment of time, treatment of regions, treatment of nonconvexities and nonlinearities of relations (such as economies of scale), and behavioral criteria such as optimization for single or multiple criteria. This section is limited to the consideration of three categories of models of particular significance. These are:

- Dynamic Simulation
- Mathematical Programming
- Spatial Equilibrium Models

Before the different mathematical models are introduced, we briefly discuss forest sector interactions in a static equilibrium situation.

A Qualitative Analysis of the Forest Sector

In order to illustrate the internal interactions between different parts of the forest sector, we will use the diagram in Figure 2 (see e.g., Wohlin, 1970). To simplify the discussion we assume that the forest sector consists of paper as the final product, roundwood as an intermediate product, and forest stands. The components are related to each other around a common point or origin, as shown in Figure 2.

This system remains in equilibrium as long as α is large enough to induce repairs and maintenance of the supply potential. If we assume that the demand function increases and the wood supply price remains constant, then the price of paper increases relative to wood and the incentive to invest also increases. When the resulting new capacity is

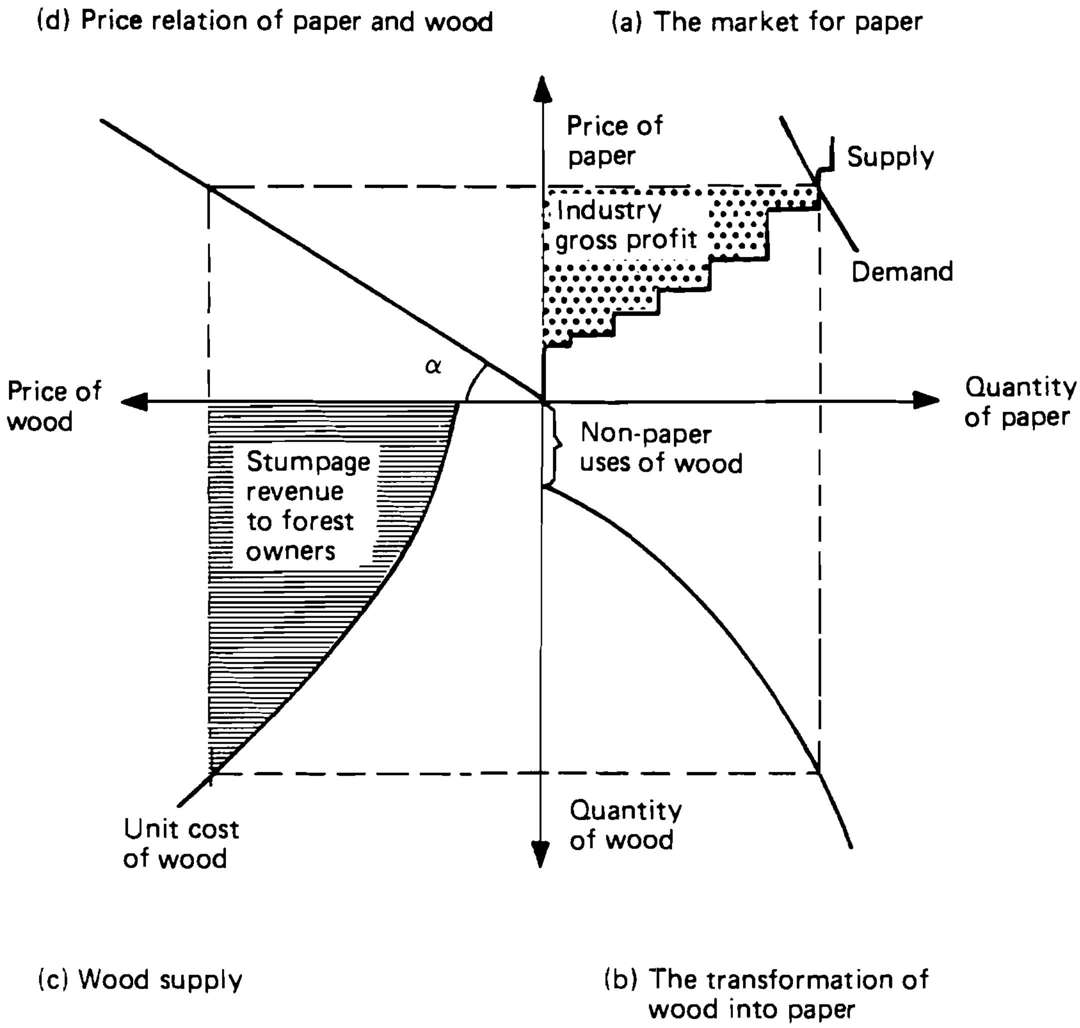

Figure 2. Diagram of interactions within the forest sector.

added, the price of paper relative to the price of wood decreases. This diminishes investment inducements and the system returns to equilibrium. An improved raw material efficiency (increased output per unit input) would lead to a reduced price of wood relative to paper. Consequently, increased inducement to invest restores the *relative* price of paper but at a lower equilibrium level. If the non-paper use of wood increases, *ceteris paribus*, this leads to an increasing price for wood, thus decreasing the *relative* price of paper. This induces capacity withdrawal, which continues until the price relation is again in equilibrium.

As illustrated by these examples, disturbances of the system are self-stabilizing. Models of the forest sector, although dynamic or disaggregated in many forest-product sectors, are normally built along the lines discussed in this section.

Dynamic Simulation

A dynamic simulation model is built on the fundamental assumption that there is a set of dynamically interacting decision bodies (constrained by technologies, resources, and other external factors) that determine a development trajectory. Generally a simulation model is a system of difference equations (for each time period t):

$$x_{t+1} = F(x_t, \cdots, x_{t-T}, u_t, \cdots, u_{t-T}, \varepsilon_t)$$
$$u_{t+1} = G(x_t, \cdots, x_{t-T}, u_t, \cdots, u_{t-T}, \xi_t)$$

where F and G are given functions, x_t is a vector of endogenous variables, u_t is a vector of decision variables (control variables), and ε_t and ξ_t are vectors of stochastic disturbances, for each time period t.

An example of such an approach is given by Lönnstedt*. His approach is rather generally applicable for studying the long-term development of the forest sector at the national level. An application is given for the specific case of Sweden.

It is well known from the theory of difference equations that a system of this type has to be restricted in terms of both functional forms and parameter values in order to obtain a well-behaved solution trajectory. As an example, it was shown many years ago by Slutzky (1937) that errors in the starting position of the system can be propagated through time and thus give rise to cycles, which would otherwise not occur. In many simulation models of the forest sector, formal stability analysis is made possible by certain linearity assumptions or by exclusion of stochastic elements. In such cases the model might take on the form

$$x_{t+1} = A(t)x(t) + B(t)u(t) + \varepsilon_t$$
$$u_{t+1} = C(t)x(t) + H(t)u(t) + \xi_t$$

where $A, B, C,$ and H are given time-dependent matrices, and $x(t) = (x_t, x_{t-1}, x_{t-2}, \cdots)$ and $u(t) = (u_t, u_{t-1}, u_{t-2}, \cdots)$.

Mathematical Programming

Dynamic linear programming (DLP) models of the forest sector employ deterministic versions of the linear system described above as an essential part of the constraint system. In addition to this constraint system, the DLP usually requires constraints on the initial and terminal states. Solutions of the model are obtained by formulating a goal function as follows:

$$\text{maximize} \sum_{t<T} [\omega_t x_t + \eta_t u_t] + \omega_T x_T$$

where ω_t and η_t are given vectors, and T is the terminal time period. By superimposing a maximand, many of the equilibrium and stability problems of simulation models can be solved. Examples of such DLP approaches for forest sector analysis are given by Kallio, Propoi, and Seppälä* for Finland and by Hultkranz* for Sweden.

An essential problem with DLP models for the forest sector is to define a reasonable goal function to represent the objectives of the industry and the multitude of other objectives associated with the use of forests for recreation, as watersheds, etc. For this reason considerable efforts have been made in the field of *multiobjective programming*. Work in this area by Kallio, Lewandowski, and Orchard-Hays (1980) is an extension of the DLP model of the Finnish forest sector of Kallio et al.* See also Rosenthal and Harrison* for an application of multiobjective optimization.

Another application of mathematical programming is reported by Hyman*. His study aims to assess alternative policies concerning fuelwood in the Philippines. The assessment considers economic, social, and environmental aspects of the problem.

Spatial Equilibrium Analysis

Regionalization of forest sector models is often required, because of geographical variation in ecological, institutional, or economic conditions. The primary problems associated with regionalization are a geometric increase in the number of variables and an arithmetic increase in the number of constraints; i.e., a considerable increase in model size.

Naturally, simulation and programming approaches apply to regional analysis as well. However, the spatial equilibrium approach is particularly suited for application to market economies as a means of determining an efficient allocation of production (over regions) to satisfy the demand in various regions (Lefeber, 1958). Such allocations are assumed to be determined on the basis of cost competitiveness, subject to constraints on resources as well as constraints determined by national and regional policies.

The spatial equilibrium approaach has been adopted by Dykstra and Kallio (1984) for studying long-term developments in the global forest sector. For another example of spatial equilibrium analysis, see Adams and Haynes*. Their model has been developed for the US Forest Service for long-term planning purposes. This Timber Assessment Market Model (TAMM) involves regional production and consumption of roundwood and mechanical wood products in the US. Another application of a spatial equilibrium model is given by Buongiorno*. The long-term supply (and price) of timber has been studied by Kallio and Soismaa*, whose approach is also based on the economic equilibrium concept.

4. REGIONAL FORESTRY ANALYSIS

4.1. Timber Supply Issues

In countries with a long tradition of forest industries, some of the most serious internal problems are connected with the availability and cost of wood raw material. The main constraints on the availability of wood are the following:

- The physical and economic limits on wood production. The Nordic countries, for example, are approaching the economic constraints.
- The mixture of tree species in the tropical and subtropical regions.
- Institutional arrangements, in terms of ownership structures, principles of taxation, and regulation of cutting. The Nordic and Central European countries and some parts of the US provide clear examples of this sort of constraint.
- Forests that are exploited for multiple use, such as tourism, outdoor recreation, hunting, and fishing, in addition to being the source of timber for the forest industry. The resulting multiple objectives of forest management normally add to the constraints on the supply of timber. This is a major constraint in many Western European countries and in some regions of the US.
- Defficiencies in transportation capacity and high transport costs from wood supplying to processing regions. The northern parts of the Soviet Union and Canada are examples here.

The article by Lőfgren et al.* studies the effect of alternative taxation rules on the supply of roundwood. Sääksjärvi* reports a successful application of a game-theoretical approach for the fair division of costs between forest industrial that cooperate in wood procurement in Finland. The estimation of forest resources is discussed in a note by Ringo*.

4.2. Forest Management

Classical Theory

The problem of optimal rotation for private forestry is a classic in the forestry science literature. The basic assumptions of the analysis developed by Faustmann (1849), Pressler (1860), and Ohlin (1921) have been summarized by Lõfgren and Johansson (1983):

- The capital market is perfect i.e., allowing for immediate exchange on equal terms for all actors;
- The forest land market is perfect;
- Future lumber prices are known without uncertainty;
- Technical lumber-yield tables are available.

It is further assumed that the growth of timber is determined by a differentiable yield function $f(t)$ where t is the age of the forest stand. The time of harvesting $t = T$ is to be determined so as to maximize the present value of forest land. The present value is the sum of an infinite series of all future revenues:

$$\begin{aligned} V(0,T) &= pf(T)e^{-rT}[1+e^{rT}+(e^{-rT})^2+\cdots] \\ &= (pf(T)e^{-rT})/(1-e^{-rT}) \end{aligned}$$

where p is the timber price reduced by variable production costs (such as labor), r is the interest rate, and T is the rotation period. This optimization criterion is known as the Faustmann formula. The determination of the optimal rotation period requires the maximization of $V(0,T)$ with respect to T. The optimality condition is the following

$$p\frac{df}{dT} = [pf + V]r,$$

or expressed verbally:

> *The forest stand should be harvested when the marginal rate of change of the value of the stand equals the interest on the stand value plus the forest land value.*

A mathematical programming approach for determining the optimal rotation time is discussed by Dykstra*. A simulation approach is used by Lyons et al.* to study optimal rotation for energy wood plantations in Ireland.

An Example of Optimal Control Theory

The question of the optimal management of forest plantations is qualitatively different from the Faustmann problem in at least one fundamental respect: harvesting and planting levels are, in this context, the central decision variables and the rotation period is a secondary concern, determined as a by-product of optimal management. The problem can be formulated in terms of optimal control theory:

$$\text{maximize} \int_0^\infty [p(t,x)ux - c(u,x,s)]e^{-rt}\,dt$$

$$\text{subject to} \quad \frac{dx}{dt} = ax - bx^2 + s - ux$$

where

x = the growing stock volume of the forest, (frequently assumed to be determined by a logistic growth function), with growth parameters a and b,

p = price per unit volume of harvested forest,

u = the rate of harvesting,

s = the rate of seeding,

c = cost of harvesting, maintenance and seeding, and

r = rate of interest.

Assume that $\pi = p - c / ux$ is independent of time and scale, and that only natural seeding takes place. Then the following three propositions concerning the asymptotic behavior of the optimal trajectory can be deduced (Andersson and Lesse, 1984):

- *The shadow value of the plantation (per unit of land) is determined by the rate of interest r.*

- *The optimal, steady-state, standing volume of wood is given by the expression $x = (a-r)/2b$ and the optimal harvesting by $u = (a+r)/2$.*

- *There is a possibility of clear cutting of the whole standing volume if $a \leq r$, i.e. if the geometrical growth term in the biological differential equation is exceeded by the real rate of interest. This can result in permanent extinction if the seeding is natural and the system is depensatory in the vicinity of the origin.*

Note that the optimal steady-state harvest, equal to $x\,u = (a^2 - r^2)/4b$, is less than the maximum sustainable yield, which equals $a^2/4b$. The relative difference compared to maximum yield is $(r/a)^2$. For example, if the parameter a corresponds to 10 percent annual growth and the interest rate r is 5 percent, then the difference is 25%.

The papers by Hellman* and by Schmidt* are based upon optimal control theory as oriented toward plantation management. The paper by Moiseev and Khmelevsky* addresses the complications caused by the dynamics of competition between different age-groups of trees. The results from the qualitative analysis of forest management can be, and have been, used as a starting point for quantitative modeling. In this sort of exercise, the set of stands to be managed are normally modeled in a linear difference equation system of the Markov type. However, control variables associated with planting and harvesting activities are added to the standard Markov model. The development of the system is controlled by maximization of a performance index. An example of such a quantitative procedure based on dynamic linear programming is given by Kallio, Propoi, and Seppälä*. In this model, forest management is treated as a submodel within a general forest sector framework. Other examples of quantitative forest management models are given by Weintraub and Navon*, by Phillips et al.*, and by Fowler and Nautiyal* (see also Dykstra, 1984). Forest hazard management as an application of *decision analysis* is discussed by Barrager and Cohan*.

4.3. Nonindustrial Use of Forests

The forests are, to industry and forestry managers, primarily a source of raw material for industrial processing into paper, building material, furniture, etc. To the general public, forests also have great value as pollution sinks (absorbing nitrogen compounds), as watersheds, for recreation, etc. Forests are consequently a *private* as well as a *public* good. In a system with free access to forests there is consequently a probable need for public intervention in decisions on harvesting and other forest management issues.

In order to account for the public character of forests, it is assumed that the welfare of each individual (or household) depends on the total forest stock, among other factors. Individual welfare is assumed to be aggregated into a social welfare index, Ω. A social optimum can be found by maximization of Ω, subject to a feasibility set reflecting the technological and institutional conditions of production and allocation of in the society. The resulting societal conditions of optimality are generally not consistent with the economic (forestry or forest industrial) conditions of optimality, which neglect the collective, nonindustrial uses of forests. For illustrations and applications of modeling for the simultaneous consideration of industrial and nonindustrial uses of forests, see e.g., Hyman*, Kilkki et al.*, and Navon and Weintraub*.

4.4 Forest Ecosystem Dynamics

Analysis of the forest sector is not sufficient if confined to the purely economic and social aspects of the matter. As has been shown by several authors (Baumol and Oates, 1975; Clark, 1976; Krutilla and Fisher, 1975), the ecological issues have to be considered in any proper systems analysis of the forest sector. A few examples will clarify the need for the inclusion of ecological issues in any forest economic analysis:

- The forest industry is a polluting subsector, primarily influencing the rivers and lakes located near to the plants;
- Forestry is a user of poisonous chemicals as insecticides, herbicides, and fertilizers;
- Plantation management concentrates the numbers of species of trees and ground vegetation at levels that are too low to be ecologically robust;
- Animals that naturally belong to the forest ecosystems are sometimes excluded from their natural habitats by fencing, the use of chemicals, etc.;
- Growing industrial output implies increasing pollution stocks of acid rain, which in the long term is likely to reduce the biomass growth potential. At present, large areas of the forests of Central Europe are threatened by such environmental risks.

Analyses of dynamic interactions between forestry and ecology are reported by, for example, Isaev, Khlebopros, and Nedorezov*. Modeling of ecology-economy-technology interactions is also urgently needed. Holling et al.* have given path-breaking examples of such modeling. By using a simple set of differential equations, the interactions between industry and forest ecology can be studied as an interdependent dynamic system evolving abruptly at times. These studies indicate that even smooth and continuous parameter changes can give rise to large structural changes in the forest ecosystem.

5. CONCLUDING REMARKS

This article has attempted to serve as an introduction to systems analysis in the forest sector and thereby to the volume outlined in the Appendix. It has described is to cover the substantive issues of concern in the forest sector as well as the various methodological approaches used. The issues include forest management (timber production, nonindustrial uses of forests, and the forest ecosystems), forest industries, forest sector issues at the scale of national economies, and issues on the international scale. The methodologies presented include various approaches from economic analysis as well as a variety of techniques of operations research and statistics.

REFERENCES

Andersson, A.E., and P. Lesse (1984) Forest Plantation Management Analysis. Laxenburg, Austria: International Institute for Applied Systems Analysis (forthcoming).

Baumol, W.J., and W.E. Oates (1975) The Theory of Environmental Policy. Externalities, Public Outlays, and the Quality of Life. Prentice Hall.

Brody, A. (1969) Proportions, Prices, and Planning: A Mathematical Statement of the Labour Theory of Value. Amsterdam: Elsevier.

Clark, C.W. (1976) Mathematical Bioeconomics. New York: John Wiley & Sons.

Dantzig, G.B. (1963) Linear Programming and Extensions. Princeton: Princeton University Press.

Dykstra, D. (1984). Mathematical Programming for Natural Resource Management. New York: McGraw Hill.

Dykstra, D., and M. Kallio (1984) A Preliminary Model of Production, Consumption and International Trade in Forest Products. WP-84-14. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Ethier, W. (1983) Modern International Economics. New York: Norton & Co.

Faustmann, M. (1849) Berechnung des Wertes, welchen Waldboden, sowie noch nicht haubare Holzbeständen für die Waldwirtschaft besitzen. Allgemeine Forst- und Jagdzeitung.

Heckscher, E. (1949) The Effect of Foreign Trade on the Distribution of Income, in *Readings in the Theory of International Trade*. H.S. Ellis and L.A. Metzler (eds.). Homewood: Irwin.

Johansen, L. (1972) Production Functions. Amsterdam: North Holland Publishing Company.

Johansen, L. (1974) A Multi-Sectoral Study of Economic Growth. Second enlarged edition. Amsterdam: North Holland Publishing Company.

Kallio, M., A. Lewandowski, and W. Orchard-Hays. (1980) An Implementation of the Reference Point Approach for Multiobjective Optimization. WP-80-35 (Revised). Laxenburg, Austria: International Institute for Applied Systems Analysis.

Klein, L.R. (1976) Five Year Experience of Linking National Economic Models and of Forecasting International Trade. H. Glejser, ed., *Quantitative Studies of International Economic Relations*. Amsterdam: North-Holland Publishing Company.

Krutilla, J.V., and A.C. Fisher. (1975) The Economics of Natural Environment. Baltimore: Johns Hopkins University Press.

Lefeber, L. (1958) Allocation in Space. Amsterdam: North-Holland Publishing Company.

Leontief, W. et al. (1977) The Future of the World Economy. A United Nations study. New York, United Nations: Oxford University Press for United Nations.

Löfgren, K.G., and P.O. Johansson. (1983) Forest Economics and the Economics of Natural Resources. Umeå: Swedish University of Agricultural Sciences.

Ohlin, B. (1921) Till frågan om skogarnas omloppstid (On the Question of the Rotation Period of the Forests) Nationalekonomiska studier tillägnade Knut Wicksell (Studies in Political Economy in Honour of professor Knut Wicksell.) published in Ekonomisk Tidskrift, no 12, 1921.

Ohlin, B. (1933) Interregional and International Trade. Cambridge: Harvard University Press.

Pressler, M.R. (1860) Aus der Holzzuwachslehre, Allgemeine Forst-Jagdzeitung.

Pöyry J., and N. Ryti. (1979) Trender Inom den Skandinaviska Skogsindustrin, Sundsvallsbanken. Sundsvall

Salter, W.E.G. (1960) Productivity and Technical Change. Cambridge Department of Applied Economics Monographs No.6. Cambridge, United Kingdom: Cambridge University Press.

Slutzky, E. (1937) The Summation of Random Causes as the Source of Cyclic Processes. *Econometrica* 5.

Vernon, R., (1966) International Investment and Trade in the Product Cycle. *Quarterly Journal of Economics* 2.

von Neumann, J. (1937) Ueber ein ökonomisches Gleichungssystem und eine Verallgemeinerung des Bronwerschen Fixpunktsatzen. *Ergebnisse eines mathematischen Kolloquiums* 8:73-83.

Wohlin, L. (1970) Skogsindustrins Strukturomvandling och Expansionsmöjlighet. IUI, Stockholm.

APPENDIX: Contents of Systems Analysis in Forestry and Forest Industries, edited by Å. Andersson, M. Kallio, A. Morgan, and R. Seppälä

Richard W. Haynes	Forest Products Markets for Long-Range Projection and Policy Analysis
Birger Solberg	Macro-Economic Model as Basis for Long-Term Forest Sector Analysis in Norway
Lars Lõnnstedt	A Dynamic Simulation Model for the Forest Sector
Börje Johansson	A Structural Change Model for Regional Allocation of Investments
Matti Kirjasniemi	The Use of Economic Value of Wood in Comparing Long-Term Strategies for Forest Industries
Eric L. Hyman	Description of FUELPRO: A Linear Programming Model for Analyzing Economic, Social and Environmental Impacts of Woodfuel Policy Alternatives
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3. Timber Markets, and Forestry Management

Andres Weintraub Daniel Navon	Mathematical Programming in Large Scale Forestry Modeling and Applications
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Stephen M. Barrager David Cohan	Value of Information in Forest Fire Management Decisions
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Karl-Gustav Löfgren Gunnel Bångman Anders Wiberg	The Supply of Roundwood and Taxation
Markku Kallio Margareta Soismaa	Economic Equilibrium for the Finnish Forest Sector
Pekka Kilkki	Long-Term Timber Production Planning via

Juha Lappi Markku Siitonen	Utility Maximisation
Terry Harrison Richard Rosenthal	A Multiobjective Optimization Approach for Scheduling Timber Harvests on Nonindustrial Private Forest Lands
Nina I. Ringo	A Note on the Problem of Forecasting a Forest State with a Number of Fixed Measurements
Dennis P. Dykstra	The Influence of Logging Costs on Optimal Rotation Age for Site I *Pinus Patula* in Tanzania
Gerard J. Lyons J. Michael Vasievich	Economic Analysis of Short-Rotation Forests for Energy in Ireland
William W. Phillips Thomas J. Corcoran Thomas B. Braun	A Data-Base System for Wood Harvest and Transportation Planning
Markku Sääksjärvi	Cost Allocation in Cooperative Wood Procurement — A Game Theoretic Approach
Olavi Hellman	On the Optimal Control of the Growth of a Forest which Consists of Several Species of Trees

4. Forest Ecosystem Dynamics

Daniel Navon Andres Weintraub	Operational Model of Supply for Wildland Enterprises
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