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Forest Products in the United Kingdom Economy

B G Jackson

Cover pictures. Home-grown logs of Douglas fir arriving at a Sussex sawmill, and being stacked in the mill yard. *Below*: Sawn timber stacked to season. *Photos, by Herbert L. Edlin, taken at the Yellowcoat Wood Sawmills of J. Alsford Ltd, Flimwell, Wadhurst, Sussex.*

FORESTRY COMMISSION BULLETIN
No. 51

Forest Products in the United Kingdom Economy

A Linear Programming Model

By
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FOREWORD

This Bulletin is a shortened version of a thesis presented by the author for the degree of Doctor of Philosophy of Oxford University. The study was supported by a grant from the Natural Environment Research Council while Dr Jackson was working at the Department of Forestry, Oxford University.

The study represents the boldest attempt so far made in Britain to create a model of the two activities of wood-producing and primary processing of wood. On the basis of specified assumptions about future costs, interest rates, prices and demands for forest products, the author presents the results of linear programming solutions specifying rates of cut, industrial investment, production and imports which together provide the highest value of net discounted benefit. The analysis extends over seven future periods up to 60 years from the present. The study thus provides a valuable demonstration of a planning technique which deserves careful consideration.

Since the optimum solutions vary with assumptions, tests are made in the final chapter of the effects of varying certain of the assumptions. Opinions will always differ about the reasonableness of specific combinations of assumptions, and in particular the reader may question the forecasts selected for future consumption and prices of individual forest products. Because of this difficulty over assumptions combined with the fact that policy is not necessarily based on the particular objective adopted in this study, the results of the analysis cannot be held to provide a plan, or plans, for action. Without accepting all the many assumptions made, the Forestry Commission commends this work, not least for its valuable review of technological and historical data on wood-processing industry, to a wider audience as a constructive contribution to the discussion of possible strategies for the development of the whole of the forest industry.

FORESTRY COMMISSION
January 1974

SUMMARY

The object of the study is to indicate an optimum strategy for the development of the wood products sector of the UK economy, in terms of maximum discounted net benefit. The model is in the form of a multi-time period linear program. One section of the model covers wood production, from state and private forests taken together. The activities are based on four grouped species, eight age classes, and various management systems. New planting of forests is allowed for in the first three time periods. These activities supply wood to the wood-processing sections of the model. The wood-processing activities allow for the production of thirteen 'final products', such as sawnwood and newsprint, from various sizes and species of wood. The set of activities is repeated for each of the seven time periods, covering a total of 60 years. Processing capacity can be increased at costs representing the capital investment per unit. Importing final products is an alternative source of supply.

The model is required to satisfy minimum levels of demand for the final products, in each time period. Two main sets of demand values are tried, one representing high future consumption, the other low consumption. The demand values used are based on extrapolation of time trends in consumption, and graphs of these are shown. Some estimates of price and income elasticities are also made.

The results, using discount rates of 5 and 10 per cent, suggest that processing of domestic wood should be concentrated on sawnwood, newsprint and particle board. Demand for printing and writing paper, packaging paper, and paperboard should be met mainly from non-integrated production in Britain, but tissue and fluting medium should be imported. New planting of forests did not occur in the solutions to the model.

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AUTHOR'S PREFACE

The research on which this Bulletin is based was carried out at the Forestry Department, Oxford University. The general objectives were to explore the application of economic models to forestry and its associated industries, and to indicate an optimum policy for these sectors of the economy in Britain.

There are many examples of the application of linear programming to forestry problems but usually they have been concerned with management decisions for particular forest estates or wood-processing firms. This study takes the process a stage further, dealing with the wood fibre industry in the United Kingdom economy as a whole. Inevitably this gain in comprehensiveness is accompanied by a reduction in the amount of detail which it is feasible to incorporate.

In the first Chapter there is a description of the aims and assumptions in the study, and a brief résumé of the structure of the model as a linear program. Chapters 2 and 3 deal with the technical coefficients used in the wood-producing and wood-using sections of the model respectively, and Chapter 4 with the estimation of coefficients for the objective function. Chapters 5 and 6 deal with demand forecasts for wood products. These are not central to the model, but some estimates of future demands have to be included, and the figures used are those emerging from some of the forecasts. The final Chapter summarises the results and draws some conclusions on methodology and policy implications.

The model was run on the IBM 360/195 computer at the Rutherford High Energy Laboratory at Chilton, using the MPS/360 program, and also on the LC 1906A computer at the Oxford University Computing Laboratory, using the LP Mark 3 program. Thanks are due to both these laboratories for the computing facilities made available. Unfortunately the need (for administrative reasons) to change computers in mid-course reduced the amount of sensitivity analysis which was possible in the time available. This applies particularly to changes in the level of wood prices over time.

Many people assisted by providing advice and information, and at Oxford I should particularly like to thank Mr J. J. MacGregor, lecturer in economics in the Department, Dr M. A. H. Dempster of Balliol College, and Mr R. Lorrain-Smith, formerly of the economics section in the Department. Members of the staff of the Forestry Commission made many helpful suggestions and provided a great deal of data. Officers of many firms and organisations in the wood-using industry gave their time to discuss with me the features and problems of the industry and I am grateful for their co-operation. They include:

Airscrew-Weyroc Ltd., Ashton Paper Mill Ltd., the Birmingham Waste Co. Ltd., Bowater United Kingdom Paper Co. Ltd., the British Paper and Board Makers Association, British Petroleum Chemicals (United Kingdom) Ltd., Flakeboard Ltd., the Princes Risborough Laboratory of the Building Research Establishment, Department of the Environment (formerly Forest Products Research Laboratory), Kimberly-Clark, Ltd., the National Coal Board, the Paper Industries Research Association, Reed Paper & Board (United Kingdom) Ltd., Thomas Tait & Sons, Ltd., Wiggins Teape, Ltd., and Wolvercote Paper Mill.

Events since this research was completed may suggest that the price assumptions in the model are unrealistic. However, although the relative prices of raw materials have increased recently, it is not certain that this will persist indefinitely, any more than it was certain in 1951. Also, the fact that the price of (say) newsprint has increased does not necessarily imply that more resources should be devoted to its production, since other alternatives may be even more profitable. The same is true of forestry as a form of land use.

B G JACKSON
Bristol
January 1974

ABBREVIATIONS USED

ad	Air dry
BL	Broadleaved species
BL1	Small broadleaved roundwood
BL2	Large broadleaved roundwood
B.off	Broadleaved (sawmill) offcuts
BPBMA	British Paper & Board Makers Association
BSD	Broadleaved sawdust
CF	Coniferous species
c.i.f.	(imports) delivered to dockside, i.e. cost, insurance, freight
C.off	Coniferous (sawmill) offcuts
Copp	Coppice
CSD	Coniferous sawdust
cu m	cubic metre
cu ft	cubic foot
D-W statistic	Durbin-Watson statistic
E	English measure
ECE	Economic Commission for Europe (United Nations)
FAO	Food and Agriculture Organisation (of the United Nations)
f.o.b.	(exports) loaded on ship, i.e. free on board
FPRL*	Forest Products Research Laboratory (UK)
gm	gram
GNP	Gross National Product (at factor cost)
HMSO	Her Majesty's Stationery Office
ICI	Imperial Chemical Industries Ltd.
kg	kilogram
LA1	Small larch roundwood
LA2	Large larch roundwood
LCES	London & Cambridge Economic Service
M	metric (measure)
m	metre
m^2	square metre
m^3	cubic metre
mc	moisture content
mill	million
mm	millimetre
NIESR	National Institute for Economic and Social Research
ob	over bark
OC1	Small "other conifer" roundwood
OC2	Large "other conifer" roundwood
OC3	Very large "other conifer" roundwood
p & w	printings and writings (paper)
PIRA	Paper Industries Research Association
$\bar{R}^2$	Coefficient of multiple determination (i.e. corrected R^2)
RHS	Right Hand Side
SP1	Small spruce roundwood
SP2	Large spruce roundwood
th	thousand
thous	thousand
TTFUK	Timber Trades Federation of the United Kingdom
UK	United Kingdom of Great Britain and Northern Ireland
USDA	United States Department of Agriculture

* Now the Princes Risborough Laboratory of the Building Research Establishment, Department of the Environment.

GLOSSARY

Apparent consumption	consumption not adjusted for changes in stocks.
Beating up	replacing young trees which have died, a year or two after the initial planting.
Furnish	the mixture of constituents in paper-making.
High forest	crops and stands of trees which normally develop a high closed canopy.
Hoppus foot	measure of wood volume formerly used in Britain. 1 Hoppus foot=0.036 m^3.
Piled cubic fathom	measure used for small roundwood. 1 piled cubic fathom=216 piled cubic feet or 151 true cubic feet (=4.28 true cubic metres).
Ride	gap between stands in a plantation, forming an access track.
Stand assortment table	a table showing the volume of logs of various diameters (at breast height) as a percentage of the volume to 7 cm. or 3 in. top diameter.
Standard	measure used for coniferous wood. 1 standard=165 true cubic feet (=4.67 true cubic metres)
Stumpage	value of standing timber i.e. before felling
Thinning cycle	the interval between thinnings, in years.
Thinning weight	the volume of wood removed at any one time.
Windthrow	uprooting by wind.
Yield class	a measure of plantation growth potential; the maximum mean annual increment, in volume terms.

Chapter 1

INTRODUCTION

Objectives and Scope

The general aim of this study is to suggest an optimum strategy for the development of the wood products sector of the UK economy. The sector is defined as wood growing and its primary processing, plus imports. At present, about 8 per cent of British consumption of wood products is obtained from domestically-produced wood, on a wood-raw-material equivalent basis (Grayson 1969, p. 5). The present study concentrates attention on this relatively small proportion of the total supply, partly because it is important in absolute terms and partly because the proportion is likely to increase in the future as young plantations reach maturity. The approach is in some respects that of a social evaluation but the study cannot be considered an example of cost/benefit analysis.

The general approach is to consider the supply and demand aspects of the market for wood fibre, in each of a number of future time periods. The wood products sector is here defined to comprise the domestic and imported supplies of wood fibre together with the primary processing of the fibre into wood products, which also may be imported. Domestic wood fibre comes from existing forest plantations and any new planting, and from waste paper recovery, although the latter can only be used to produce paper or paperboard. The term primary processing is used to cover the production of a commodity which by definition consists mainly of wood fibre. The main categories resulting from this definition are sawn-wood, wood-based sheets (such as plywood), paper, paperboard and pitprops. An example of secondary processing is furniture manufacture, where wood may be used but is not actually necessary.

In principle, paper should also be excluded from the model since it can be made from plastic or from other cellulosic fibres as well as wood pulp, but because of the integrated nature of much paper production it is not practicable to separate the pulp and paper stage. In some cases, such as tissue, it is also difficult to separate the paper production and conversion stages, where conversion means the cutting and boxing of paper tissues, for example.

As final products in the model are intermediate goods in the economy as a whole, demand for them is a derived demand. Any commodity which may be produced domestically is also considered importable, including pulp for paper manufacture in non-integrated plants within the United Kingdom. However, dissolving pulp (used to make rayon) and veneers are excluded from consideration. Dissolving pulp is entirely imported and unlikely to be made in the United Kingdom because of pollution problems and the low recovery rate from roundwood. Veneers also are imported and although in the future constructional grade plywood may be made from domestic logs, significant quantities of other veneers seem unlikely because of log quality problems.

Importance of the wood-based Sector

The forested area in the United Kingdom represents about 8 per cent of the total land area (*Annual Abstract of Statistics 1971*), and most of the existing forests are relatively young, about two-thirds of the conifer plantations being less than 20 years old (Jackson 1971, p. 131). For these reasons most wood products consumed in the United Kingdom originate in imported wood fibre. In many cases, however, much of the processing is carried out in the United Kingdom so that the contribution to total net output is substantial, although difficult to quantify in a precise way. One method of quantification which has been used is to apportion the total net output for each industry according to the proportion of wood-based inputs in total purchased materials (Hair 1963). The result gives an indication of the industrial importance of wood but it is difficult to decide exactly what the figures show. In general, the further the processing stage is from the original roundwood, the less meaningful the calculation. According to the 1963 Census of Production in Britain, wood-based inputs accounted for about 9 per cent of total materials purchased by manufacturing and extractive industry as a whole, with wide variation between industries. The highest percentage for the industry divisions used by the Census was 81 for "Newspaper and magazine publishing". While it is true that publishing cannot occur without some form of paper, it does not seem meaningful to argue that four-fifths of value added in this industry is attributable to the newsprint and other paper.

The main problem in assessing the importance of the forestry sector is estimating net output itself. This is because of the difficulty of valuing young tree plantations, whose output will come in the future. One method is to value them at the cumulated cost of planting and maintenance but this implies that the most difficult sites are the most valuable. Another method is to estimate the discounted revenue from the future wood yield. The basic difficulty is that whereas it is reasonable to assume that the wood-based inputs bought by processing industries can be used profitably, it is inherently less certain that establishment of new plantations is a profitable operation, at least in terms of market prices.

In terms of imports, wood products account for about 8 per cent of the total, or about 7 per cent if wood manufactures are excluded. A breakdown of the figures for 1969 is given in Table 1.

TABLE 1

COMPOSITION OF UNITED KINGDOM IMPORTS OF WOOD PRODUCTS 1969

	£m, c.i.f.		%
Wood and lumber	216·8		31·8
Pulp and waste paper	165·4		24·3
Wood manufactures	88·2		12·9
Paper and paperboard	203·6		29·9
Furniture of wood	7·3	%	1·1
Sub-total	681·3	8·2	100·0
Total imports	8315·1	100·0	

Source:
Annual Statement of Trade of the United Kingdom

Structure of the Model

The general structure of the model is shown in the summary flow chart (Figure 1.1). The sections of the flow chart refer to any time period, with the exception of "existing plantations", which are a separate section of the model and at the start are of specific age classes. These, and any new planting, supply wood in various periods, the wood varying according to species and log size, and the supply is supplemented by pulpwood imports if necessary. Additional wood fibre comes from domestic recovery of waste paper, of two grades, again with the possibility of imports. The total wood fibre supply is distributed to various types of domestic primary processing, which vary according to product and method of production. Imports of wood pulp for further processing are allowed because much domestic paper production is of this kind. Finally the primary processed products go to satisfy demands from user industries.

Time Periods

To allow for the evaluation of new plantations, the model has a time horizon of sixty years, divided into seven periods. In British conditions, plantations normally require a growing period of at least forty years before they produce substantial amounts of useful timber. Obviously it is impossible to do more than speculate about conditions so far ahead, and therefore the length of the time periods is varied so as to give proportionately more attention to the nearer future. The pattern is shown in Table 2.

Age Classes

The age structure of domestic forests is important because of its influence on the timing of future wood yields. Since the available data are recorded in ten-year age classes, based on decades since 1900, these are the groupings used; there are also figures for areas planted before 1900 and before 1861. The pre-1861 plantations, consisting of privately-owned woodland of broadleaved species, can be considered amenity woodlands and are excluded from the model. In the model, state and private forests are combined, on the assumption that inputs and outputs per unit area are similar in the two sectors, other things being equal. This proposition is supported by available data on costs in forestry.

Criteria and Assumptions

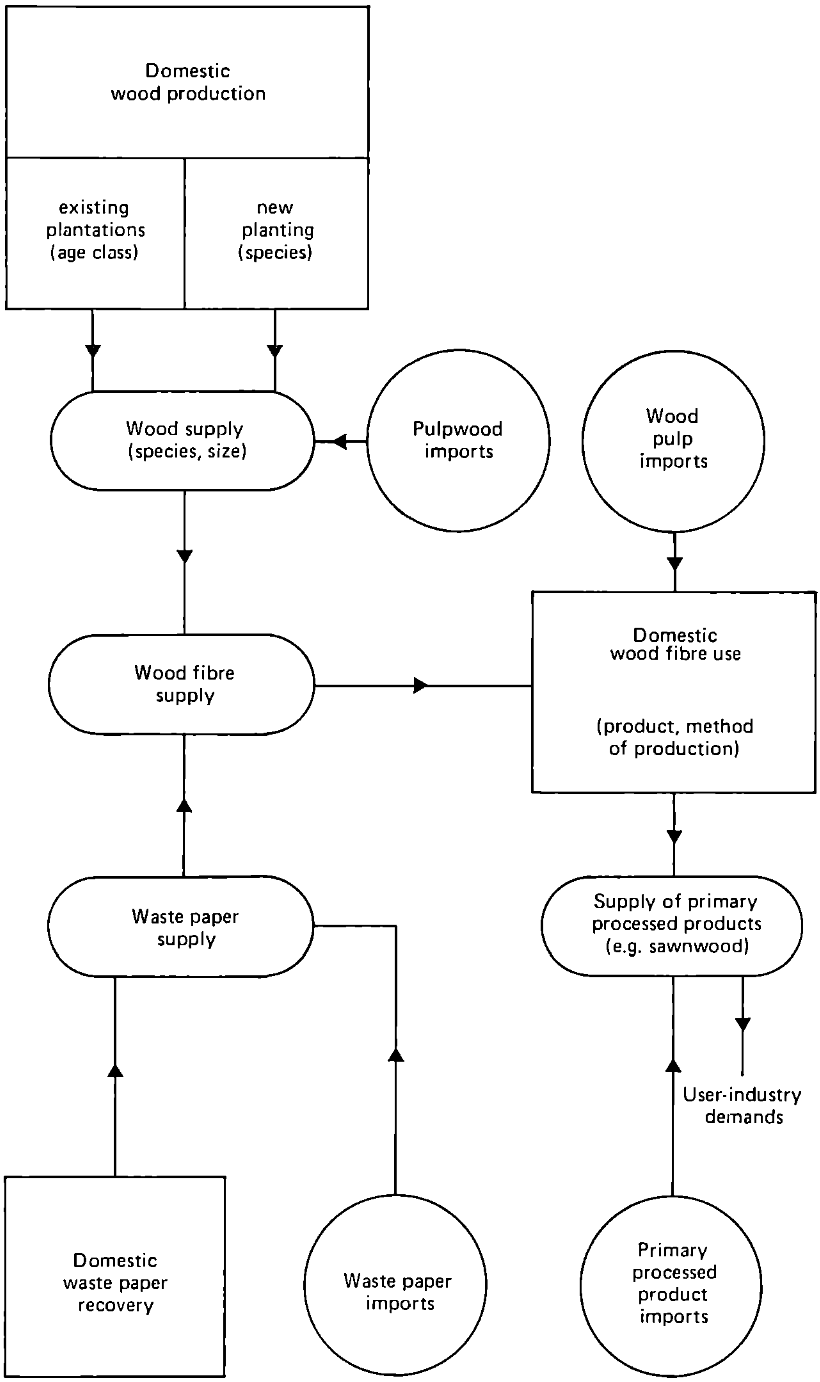
Since the aim of the model is to indicate an optimum strategy for the wood products sector, a criterion (of optimality) is needed. This is defined as discounted net benefit from the wood products sector as a whole. In other words, costs are subtracted from benefits and the result is discounted according to the time period in the future, on the argument that benefits in the future are less valuable than corresponding benefits at the present. The aim of the model is thus to maximise the total net discounted benefit, taking all sections of the model together. Since the wood-supplying and wood-using sections of the model are linked, it avoids the need to value young

TABLE 2

TIME PERIODS IN THE MODEL

Period no.	1	2	3	4	5	6	7
Length (years)	5	5	5	10	10	10	15
Years from present	1–5	6–10	11–15	16–25	26–35	36–45	46–60
Mid-point for discounting	2·5	7·5	12·5	20	30	40	52·5
Date: start of period	1971	1976	1981	1986	1996	2006	2016
mid-period	1973	1978	1983	1990	2000	2010	2020·5

Figure 1.1 Summary flow chart of the model



plantations, apart from including management costs yet to be incurred.

Benefits are taken to be represented adequately by market prices, and it is therefore reasonable to use the term "revenue" interchangeably with "benefit". Market prices may be criticised for various shortcomings but in a sectoral study it is necessary to take many variables as exogenous. For "final products" the prices used are projections of recent world market prices in so far as these can be ascertained, and in this sense the model utilises "border pricing", as the term is used by Little and Mirlees (OECD 1968), for example. The costs subtracted from these benefits (prices) to obtain net benefits, are the usual inputs, labour, chemicals, water and maintenance materials, together with imported wood pulp where this is used by UK producers in non-integrated plants. The cost of domestic wood fibre is not subtracted directly, because it is already allowed for in the wood-supplying section of the model, which is linked to the domestic processing section. This arrangement is described more fully in the final section of this Chapter.

The price of labour is taken to be determined exogenously to the model, and in particular no merit *per se* is attached to creation of employment in forestry or forest industries. Thus full employment in the economy as a whole is assumed, with a social opportunity cost of labour represented by the wage rate. The realism of this assumption varies from time to time and also regionally. In the model, regional aspects are included implicitly rather than explicitly. For example, if the results of the study indicate that a plywood factory (using domestic logs) should be set up, this would probably be in Scotland because of the log supply situation.

Social Evaluation

The benefits allowed for do not include intangibles such as the possible amenity value of forests, partly because there is so much disagreement about amenity effects of afforestation, especially with conifers. Also the increased water loss (through evapotranspiration) which may occur when catchment areas are afforested, is not taken into account, although in certain circumstances the effect may be significant (Collet 1970). If the amenity effect of afforestation is assumed to be positive, these two factors would tend to offset each other. This was the case, for example, in a recent British government study of the forestry sector (Treasury 1972, chapters 5 and 6, and p. 50).

Although the exclusions just mentioned mean that the study cannot reasonably be described as a cost/benefit analysis, two features of the model are consistent with a social evaluation. Firstly, sunk costs are ignored, and secondly, the discount rate is supposed to be a social discount rate. The sunk costs comprise the establishment cost of existing plantations, and the capital investment costs of processing factories. In practice the equipment in these factories would generally be saleable on the second-hand market, but to allow for decreasing and increasing processing capacity simultaneously would have required roughly 125 additional constraints in the model. The exclusion of amortisation from net revenues of processing industries increases the realism of the linear assumption inherent in the model, because economies of scale usually arise from spreading of fixed charges over larger outputs.

The derivation of a social discount rate is the subject of much disagreement (Pearce 1971, chapter 6) and there seems little point in rehearsing the arguments again. There is perhaps general agreement that a social discount should be lower than a private rate (Henderson 1969, p. 98) and lower than a market rate because the latter contains an element to allow for inflation (Webb 1966), whereas a "true" rate should be assessed at constant prices. The aim in the present study is to discount net benefits at the social time-preference rate, and there is some slight evidence that it may be about 4 or 5 per cent for the United Kingdom (Pearce 1971, p. 44). In the model the principal rate used is 5 per cent, together with a rate of 10 per cent to test the sensitivity of the solution to a rate possibly closer to the social opportunity cost.

Structure of the Model in Matrix Form

The linear programming method is to maximise (or minimise) a linear function of variables (activities) subject to linear constraints. In the present case the activities are concerned with forests, manufacturing processes, and importing. Each activity is defined in terms of unit area, volume or weight. For example, the management of a unit area of a particular type of forest results in given wood volumes being produced in specified future time periods, assuming that the yield class is known and that the trees are not affected by disease or other hazards. The discounted net revenue (or benefit) is calculated per unit of every activity, and the answer given by the program shows the number of units of each activity which together maximise the discounted net revenue. The constraints mentioned are included to ensure that the results are realistic. For example, there are equations (constraints) to ensure that the amount of wood used in processing does not exceed that available, that production does not exceed processing capacity, and that future demands for wood products are met. If these constraints are actually limiting, the program also shows how much it is worth paying for additional resources of that particular kind, provided they are available. It is assumed that the activities are reasonably linear in form, or in other words that they are not materially affected by changes in the scale of operations. This point is touched on in later chapters where relevant, particularly Chapter 4.

Presentation of the basic structure of the model in matrix form may help to clarify the method of approach. Table 3 illustrates a model in which there are two time periods, species, plantation age classes and products. The first four activities (columns) represent management of the existing plantations, and since there are limited areas of each species/age class combination, it is necessary to specify this by the first four constraints (rows). Because the RHS values (b_1 to b_4) are required to be larger than the sum of the left hand side, the forest areas appearing in the solution cannot exceed the actual areas (shown by b_1 to b_4). The wood volumes produced from these plantations in the two periods are shown by the negative coefficients in rows 6 to 9. The reason for the negative value is explained shortly. The wood volumes (expressed as cubic metres per hectare) depend on the management system assumed, and it is possible that one or more of these coefficients could be zero (for example, if a no-thinning system were practised).

The fifth activity allows for planting of species 1 in the first period, and it is assumed for expositional purposes that some wood output is produced in the next period (coefficient $a_{8\cdot5}$), although in practice this is highly unlikely. Any planting is limited by the plantable land available (b_5) but if the management of existing plantations had involved felling in period 1, this would have created additional plantable land as indicated by the -1 in brackets, in column 2. It will be realised that in this case coefficient $a_{8\cdot2}$ would be zero.

The sixth activity is the import of species 1 in roundwood form, contributing to the supply of wood as shown by -1 in row 6. The next four activities represent manufacture of products 1 and 2 from wood of species 1 and 2. The coefficient $a_{6\cdot7}$, for example, is the volume of species 1 required to make one unit of product 1. Production is limited by domestic processing capacity, which is the purpose of constraints 10 and 11 (also 12 and 13, for period 2). However, the effect of these constraints can be eased by installing new capacity (activities 11 and 12) which therefore have a negative coefficient ($-\cdot5n$, where n is the length of the time period). The value of $\cdot5n$ reflects the fact that construction is assumed to occur at the mid-point of a time period. However, in the next time period the new capacity should be fully available, hence the $-n$ corresponding to coefficients $a_{12\cdot11}$ and $a_{13\cdot12}$. Activities in this section of the model refer to unit weight or volume of manufactured output, such as paper.

Returning to rows 6 and 7, the wood produced by activities 1 to 4, and 6, may be used by the production activities 7 to 10. To avoid using more wood than is available, the wood-supplying activities are given negative coefficients, and the wood-using activities positive coefficients, with the overall requirement that each equation should be less than or equal to zero. For species 1 the wood supply is infinite because imports are not restricted, although there is a cost of purchase.

Before dealing with the last four rows, it is convenient to consider the values of the coefficients (c_1 to c_{23}) in the objective function row. The management of existing plantations, and new planting, are given negative values, the costs per unit area of these operations discounted according to the period when they are incurred. Variable 6 also has a negative net revenue, the import cost. All these are regarded as means to the "end" of manufacturing products 1 and 2, whose c coefficients are positive, representing sale value *less* processing costs excluding wood; the latter has already been allowed for. Amortisation of capital is also excluded, as a sunk cost. However, new manufacturing capacity is given a negative net benefit, equivalent to the construction cost per unit of product (tonne or cubic metre).

Imports of products also contribute towards meeting demand and they are credited with a small positive net revenue, representing importers' profit on their operations. This approach is based on the argument that importation of products can free domestic resources for use elsewhere in the economy. However, the output from existing domestic forests should have an advantage over imported wood in so far as the former are not charged their establishment costs whereas some import prices presumably contain an allowance for regeneration. For example, in Sweden re-stocking of felled plantations is a legal requirement.

This treatment of imports has an implication for the constraints representing demand for wood products (rows 14 to 17). Each production activity (X_7 to X_{10}, and X_{16} to X_{19}) creates a supply of a product which helps to satisfy the estimated demands specified as b_{14} to b_{17}. If the signs were the other way round, importing would continue indefinitely and the solution would be unbounded. With the formulation shown in Table 3 the demand values b_{14} to b_{17} are always fully met, since it is always "profitable" to make up any deficit of domestic wood supply by importing final products. The imported product may also be more competitive than domestic production.

The method of linking the production and use of wood through material balance equations means

TABLE 3

BASIC STRUCTURE OF THE MODEL IN MATRIX FORM

(Variable name)	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}		
	PERIOD 1														PERIOD 2										
	Manage existing plantations				Plant Species	Import Species	Manufacture: Product 1		Manufacture: Product 2		New capacity		Import Product		Import Species	Manufacture: Product 1		Manufacture: Product 2		New capacity		Import Product			
	Species 1		Species 2		1	1	from 1	Species 2	from 1	Species 2	Product 1	Product 2	1	2	1	from 1	Species 2	from 1	Species 2	Product 1	Product 2	1	2		
	Age 1	class 2	Age 1	class 2																					
(Unit)	area					wood vol	weight or volume								wood vol	weight or volume									Right Hand Side
(Objective function)	$-c_1$	$-c_2$	$-c_3$	$-c_4$	$-c_5$	$-c_6$	c_7	c_8	c_9	c_{10}	$-c_{11}$	$-c_{12}$	c_{13}	c_{14}	$-c_{15}$	c_{16}	c_{17}	c_{18}	c_{19}	$-c_{20}$	$-c_{21}$	c_{22}	c_{23}	Sign	(RHS)
(Constraints) 1. Area of Species 1 age class 1	1																							<	b_1
2. Area of Species 1 age class 2		1																						<	b_2
3. Area of Species 2 age class 1			1																					<	b_3
4. Area of Species 2 age class 2				1																				<	b_4
5. Plantable land period 1		(−1)			1																			<	b_5
6. Wood volume, Species 1, p.1	$-a_{6\cdot1}$	$-a_{6\cdot2}$				−1	$a_{6\cdot7}$		$a_{6\cdot9}$															<	0
7. Wood volume, Species 2, p.1			$-a_{7\cdot3}$	$-a_{7\cdot4}$				$a_{7\cdot8}$		$a_{7\cdot10}$														<	0
8. Wood volume, Species 1, p.2	$-a_{8\cdot1}$	$-a_{8\cdot2}$			$-a_{8\cdot5}$										−1	$a_{8\cdot16}$		$a_{8\cdot18}$						<	0
9. Wood volume, Species 2, p.2			$-a_{9\cdot3}$	$-a_{9\cdot4}$													$a_{9\cdot17}$		$a_{9\cdot19}$					<	0
10. Manuf. capac. Product 1, p.1							1	1			$-\cdot5n$													<	b_{10}
11. Manuf. capac. Product 2, p.1									1	1		$-\cdot5n$												<	b_{11}
12. Manuf. capac. Product 1, p.2											$-n$					1	1			$-.5n$				<	b_{12}
13. Manuf. capac. Product 2, p.2												$-n$						1	1		$-\cdot5n$			<	b_{13}
14. Demand for Product 1, p.1							1	1					1											<	b_{14}
15. Demand for Product 2, p.1									1	1				1										<	b_{15}
16. Demand for Product 1, p.2																1	1					1		<	b_{16}
17. Demand for Product 2, p.2																		1	1				1	<	b_{17}

that the program itself values the wood, and distributes it to the most profitable uses. This integrated nature of the model also distinguishes it from models of the forestry sector alone, where a general rise in the price of wood is accounted a benefit because it increases stumpage values.

The matrix in Table 3 shows the basic features of the model but in a very simplified form. The model described in the following chapters has the same general structure but incorporates much more detail. For example, plantations are divided according to management system as well as species and age class, and processing activities can use wood of different sizes as well as different species. The result is a matrix with approximately 1075 columns (variables) and 510 rows (constraints).

Chapter 2

WOOD PRODUCTION

There are two main domestic sources of wood fibre in the United Kingdom, plantations and waste paper. Currently waste paper is more important in both weight and value terms, but its relative importance could decline as post-war plantations develop significant wood volumes.

The present chapter is concerned only with the supply of wood fibre from domestic plantations; waste paper is dealt with in Chapter 3. The general aim of this section of the model is to indicate an optimum overall management plan for UK forests, irrespective of ownership. In this context "management plan" refers to length of rotation and number of thinnings, which may be zero. The wood volumes produced are distributed among the various processing industries by the wood-producing and wood-using sections of the model operating together. The first part of the chapter describes the forest resources in existence, and the second part shows how the management plan alternatives are specified.

Domestic Forest Resources

Production of wood is mainly from plantations classed as high forest, but there are also considerable areas of less productive woodland, classified by the Forestry Commission Censuses as utilisable and unutilisable scrub. In addition there are areas of coppice and coppice-with-standards, which by regrowth produce small crops of wood at intervals of 10 to 15 years, compared with the usual high forest rotations of 40 years and more. The descriptions of scrub as utilisable and "unutilisable" are derived from the idea of production of logs suitable for sawmilling, rather than chipping or pulping, but with unutilisable scrubs the high proportion of bark in the total yield, and the difficulty of extracting small and misshapen stems, justifies its exclusion as a source of wood. The estimated area of each of these categories in the United Kingdom at the beginning of 1971 is shown in Table 4.

TABLE 4

AREAS OF MAIN WOODLAND TYPES 1971 (UNITED KINGDOM)

	Thousand hectares	Thousand acres
High forest: coniferous	860	2105
broadleaved	285	712
Total	1145	2817
Utilisable scrub	65	160
Unutilisable scrub	290	710
Coppice and Coppice-with-standards	28	70

Sources:
Locke (1970a and b) and Simpson (1971).

Note:
High forest areas are net of rides, etc.

Species and Areas

High forest can be taken to represent plantations created by man, and subject to more or less continuous management such as periodic thinning. A main division is into coniferous and broadleaved species, a botanical classification but one also important industrially, as the wood characteristics are different. These two groups can be further broken down according to species, of which the most important groups are listed in Table 5, together with their approximate areas. Coppice and scrub are not included but can be taken as broadleaved.

TABLE 5

AREAS OF MAIN HIGH FOREST GROUPED SPECIES 1971 (UNITED KINGDOM)

	Thousand hectares	Thousand acres
Pines (Pinus nigra, sylvestris and contorta)	310	765
Spruces (Picea abies and sitchensis)	355	875
Larches (Larix decidua, kaempferi and eurolepis)	130	320
Firs, etc. (Pseudotsuga menziesii, Tsuga heterophylla, etc.)	65	160
Broadleaved (Fagus, Quercus, etc.)	285	705

The same data arranged in a different way are shown in Table 6, to give a broad indication of the age class structure within the state and private forests, also broken down into coniferous and broadleaved species.

From Table 6 it is clear that the age and species structures in the two ownership categories are very different. The relatively young age structure and predominance of conifers in the state-owned sector, are a reflection of the fact that large-scale state afforestation occurred only after 1945, with the emphasis on quick-growing species of commercial interest.

Most of the private planting of woodlands in the

TABLE 6

APPROXIMATE AGE DISTRIBUTION OF UNITED KINGDOM HIGH FOREST 1971
(thousand hectares)

Age Class	State				Private				Total			
	CF	BL	Total	%	CF	BL	Total	%	CF	BL	Total	%
Below 20 years	402	17	419	69	158	15	173	32	560	32	592	52
20–49 years	170	11	181	29	76	28	104	20	246	39	285	25
50 years +	5	6	11	2	50	207	257	48	55	213	268	23
	577	34	611	100	284	250	534	100	861	284	1145	100

Notes:
1 State forests are those of the British Forestry Commission plus government-owned forests in Northern Ireland.
2 "Private" forests include some owned by local authorities and other public bodies.
Source:
Based on Locke (1970a and 1970b): see Appendix A.

same period has been in response to tax concessions, obtainable by guaranteeing that the land planted will remain as woodland in perpetuity or until the Forestry Commission gives permission for a change of use. In spite of this incentive to plant, nearly half of private forests are more than 50 years old and much of the broadleaved forest was planted before 1861.

A better indication of the standing volumes is given by Table 7 where the age class divisions are slightly different from those of Table 6, and the figures refer to 1965.

Regional Distribution of Forests

Although the model is not constructed on a regional basis, for climatic reasons there is considerable variation in the distribution of forested land within the United Kingdom. Generally speaking, broadleaved species are concentrated in the warmer southern half of England, particularly the south-east. Conversely, coniferous species are concentrated in northern England, Wales and Scotland. Most of the forest area is in relatively small fragmented sections, which is a handicap for management purposes, but there are some large contiguous areas of coniferous forest on the England–Scotland border in particular.

Of the two main broadleaved species, oak is widespread but there are concentrations in south-east England from Kent to the New Forest, in the Dean Forest (Gloucestershire) and in the Furness division of Lancashire. Beech grows well on chalk and limestone and for this reason forests are much more localised, on the Chiltern and Cotswold hills, in the New Forest and in West Sussex.

Pines are concentrated in Scotland, especially on Speyside, Deeside, and around the Moray Firth. In England they tend to be concentrated in a number of small areas.

In eastern England there are concentrations on the Breckland, the Suffolk coast, and on the North York moors; Corsican pine is the main species in these drier areas. Further west there are pine forests in the Camberley region (Surrey) and in the ancient forests such as Sherwood, Cannock Chase and the New Forest. The native species is Scots pine.

Spruces are more tolerant of wet conditions and are concentrated in Wales, especially the north, in Argyllshire and in the Border country (Kielder forest in particular).

TABLE 7

APPROXIMATE WOOD VOLUMES IN UNITED KINGDOM HIGH FOREST 1965
(million cubic metres)

Age Class	State				Private				Total			
	CF	BL	Total	%	CF	BL	Total	%	CF	BL	Total	%
Below 30 years	5·3	—	5·3	17	2·1	0·4	2·5	3	7·4	0·4	7·8	7
30–49 years	18·7	0·5	19·2	61	13·3	3·0	16·3	19	32·0	3·5	35·5	30
50 years +	3·3	3·5	6·8	22	19·7	46·6	66·3	78	23·0	50·1	73·1	63
	27·3	4·0	31·3	100	35·1	50·0	85·1	100	62·4	54·0	116·4	100

Source:
Based on Locke 1970a.

Larches are more widespread, but are less common in the drier areas, particularly eastern England.

Definition of Wood-supplying Activities

The brief summary of the model given in Chapter 1, indicated that the wood-producing section of the model consists of a number of activities representing different ways of obtaining roundwood. These activities are of three main types:

Management of existing plantations
Establishment of new plantations
Importing pulpwood

The principal difference between the first and second types is that the latter are charged their establishment costs. Other things being equal they will also produce wood at a later date than existing plantations. The wood volumes produced are divided according to log size, generally into sawlogs (minimum diameter over bark of 18 cm.) and pulpwood (from 18 cm. to 7 cm. diameter). Sawlogs are excluded from the importing activities of the model, so that roundwood imports are specified as pulpwood, although in fact a declining volume of hardwood logs is imported for sawing and plywood manufacture. Sawnwood is regarded as a final product in the context of the model, and has its own importing activities.

Within each of these three groups the activities may vary in a number of ways. Activities for existing plantations are defined as combinations of the following four characteristics:

Species
Age class
Rotation length } management system
Number of thinnings }

These also apply to new plantations except that "age class" is replaced by "period of planting". Round wood importing is confined to an activity for importing pulpwood (small spruce) in each period. Imported logs of broadleaved species are excluded from the model, although in fact some plywood is produced in England using tropical hardwood logs.

Existing Plantations

The following paragraphs describe the four groups of characteristics mentioned above. The basic division of forests is into species/age class combinations, and within these different management systems are defined in terms of rotation length and number of thinnings.

Species

For the purposes of the model, the high forest species grown commercially in the United Kingdom are amalgamated into four "grouped species", plus coppice:

Spruce	—Norway and Sitka spruce
Larch	—European, Japanese and Hybrid larch
Other conifer	—pines, plus Douglas fir and minor species
Broadleaved	—mainly oak and beech
Coppice	—including coppice with standards, and utilisable scrub

Most of the coppice is Spanish chestnut, with oak the commonest species of standard (Locke 1970a).

Spruce is considered separately because the wood is particularly in demand for mechanical pulp to produce newsprint (Baguley 1970). Conversely larches are distinguished because their wood is less suitable for a number of processing activities (e.g. Packman 1968, p. 142), although locally it may be readily saleable in small quantities (Edwardson 1970). The remaining conifer species either appear reasonably homogeneous in their wood characteristics, or are of small extent, and are therefore grouped together; an exception is that the plantations less than 20 years old are divided into "pines" and "firs", the latter being mainly Douglas fir. This is because the areas involved are sufficient to make the division worth while in terms of possible differences in management system and growth characteristics.

Age Classes

The age distribution of United Kingdom high forests is represented by a maximum of eight ten-year age classes, in accordance with the arrangement of available survey data. The eighth age class represents 39 planting years, from 1861, as far as this can be estimated. There are also substantial areas of broadleaved species planted before 1861 but in general these can be considered amenity woodlands and excluded from the model (Locke 1970b).

Species/Age Class Combinations

The domestic wood supplying activities are based on those combinations of the four grouped species and eight age classes for which there are significant areas, plus the coppice and utilisable scrub. The position is summarised in Table 8. The areas refer to fully-stocked stands of high forest, and are therefore net of allowances for roads, rides, firebreaks, etc., for which a standard reduction of 15 per cent has been made (Forestry Commission 1966, p. 79). An allowance for areas felled since the most recent censuses has been made on the basis of estimates by Locke (1970b), but the allocation to species and age classes must be arbitrary. The average yield classes shown are derived from census estimates, except for age class 1, which is assumed to be similar to age class 2. They are the basis for the wood volumes assumed to be produced by thinning and felling.

The total area of coppice and similar woodland has recently been estimated at about 30 thousand hectares, of which about half is now being worked (Locke 1970, pp. 47–50).

The usual coppice cutting rotation is 16 to 17 years and existing areas are assumed to be divided equally between two age classes, less than 10 years and 10–16 years. The average ages are taken to be 5 and 13 years respectively, which results in some cutting ages different from those listed in Table 9. These are shown in the section on yields, at the end of this Chapter.

Fuller details of the method of estimation of high forest areas and yield classes are given in Appendix A.

Management Systems

Within each of the combinations referred to, management systems are specified, consisting of rotation age and number of thinnings, which may

TABLE 8

TOTAL AREAS AND AVERAGE YIELD CLASSES FOR UNITED KINGDOM HIGH FOREST, 1971

Areas in th.hectares (M) and th.acres (E); yield classes in cu. m. (M) and Hoppus feet (E)

Age class (Planting years)	Average Stand Age		Spruce M	Spruce E	Larch M	Larch E	Other Conifer* M	Other Conifer* E	Broad-leaved M	Broad-leaved E	Total inc. Fir M	Total inc. Fir E
1 (1960–70)	5 yrs.	Area	130·7	323	16·8	42	80·6	199	7·3	18	259·9	642
		YC	12·8	144	8·8	99	8·5	95	5·7	64	11·1	125
2 (1950–59)	15	Area	114·4	283	57·0	141	111·1	275	24·5	60	331·7	820
		YC	13·4	150	9·3	104	9·5	107	5·8	65	10·9	122
3 (1940–49)	25	Area	50·8	126	14·4	36	30·1	74	12·6	31	107·9	267
		YC	12·3	138	8·5	95	9·6	108	5·8	65	10·3	116
4 (1930–39)	35	Area	39·4	97	19·2	47	33·5	83	14·5	36	106·6	263
		YC	12·4	139	8·3	93	10·1	113	5·3	60	10·0	112
5 (1920–29)	45	Area	15·1	37	11·8	29	33·5	83	12·7	31	73·1	181
		YC	12·2	137	8·1	91	10·1	113	5·2	58	9·4	106
6 (1910–19)	55	Area	1·4	3·5	4·3	11	7·3	18	13·1	32	26·1	64
		YC	10·2	114	6·8	76	8·9	100	5·1	57	6·7	75
7 (1900–1909)	65	Area	1·4	3·5	3·3	8·1	7·7	19	21·7	54	34·1	84
		YC	11·0	123	6·3	71	7·8	88	4·6	52	6·7	75
8 (1861–1899)	90	Area	1·1	2·7	3·4	8·4	17·1	42	104·0	257	125·6	310
		YC	8·4	94	5·5	62	6·3	71	4·0	45	4·4	49
9 (pre-1861)		Area	—	—	—	—	7·3	18	74·5	184	74·5	184
		YC	—	—	—	—	5·6	63	4·0	45	4·5	51

Age class		Fir etc. M	Fir etc. E
1	Area	24·5	60
	YC	14·2	159
2	Area	24·7	61
	YC	14·4	162

* The figures for age classes 1 and 2 refer to Pines only.

Source: Adapted from Forestry Commission data.

be zero. Felling is assumed to occur at the mid-point of a time period, which means that rotation age is not continuously variable, and in some cases results in rather odd felling ages, e.g. 52·5 years. A similar system is used in specifying thinnings, with some modifications mentioned below. The average ages for each age class and time period are shown in Table 9; for example, a stand of age class 3 thinned in period 2 has an average age of 32·5 years, and the volume produced depends on this, in conjunction with the yield class and species.

Table 9

Average Age at Thinning or Felling

Age class	Time period 1 (Years)	2	3	4	5	6	7
1	7·5	12·5	17·5	25	35	45	57·5
2	17·5	22·5	27·5	35	45	55	67·5
3	27·5	32·5	37·5	45	55	65	77·5
4	37·5	42·5	47·5	55	65	75	87·5
5	47·5	52·5	57·5	65	75	85	97·5
6	57·5	62·5	67·5	75	85	95	
7	67·5	72·5	77·5	85	95	105	
8	77·5	82·5	87·5	95	105		

The thinning weight assumed is that used in the preparation of the Forest Management Tables (Forestry Commission, 1966). These yield tables recommend volume removal equivalent to 70 per cent of the maximum mean annual increment (yield class) each year, which is equivalent to 350 per cent every five years, or 700 per cent every ten years. The specification of thinnings as occurring at the mid-point of time periods means that in periods 5 and 6 the thinning cycle is ten years, rather longer than recommended if the danger of windthrow is to be avoided (Hamilton 1969).

The factors affecting windthrow are not fully known, but in general it affects stands of 12 metres (40 feet) and over, if relatively large gaps are made in the tree canopy, as would happen if 700 per cent of the yield class value were removed at one operation. The danger lasts for only a few years, until the edge trees have a chance to strengthen their root system. To avoid this problem, thinning volumes in periods 5 and 6 are based on the average stand age at the mid-point of the period, but thinning costs are based on the assumption of a 5-year thinning cycle. For the same reason management options involving thinning after long periods of no-thinning are excluded, and the main alternatives considered are frequent thinning and no-thinning, with some options involving thinning followed by no-thinning, which avoids windthrow risk.

No-thinning

Provisional yield tables for plantations of various species and yield classes have been drawn up by the Forestry Commission, and they show that the volume yield from unthinned stands is proportionately lower than for thinned stands of the same yield class and age, and the percentage fall increases with age. Wood volumes from stands which are thinned one or more times and then left unthinned, can be estimated by applying the percentage reduction in yield for the appropriate yield class and length of time, taking the time of last thinning as 100 per cent. Absence of thinning also reduces tree size, and although the no-thinning tables show breast height diameter at various ages, from which volumes to various top diameters can be calculated (from a stand assortment table), these figures do not apply exactly when no-thinning follows thinning.

In selecting the activities for existing plantations the approach is to make the number roughly proportional to the area of woodland involved, subject to the fact that young and old plantations have less scope for varying the period of felling, compared with those of intermediate age. The number of activities in each species/age class com-

Table 10

Numbers of Activities for Existing Plantations

<table>
<tr><th rowspan="3">Age Class</th><th colspan="6">Species</th><th rowspan="3">Total</th></tr>
<tr><th rowspan="2">Spruce</th><th rowspan="2">Larch</th><th colspan="2">Other Conifer</th><th colspan="2">Broadleaved</th></tr>
<tr><th>Pine</th><th>Fir</th><th>High Forest</th><th>Coppice</th></tr>
<tr><td>1</td><td>8</td><td>8</td><td>5</td><td>6</td><td>4</td><td>2</td><td>33</td></tr>
<tr><td>2</td><td>12</td><td>8</td><td>8</td><td>9</td><td>7</td><td>4</td><td>48</td></tr>
<tr><td>3</td><td>15</td><td>12</td><td colspan="2">12</td><td>10</td><td></td><td>49</td></tr>
<tr><td>4</td><td>10</td><td>10</td><td colspan="2">12</td><td>11</td><td></td><td>43</td></tr>
<tr><td>5</td><td>7</td><td>6</td><td colspan="2">10</td><td>9</td><td></td><td>32</td></tr>
<tr><td>6</td><td>3</td><td>3</td><td colspan="2">6</td><td>6</td><td></td><td>18</td></tr>
<tr><td>7</td><td></td><td>3</td><td colspan="2">5</td><td>7</td><td></td><td>15</td></tr>
<tr><td>8</td><td></td><td></td><td colspan="2">5</td><td>4</td><td></td><td>9</td></tr>
<tr><td>Total</td><td>55</td><td>50</td><td colspan="2">78</td><td>58</td><td>6</td><td>247</td></tr>
</table>

bination is shown in Table 10. A more complete list is given in Appendix B.

In the matrix the total area of existing woodland of each species/age class combination is included as a resource constraint in the RHS. Together with coppice, the total number of rows for this purpose is therefore 33, and each activity (column) has a coefficient of 1 in the appropriate row. These equations only appear in the matrix because the wood producing activities are complete strategies which define wood outputs in the various time periods.

New Plantations

Currently new planting in the United Kingdom is about 40 thousand hectares (100 thousand acres) annually, of which about 25 thousand hectares (60 thousand acres) is in state forests. Most of the planting consists of quick-growing conifers, especially Sitka spruce, since sprucewood is particularly suitable for many processing industries. The activities defined for the model follow this general pattern, but initially they are not forced into the solution. Planting is only allowed for in the first three time periods, because plantations established later could not produce useful volumes of wood by the year 2030, the planning horizon adopted. (Ideally the planning horizon would be infinite, with planting allowed in every period, but this is not practicable.) Therefore any planting in later periods would arise only through the inclusion of constraints on the terminal age-structure of UK forests, or by forcing it in directly. However, since a model of the kind developed here is supposed to be re-run at intervals, using revised data, it is considered unnecessary to allow for planting beyond the first three time periods. Put another way, the absence of planting in a 5-year time period does not in practice have an irretrievable effect on future forest age structure.

There are two related problems of detail created by the inclusion of planting activities. The first is that the plantable areas corresponding to given species and yield classes are not known except in the most general way. The second is that planting can occur on land where felling of existing stands has just taken place, but it is difficult to specify realistically the "category" of plantable area to which it should make a contribution. (By 'category' is meant the area corresponding to a given species and yield class.) For example, if a hectare of spruce of specified yield class is felled, it is necessary to specify its yield class if planted with Douglas fir. There is some evidence (Keeves 1966) that yield class on a second rotation of the same species is rather lower, but this is not necessarily true for another species. Another consideration is that land where felling has occurred will certainly have forest roads, and other things being equal would be preferred to unroaded land for new planting.

The problem of recently felled land is in practice not too serious because planting is only provided for in the first three periods (i.e. fifteen years) and the existing areas of older coniferous high forest are relatively small. There is more old broadleaved forest, especially in age-class 8, but this is mainly in the southern half of England where extensive replanting with conifers is not very realistic. For this reason the procedure is to assume that land becoming available through felling of older stands in any of the first three time periods, is replanted (if at all) by the same species. The few exceptions to this method are noted below.

Species

Three coniferous species are considered for planting, Sitka spruce, Lodgepole pine and Douglas fir. Larch is excluded because of its disadvantages in the main processing industries, although locally and for aesthetic reasons it may be suitable. Oak and beech, and also coppice, are included in a minor way, although for oak and beech the maximum rotations possible in the model are rather short for the yield classes usually obtainable on British sites. Two specific yield classes for each coniferous species are allowed for, one representing a reasonable average of the yield classes which have been achieved in recent decades, the other a higher yield class. However, the higher yield class alternatives must be excluded from the matrix if the lower alternatives are to be tested. The idea is to give some idea of the level of yield class at which planting enters the solution, if it does enter at all. The plantable area for the higher yield class should be less than that for the lower, but estimates of these available areas are to a large extent guesses.

Periods of Planting

As already mentioned, planting is allowed for in the first three of the seven periods in the model. The possible (average) rotations lengths are in Table 11.

TABLE 11

PLANTING PERIODS AND STAND AGES

Plant in period	Average stand age at mid-point of period 1	2	3	4	5	6	7
				Years			
1	P	5	10	17·5	27·5	37·5	50
2	—	P	5	12·5	22·5	32·5	45
3	—	—	P	7·5	17·5	27·5	40

TABLE 12

NUMBERS OF ACTIVITIES FOR NEW PLANTING*

Species Yield Class	Sitka spruce 12	 14	Lodgepole pine 8	 12	Douglas fir 14	 16	Oak 4	Beech 6	Coppice –	Total
Period of planting:										
1	5	4	5	4	4	5	1	1	1	30
2	3	5	2	3	4	4	1	1	1	24
3	2	2	2	2	2	2			1	13
Total	10	11	9	9	10	11	2	2	3	67

* The activities involving coniferous species are duplicated for roaded and unroaded plantable land, i.e. in total there are twice the numbers shown.

Specification of Activities

The activities for new planting are based on combinations of species and planting period. Within each of these combinations, the management systems which distinguish the activities are defined in terms of rotation age and number of thinnings (as with existing plantations). The options are summarised in Table 12, and further detail is given in Appendix B. Most fellings are specified for periods 6 or 7, but the higher yield class Douglas fir is tried in period 5, a rotation of 27·5 years with no thinning. The total is 64 activities for high forest, plus 4 for coppice, but only one yield class per species is included for a given program run. Since new planting of conifers may be on roaded or unroaded land, these activities are 'duplicated', the difference between them being the value of the (negative) net discounted revenue coefficient in the objective function, as described in Chapter 4. Broadleaved and coppice planting is assumed to be primarily in the south of England, on land already provided with roads.

For the purposes of the LP matrix, four types of plantable land are distinguished, spruce, other conifer, broadleaved, and coppice. The first two of these may be roaded or unroaded, giving a total of six rows per period, or 18 for the whole model. Roaded land is provided by areas felled in periods 1 to 3, initially with larch contributing one third to spruce plantable land and two-thirds to other conifer; this breakdown is based on the proportion of larch in the wetter ('Spruce land') and drier ("Pine/fir land") areas of Britain, and is recognised to be an approximation.

Calculation of Wood Volumes

The wood volumes from each activity are derived from yield table data, according to the species, yield class, age class and management system.

Each species/age class combination is assumed to have an evenly-distributed age structure within the age class; the average age is therefore the mid-point of the class, which is assumed to have been regularly thinned up to the present time. The weighted average yield class for the combination is used to interpolate between the wood volumes shown in the yield tables for specific yield classes. For existing plantations, the Sitka spruce yield tables are used for the 'spruce' areas, Japanese larch for "larch", Scots pine for "other conifers", Douglas fir for "fir" (age classes 1 and 2 only) and oak for "Broadleaved". With new planting, the species are Sitka spruce, Lodgepole pine, Douglas fir, oak and beech.

Log Size

Basically two size categories are recognised, corresponding to wood suitable only for pulping or chipping, and wood suitable also for sawing. A third category, wood large enough for plywood, is included for "other conifers" (i.e. pine and fir), because only these species have been found technically suitable (Carruthers 1969). The minimum diameters specified for these three categories are those used in the Forestry Commission yield tables, since the diameters are appropriate for the purpose:

Small: Minimum diameter over bark of 7 cm. (c. 3 in.)

Large: Minimum diameter over bark of 18 cm. (c. 7 in.)

Very large: Minimum diameter over bark of 24 cm. (c. 9 in.)

Some examples of wood volume outputs from specified activities are given in Table 13, to illustrate the orders of magnitude involved.

Coppice

According to Begley (1955) a hectare of chestnut coppice managed on the usual cutting rotation of 16–17 years should yield about 80 cu. m. per cutting, or about 4·5 cu. m. per annum on average. However, the yield depends on the site characteristics, the species and whether standards are present. Begley's figures are given only for 16- or 17-year-old stands, but Italian data (Contiani 1963) indicate that growth is approximately linear, especially after ten years. Therefore, yields for coppice activities are estimated as follows:

The yields for 15·5 and 20·5 years are shown because these ages result from the combination of initial coppice ages of 5 and 13, and the time intervals imposed by the time period structure of the model. For example, cutting coppice of age class 2 (average age 13) in period 1, gives an average age at cutting of 15·5 years.

Years old at cutting	Yield m^3 o.b. per hectare
12·5	56
15	67
15·5	70
17·5	79
20	90
20·5	92
22·5	101

TABLE 13
EXAMPLES OF WOOD VOLUME OUTPUTS IN SOME WOOD-SUPPLYING ACTIVITIES

		Activity definition			
Period	Log size	Spruce, age class 3, felled in period 4, thinned in periods 1, 2 and 3	Larch, age class 2, felled in period 5, thinned in periods 3 and 4	'Other Conifer', age class 4, felled in period 2, no thinning	Broadleaved, age class 4, felled in period 5, thinned in periods 1, 2, 3 and 4
		Cubic metres per hectare			
1	1	21			9
2	1	43		210	18
	2			20	
	3		80	15	
3	1	43			18
4	1	165	40		28
	2	185	10		
5	1		70		60
	2		210		160
Average initial age (years)		25	15	35	35
Average yield class (metric)		12·3	9·3	10·1	5·3

Chapter 3

WOOD USE

This chapter contains details of the product groups used in the wood-processing section of the model, and the way in which they are included in the matrix. Mechanical and chemical pulp are dealt with before final products because they are an intermediate stage with separate production activities in the model. On the other hand, semi-chemical pulp is used only for fluting manufacture and is described under that heading. Although waste paper is a source of wood fibre (the subject of Chapter 2) it is included in this chapter because of its close connection with the processing industry.

Primary Processed Products

For the purposes of the model, wood use is restricted to the products of primary processing, comprising sawnwood, wood-based sheets, and paper and paperboard. The general objective is to confine attention to products which must be made from wood, and to exclude secondary processing such as furniture manufacture, where wood may be used but is not actually necessary. However, it is difficult to maintain this distinction in the case of pulp and paper, because of the integrated nature of the operations, although theoretically paper need not be made from wood pulp. There is also some consideration of user industries in connection with predictions of demand for wood products, discussed in Chapter 6.

In the model thirteen wood products are distinguished, of widely varying importance. They are listed below, with alternative descriptions in brackets:

1. Coniferous sawnwood (sawn softwood)
2. Broadleaved sawnwood (sawn hardwood)
3. Plywood (inc. blockboard) } wood-based sheets
4. Particle board (wood chipboard) }
5. Fibreboard (building board) }
6. Newsprint
7. Uncoated printing and writing paper } printing and writing paper or cultural paper
8. Coated printing paper }
9. Tissue
10. Fluting medium (corrugating medium) } packaging paper*
11. Other packaging and special paper }
12. Paperboard*
13. Pitprops (exc. sawn pitwood)

An indication of their current relative importance is given in Figure 3.1. which is based on gross money values. Imports and domestic production are both valued at c.i.f. import prices, and exports at f.o.b. prices, but it should be appreciated that the areas of the symbols in the diagram do not represent value-added. For example, the symbols for paper include the value of the wood pulp, which is shown to their left. Valuing domestic waste paper at average import price probably rather overstates its importance, since quantities imported are marginal.

The reasons for this particular breakdown of products are partly the availability of necessary data, and partly the suitability or otherwise of the product for production in the United Kingdom. The limited domestic resources of wood (by comparison with Scandinavia and North America) restricts the introduction of integrated processing where economies of scale are important. Broadly speaking these are paper and paperboard products, for which effluent disposal is also a problem. Economies of scale in sawmilling and some wood-based sheets are generally smaller and it is therefore reasonable to deal with them in more detail than their relative importance indicates. Currently all the products listed are made in integrated plants from domestic roundwood, except for plywood, coated printing paper and tissue. These three are manufactured in the United Kingdom but from imported raw materials. Domestic waste paper is also an important constituent of paperboard and packaging paper.

Wood products which are excluded from the model are rayon (based on dissolving pulp) and veneers other than those in plywood.

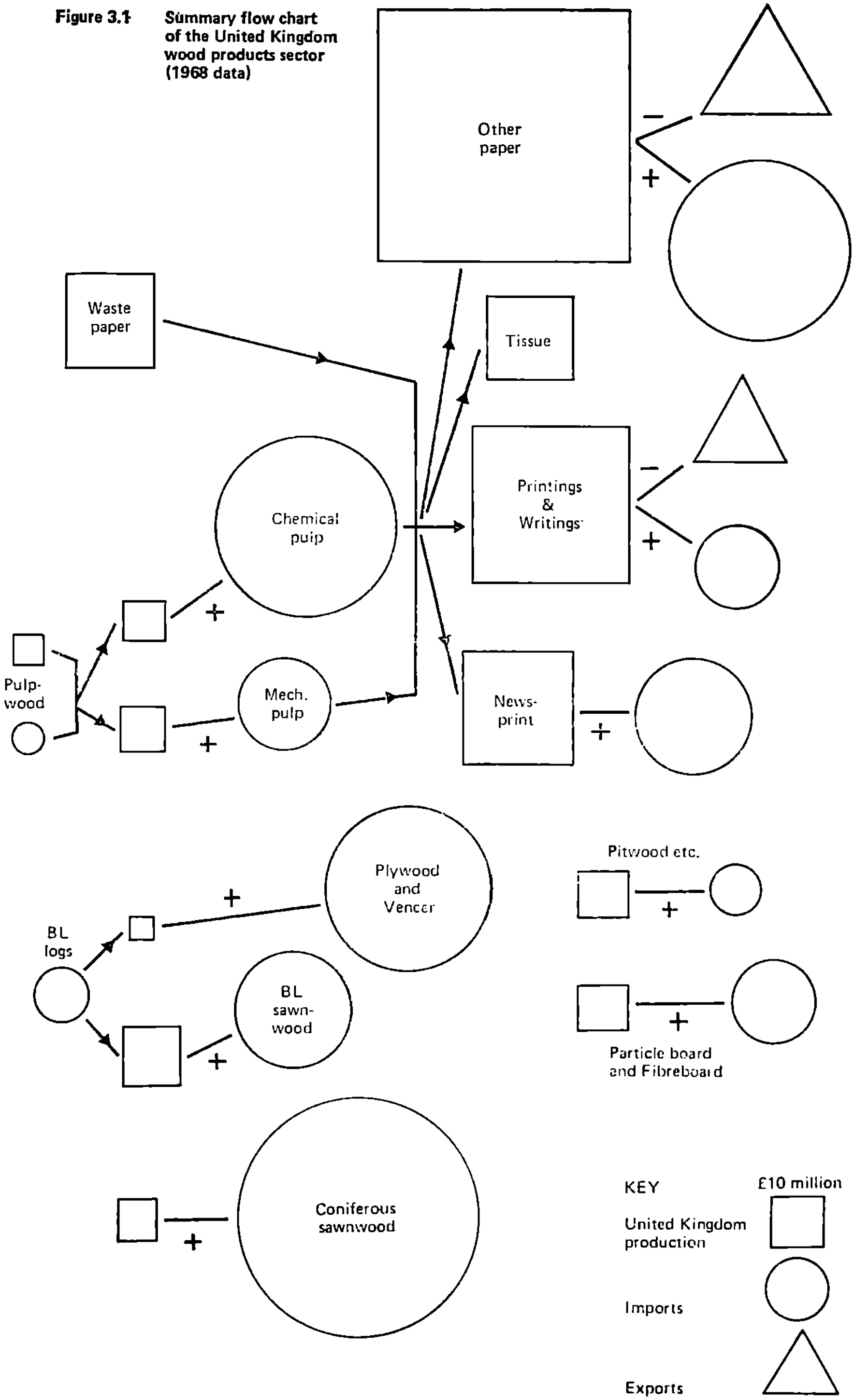
Dissolving pulp is currently entirely imported and unlikely to be made in the United Kingdom because of the large-scale nature of an economic plant, the associated water pollution problems and the low yield of dissolving pulp in relation to wood input. The veneers excluded are mainly those from tropical hardwoods, and are not directly competitive with potential domestic production. The quantities involved are also relatively small.

General Approach

The general approach is to define a series of production activities, which supply one unit of a given product, and use specific types of roundwood or other materials. Production in any period is limited

*Most countries differentiate paper and paperboard at 250 gm/m^2 but in the United Kingdom the dividing line is 220 gm/m^2, which is roughly equivalent to a thickness of ·25 mm (·01 in.) (Higham 1968, p. 350).

Figure 3.1 Summary flow chart of the United Kingdom wood products sector (1968 data)



by available machine capacity, which can be increased through new investment. The output produced contributes to satisfying maximum demands which are specified on the basis of forecasts. An example of a production activity is the production of coniferous sawnwood from large spruce logs. One cu. m. of sawnwood is estimated to require 1·9 cu. m. of large spruce logs (minimum diameter 18 cm., over bark), uses up one unit of available sawmilling capacity (defined in terms of output), and by definition contributes 1 cu. m. of coniferous sawnwood to total demand for this commodity. It also produces ·47 cu. m. of offcuts and ·25 cu. m. of sawdust. These technical coefficients are included in the matrix for each period as shown in Table 14. Fibreboard, newsprint and paperboard all make use of mechanical wood pulp (described more fully below), and printing and writing paper and tissue are made from chemical pulp. To save columns in the matrix, production of these two types of pulp is represented by sets of activities in the model, and the "output" is distributed to the various possible uses. This is only relevant to integrated production from domestic roundwood. However, newsprint is allocated its own set of activities because newsprint manufacturers do not accept larch. For chemical pulp, separation of the pulp and paper stages facilitates introducing integrated tissue production as an option. The arrangement for mechanical pulp in the model is illustrated by the part-matrix in Table 15, where the paperboard-making activity is assumed to have about one third of its furnish as mechanical pulp. The coefficients for the maximum proportion of larch imply a maximum of 35 per cent by weight.

Mechanical and chemical pulp, and waste paper, are inputs to other manufacturing activities (and waste paper is also an output from some products); for this reason their status in the model is described first.

TABLE 14

EXAMPLE OF TECHNICAL COEFFICIENTS FOR A MANUFACTURING ACTIVITY

Constraint, period n	Activity, period n: CF sawnwood from spruce logs, period n. m^3
Supply of spruce sawlogs	1·9
Sawmilling capacity	1
Demand for CF sawnwood	1
Supply of CF offcuts	−·47
Supply of CF sawdust	−·25

Mechanical Pulp

Wood consists essentially of cellulose fibres from 1 to 5 mm. long, joined by lignin. In papermaking the fibres must be separated so that they can be interfelted and then compressed, so as to form a sheet. The separation of the fibres is described as pulping, since the mixture of liquid and wood fibres forms a pulp. If the fibres are separated without the use of chemicals the pulp is described as mechanical pulp or groundwood. If chemicals are used to dissolve the lignin bonds it is termed chemical pulp. Processes combining the two methods produce semi-chemical pulp, and chemi-groundwood. In all processes involving chemicals the logs are first chipped.

Until recently mechanical pulp was produced by grinding debarked logs against continuously revolving grindstones, in the presence of water—hence the name groundwood. This is still a common method but in the past decade production by disc refining of wood chips has been preferred, and has made possible the utilisation of grades of wood hitherto considered unsuitable for groundwood (Packman 1967, p. 339). Also, peroxide bleaching can be carried out during first stage refining, if desired, and leaves no chemical residue (Higham

TABLE 15

EXAMPLE OF METHOD OF DISTRIBUTING INTERMEDIATE PRODUCT TO FINAL USES (TECHNICAL COEFFICIENTS ONLY)

Constraint, period n	Activity, period n: Mechanical pulp from: Spruce Size 1	Mechanical pulp from: Spruce Size 2	Mechanical pulp from: Larch Size 1	Mechanical pulp used for: Fibreboard	Mechanical pulp used for: Paperboard	RHS
Supply spruce size 1 (m^3)	3·0					<0
,, ,, ,, 2 ,,		3·05				<0
,, larch ,, 1 ,,			2·8			<0
,, mech. pulp (a.d. tonne)	−1	−1	−1	1·05	·33	<0
Max. % larch in furnish	−·35	−·35	·65			<0

TABLE 16

DERIVATION OF RAW MATERIAL COEFFICIENTS FOR MECHANICAL PULP

Activity definition (1 a.d. tonne)		Percent loss in: Barking (by vol) (1)	Percent loss in: Pulping (by vol) (2)	Oven-dry density kg/m³ (3)	Raw material requirement per a.d. tonne pulp: excl. loss in barking $\frac{900}{1-\frac{(2)}{100}}/(3)$ m³ (4)	Raw material requirement per a.d. tonne pulp: incl. loss in barking $(4)/\left(\frac{1-(1)}{100}\right)$ m³
Coniferous mechanical pulp from:	*spruce*					
	size 1	14	6	375	2·55	3·0
	,, 2	12	6	360	2·66	3·05
	larch					
	size 1	18	6	420	2·28	2·80
	other conifer					
	size 1	17	6	390	2·45	3·0
	,, 2	15	6	410	2·34	2·8
	,, 3	15	6	410	2·34	2·8
	offcuts	—	—	400	2·4	2·4
	plylog cores	—	6	420	2·3	2·3
	sawdust	—	6	400	2·4	2·4
Broadleaved mechanical pulp from:	BL size 1	inc.	9	430	2·30	2·30
	,, ,, 2	inc.	9	430	2·30	2·30
	coppice	inc.	9	430	2·30	2·30
	offcuts	—	9	430	2·30	2·30
	sawdust	—	9	430	2·30	2·30

Sources:

(1) Based on Forestry Commission *Forest Records* nos. 5, 8, 9, 10, 11, 14, 15.
(2) Eklund (1969).
(3) Based on figures supplied by Forestry Commission.
* The process was originated by the firm of Stora Kopparberg in Sweden.

1968, p. 274). Any expansion of mechanical pulp capacity is assumed to be disc refining of wood chips; capacity expansion is discussed at the end of this chapter.

Coniferous and broadleaved mechanical pulp are treated as separate products in the model, because of differing uses, but there is no distinction in terms of manufacturing capacity. The estimation of raw material coefficients per tonne of air-dry pulp is summarised in Table 16. The offcuts referred to in

TABLE 17

INPUT AND OUTPUT COEFFICIENTS FOR SOME MECHANICAL PULP ACTIVITIES

Constraint, period *n*	Activity, period *n* — Produce 1 a.d. tonne of pulp from: Large spruce	Small larch	Coniferous (CF) sawdust	Small broadleaved (BL1)	RHS
Supply of large spruce (m³)	3·05				<0
,, small larch ,,		2·8			<0
,, CF sawdust ,,			2·4		<0
,, BL1 ,,				2·3	<0
,, CF pulp (tonne)	−1	−1	−1		<0
,, BL ,, ,,				−1	<0
Max. % larch in CF pulp	−·35	·65	−·35		<0
,, ,, CF sawdust	−·15	−·15	·85		<0
Capacity for mech. pulp (tonne)	1	1	1	1	< capac.

the Table are from sawlogs, and are therefore already debarked; the same applies to plylog cores and sawdust. In coniferous pulp the proportion of larch is restricted to 35 per cent, and for both types the proportion of sawdust is limited to 15 per cent. These maxima are only approximate but they indicate the limits usually imposed by users of the pulp. For coniferous pulp, users are paperboard and fibreboard (newsprint is dealt with separately), and for broadleaved pulp, fibreboard. As there are fifteen activities in this section, the input and output coefficients for only a sample of the activities are shown (Table 17). The coefficients for others can be obtained from Table 16 and by inference.

Chemical Pulp

This results from separating the cellulose fibres in wood by dissolving away the lignin bonds with heat and chemicals. The chemicals used vary according to the process and product but common ones are calcium bisulphite ($Ca(HSO_3)_2$), magnesium bisulphite ($Mg(HSO_3)_2$) and sodium hydroxide (Na OH). Bleaching is necessary if the pulps are to be used in printing or writing paper. In Britain the only chemical pulp is produced by Wiggins Teape Ltd. at their mill near Fort William (Inverness-shire). The mill uses a two-stage process of the "stora" type*, based on sodium bisulphite. This process was selected because of its ability to pulp a variety of species, particularly pines and larch (Packman & Orsler 1964, p. 179). Spruce is the most suitable species but there are large plantations of pines and larches.

Wood input at Fort William mill averages 5·1 tonnes unbarked soft-wood per air-dry tonne of pulp, at a moisture content of about 56 per cent (wet basis) (Budden 1971). Oven-dry densities vary somewhat according to the species but in general softwoods are about 400 kg. per cu. m. Volume equivalents therefore average about (5100 × ·44)/400 cu. m., or 5·6 cu. m. per a.d. tonne of pulp. As the activities in the model specify making pulp from separate species and sizes, the average coefficient of 5·6 cu. m. is adjusted to allow for varying wood densities, and the coefficient for larch is increased by 5 per cent to allow for higher loss in pulping (Packman 1968, p. 14). These adjustments are only approximate but they should be in the right direction.

TABLE 18
DERIVATION OF RAW MATERIAL COEFFICIENTS FOR CHEMICAL ("STORA") PULP

Activity definition Chemical pulp from:	Size	(1) Oven-dry density kg/m³	(2) Coniferous wood requirements per a.d. tonne pulp Gross: 2244/(1) m³	(3) Net of hardwood pulp: (2) × 2/3 m³
Spruce	1	375	5·98	3·99
,,	2	360	6·23	4·16
Larch	1	420	5·56	3·71
,,	2	430	5·48	3·66
Other conifer	1	390	5·75	3·84
,, ,,	2	410	5·47	3·65
,, ,,	3	400	5·61	3·74
Plylog cores (hypothetical)		400	5·10*	3·40

Notes and Sources:
(1) Based on figures supplied by the Forestry Commission.
(2) 2244 is 5100 kg. roundwood × ·44 (56% m.c.); *5·61 × ·91 because 9% bark loss by weight does not apply; larch coefficients are multiplied by 1·05 (see text).

About one third of the furnish at the paper machine is hardwood pulp manufactured separately using imported hardwood chips, needing about 4·5 tonnes of chips per tonne of pulp. Allowing for this addition the net coniferous wood requirement is two-thirds the gross figure, as shown in columns (2) and (3) of

TABLE 19
INPUT AND OUTPUT COEFFICIENTS FOR SOME CHEMICAL PULP ACTIVITIES

Constraint, period *n*	Activity, period *n*: Produce 1 a.d. tonne of pulp from: Small spruce	Large larch	Plywood cores (hypothetical)	RHS
Supply of small spruce (m³)	3·99			<0
,, large larch ,,		3·66		<0
,, plywood cores ,,			3·4	<0
,, chemical pulp (tonne)	−1	−1	−1	<0
Max. % larch in furnish	−·2	·8	−·2	<0
Cap. for chemical pulp (tonne)	1	1	1	< capacity

Table 18. The inclusion of plylog cores as a source of raw material is a recognition of the fact that any domestic plywood mill would probably be situated in Scotland, and the cores could provide a source of raw material. Examples of input and output coefficients for chemical pulp are shown in Table 19 where all the relevant rows except some for wood supply are included.

Waste Paper

As mentioned in Chapter 2, waste paper is the main domestic source of wood fibre in the United Kingdom, although the paper recovered may originally have been imported. Most types of paper and paperboard can be re-used in paper or board manufacture, provided they can be recovered in a reasonably clean condition. The BPBMA classifies waste paper into eight types. Usually "mixed paper" accounts for about 65 per cent of the total annual consumption by weight, which is currently approaching 2 million tonnes (BPBMA 1969, p. 52).

Up to the present imports have been unimportant, around 1 or 2 per cent of total consumption (ibid. p. 49), and average import prices cannot be considered very representative. Domestic market prices vary widely according to the type, from about £50 per tonne for the best grade down to about £12 per tonne for mixed waste paper (Francis 1971). These prices are ex-merchant, excluding transport costs to the final user. From the point of view of the model they are only relevant as an indication of collection costs.

In the model only two grades of waste paper are differentiated, broadly describable as high quality and low quality. Newsprint and uncoated printings and writings, are regarded as yielding high quality waste, while coated printings, fluting medium, other packaging paper, and paperboard yield low quality waste. Coated printings are classed in this way because they are unsuitable for newsprint production by de-inking of waste paper. Approximate recovery percentages were estimated for newsprint, printings and writings, and other paper and board, on the basis of the BPBMA groupings. The results indicated about 11 per cent recovery for newsprint and printings and writings, and 40 per cent for other paper and board. This compares with an overall average of roughly 30 per cent for "recoverable paper", a proportion which has been fairly constant over the past few years (BPBMA 1968, p. 53). Recoverable paper is total consumption less those products whose use or processing prevents their recovery, e.g. wallpaper, tissue, plastic covered paper. The BPBMA estimate recoverable paper as about 87 per cent of total paper available for consumption (BPBMA 1968, p. 53). The percentages currently recovered might be increased, mainly through better recovery from households via local authority collections, but local authority attempts to run their paper collections on a commercial basis have met with difficulties because of rising costs (Callow 1969).

Because paper and paperboard production activities may produce waste paper as well as use it, the model requires one equation for supply and another for use, for each of the two grades in each time period. An illustration of the procedure used is given in Table 20, where better quality waste paper, designated WP1, is an input for production of newsprint by de-inking, and 11 per cent of the production is recovered for re-use. The recovered paper is transferred to the use row by an activity for which the collection and transport cost (in the objective function) represents the cost of waste paper to the newsprint manufacturer. The coefficient of −1 for imported WP1 could be in either the supply or the use row, but inclusion in the use row is the more direct approach. Alternatively the WP1

TABLE 20

EXAMPLE OF THE PROCEDURE FOR INCLUSION OF WASTE PAPER

Objective function	Activity, period *n*: Newsprint from de-inking	Import WP1	Transfer WP1 from supply to use	Transfer WP1 to WP2	RHS
Constraint, period *n*	NPV for newsprint exc. waste paper cost	−(c.i.f. price + transport cost)	−(collection + transport cost)	0	
Supply WP1	−·11		1		<0
Use WP1	1·06	−1	−1	1	<0
Supply WP2					<0
Use WP2				−1	<0

Notes:
1 Coefficients refer to a tonne of newsprint or waste paper, in any time period.
2 The coefficient of 1·06 tonnes WP1 assumes 90% of the furnish is waste paper, and pulping losses are 15% (·9/·85).

can be used to increase the supply of lower quality waste paper, WP2 at zero transfer cost. This will only occur if the WP2-using activities (not shown in Table 3·7) can afford the rather higher collection costs of WP1.

In the model, waste paper of grade 1 (higher quality) is used as an input to newsprint manufacture by de-inking, while grade 2 is an input to fluting medium, other packaging paper, and paperboard, as described in the relevant sections of this chapter.

Sawnwood

The two principal categories are coniferous and broadleaved sawnwood (usually known as softwood and hardwood, respectively). Currently consumption of sawn softwood (including some pitwood) is about 9 million cu. m. (1·9 mill. standards) and has been roughly static for the past few years. Hardwood consumption is about 1·75 million cu. m. (61 million cu. ft.) but has been declining gradually over the past 20 years. Imports account for about 97 per cent of softwood and 75 per cent of hardwood. Of the sawnwood which is produced in the United Kingdom, about two-thirds is from domestic logs. The remainder is from imported hardwood logs, which are included in the consumption figures given above. Trends in consumption of these and other products are covered more fully in Chapter 6.

Losses of wood in sawing depend on the number of cuts made and the thickness of the saws. FAO (1969) suggest average yields of sawnwood of 60 per cent for coniferous logs and 55 per cent for broadleaved species. Neville (1970) believes 50 per cent is a more realistic yield figure for broadleaved logs of the quality available in Britain. The minimum diameter required is not very sharply defined but 18 cm. (7 in.) over bark is a reasonable estimate and coincides with one of the size categories used by the Forestry Commission in their yield tables (Forestry Commission 1966). All the four 'species' defined in the model can produce satisfactory sawnwood, and since for "other conifers" there are two log sizes which are potentially sawable, the total number of sawmilling activities per period is five.

TABLE 21

DERIVATION OF ROUNDWOOD COEFFICIENTS FOR SAWMILLING ACTIVITIES

Activity definition 1 m³ sawnwood from:		(1) Roundwood coefficient before bark allowance m³	(2) Bark percentage by vol.	(3) Roundwood coefficient after bark allowance m³
Spruce	size 2	1·67	12	1·9
Larch	,, 2	1·67	15	1·97
Other conifer	,, 2	1·67	15	1·97
,, ,,	,, 3	1·67	14	1·95
Broadleaved	,, 2	2·0	10	2·2

Sources:
(1) FAO *Yearbook of Forest Products 1969.*
(2) Forestry Commission *Forest Records*, nos. 5, 8, 9, 10, 11, 14, 15, and Neville (1970).

Sawnwood yields of 50 and 60 per cent (see above) imply roundwood coefficients of 2·0 and 1·67 per unit of sawnwood, but as the wood volumes are over bark, bark allowances increase these coefficients as shown in Table 21.

The complete set of technical coefficients for sawmilling activities is given in Table 22.

TABLE 22

INPUT AND OUTPUT COEFFICIENTS FOR SAWNWOOD

Constraint, period *n*	Activity, period *n* — Produce 1 cu. m. sawnwood from: Large spruce	Large larch	Other conifer: Large	Other conifer: v. large	Large broadleaved	RHS
Supply of large spruce	1·9					<0
,, ,, ,, larch		1·97				<0
,, ,, ,, other conifer			1·97			<0
,, ,, v. large other conifer				1·95		<0
,, ,, large broadleaved					2·2	<0
,, ,, CF offcuts	−·47	−·49	−·49	−·49		<0
,, ,, BL ,,					−·55	<0
,, ,, CF sawdust	−·25	−·25	−·25	−·25		<0
,, ,, BL ,,					−·25	<0
Capacity for sawmilling	1	1	1	1	1	< cap.
Demand for CF sawn wood	1	1	1	1		< dem.
,, ,, BL ,,					1	< dem.

Plywood

This is defined as "a panel manufactured by gluing together one or more veneers to both sides of a veneer or solid wood core. The grain of alternate layers is crossed, generally at right angles" (FAO 1966, p. 3). Plywood with a solid wood core is usually described as blockboard. UK consumption is currently about 1 million cu. m.

At present the only plywood produced in Britain is made from imported hardwood logs, but trials at the FPRL have indicated that constructional grade (i.e. lower quality) plywood could be made from domestic logs of Scots pine and Douglas fir, although spruce was less satisfactory (Carruthers 1969). With modern log peelers, the minimum log diameter is about 25 cm. (10 in.) and in the model is taken to be 24 cm., the largest of the Forestry Commission size categories. Because the log must be held at each end during the peeling process, a core always remains unused, but this may be as small as 5 cm. (2 in.). The recovery of veneers from a log depends on its size but a representative figure is 40 per cent (Carruthers 1969). About two-thirds of the losses occur as cores, and the remainder in pressing and trimming.

In the model, plywood is assumed to be producible from 'other conifer' logs of size 3. With a probable recovery of about 40 per cent the roundwood coefficient per cu. m. of plywood is $1/{\cdot}4 = 2{\cdot}5$; adjusted for bark percentage this becomes 3·0 cu. m. per cubic metre of plywood. Residues are 40 per cent of the barked volume, plus the trimmings, i.e. $({\cdot}4 \times 2{\cdot}5) + {\cdot}2$, or 1·2 cu. m.

Particle Board

This comprises flaxboard and wood chipboard, of which only the latter is produced in Britain. At present consumption is about 600 thousand cu. m. (21 million cu. ft.), but it has been rising rapidly over the past few years, e.g. in 1960 consumption was only about 100 thousand cu. m. Domestic production is about 300 thousand cu. m. of chipboard, and imports include some 75 thousand cu. m. of flaxboard, mainly from Belgium.

Particle board is defined by FAO as 'a panel manufactured from particles of wood or other lignocellulosic materials bonded by the use of one or more agents such as heat, pressure, moisture, catalyst etc.' (FAO 1966, p. 13). The bonding agent is in fact a resin glue, either urea formaldehyde (UF) or phenolformaldehyde (PF). In general PF board is more expensive to make but is stronger. The board is made by spraying the wood (or other) chips with resin and forming mats of the coated particles, which are then bonded by heat and pressure. Production may be in batches or continuous, depending on the equipment, and the usual density is from 0·4 to 0·8 g/cm^3 (25 to 50 lb./ft^3).

There is a good deal of disagreement about the suitability of different species for chipboard manufacture. Coniferous species are favoured, but "most domestic particle board manufacturers consider that a maximum of ten percent hardwood is permissible" (Hudson 1970). On the other hand many continental manufacturers use much higher percentages, although usually the hardwood chips are concentrated in the centre layers, to avoid darkening the surface of the board. Core chips may retain the bark, to increase recovery and avoid debarking problems with species such as oak and elm. Larch is an unpopular softwood species and some manufacturers refuse to take it. The particles may be produced by chipping roundwood, or from sawmill residues such as shavings and slabs. A proportion of sawdust can be included in the outer layers, and helps to produce a smooth surface.

In the model, chipboard may be made from all the four 'species' but larch and broadleaved are each restricted to a maximum of ten per cent of the total furnish, as is sawdust. Table 23 shows the

TABLE 23

ROUNDWOOD COEFFICIENTS FOR PARTICLE BOARD

Activity definition 1 m^3 particle board from:	*Size*	Roundwood coefficient (1·3 m^3 adj. for bark, if any) m^3	
Spruce	1	1·5	
,,	2	1·45	
Larch	1	1·6	maximum 10% of raw material
,,	2	1·55	
Other conifer	1	1·55	
,,	2	1·5	
,,	3	1·5	
Broadleaved	1	1·45	maximum 10%
,,	2	1·45	
(,,) coppice		1·45	
Broadleaved offcuts		1·45	
Coniferous ,,		1·5	
,, sawdust		1·3	maximum 10%
Broadleaved ,,		1·3	
Plylog cores		1·3	

Sources:
1. Eklund (1969).
2. Forestry Commission *Forest Records* nos. 5, 8, 9, 10, 11, 14, 15.

activities defined, and roundwood coefficients. These are based on a barked roundwood requirement of 1·3 cu. m. roundwood per cu. m. of board (Eklund 1969). The input and output coefficients for a representative sample of production activities are given in Table 24.

TABLE 24

EXAMPLES OF INPUT AND OUTPUT COEFFICIENTS FOR PARTICLE BOARD

Constraint, period *n*	Activity, period *n*						
	Produce 1 m³ of particle board from:						
	Small spruce	Small larch	Large broadleaved	Sawdust Conif.	Sawdust BL	Conif. offcuts	RHS
Supply of small spruce m³	1·5						<0
,, ,, ,, larch ,,		1·6					<0
,, ,, large BL ,,			1·45				<0
,, ,, conif. offcuts m³						1·5	<0
,, ,, ,, sawdust ,,				1·3			
,, ,, BL ,, ,,					1·3		<0
Max. % larch	−·1	·9	−·1	−·1	−·1	−·1	<0
,, ,, broadleaved	−·1	−·1	·9	−·1	·9	−·1	<0
,, ,, sawdust	−·1	−·1	−·1	·9	·9	−·1	<0
Capacity for particle board	1	1	1	1	1	1	< cap.
Demand for particle board	1	1	1	1	1	1	< dem.

Fibreboard (building board)

Fibreboard is "a sheet of material made from fibres of wood or other lignocellulosic material and manufactured by an interfelting of the fibres followed by compacting between rolls or in a platen press" (FAO 1966, p. 10). The production method is therefore similar to papermaking and different in principal from that for particle board, where the chips are in effect stuck together. There are two principal types of fibreboard, compressed (hardboard) and non-compressed (insulation board), with the dividing line drawn at a density of 0·4 g/cm³ (25 lb/ft³). Within these two categories there are also further subdivisions based on density, but the usual type of hardboard has a density of about 1 g/cm³ (62·5 lb/ft³). Consumption is about 300 thousand tonnes annually, of which about 80 per cent is hardboard.

Fibreboard can be made from practically any species of wood grown in Britain, including the bark. The first stage is the production of coarse mechanical pulp. Because mechanical pulp manufacture is represented in the model by separate activities, there are only two activities specifically for fibreboard manufacture, one using coniferous mechanical pulp and the other broadleaved pulp. Losses of fibre in pulp making are allowed for in the roundwood coefficients of the pulpmaking activities; losses at the boardmaking stage depend on trimmings, which are estimated at 5 per cent. The coefficient is therefore 1·05 tonnes pulp per a.d. tonne of fibreboard.

Newsprint

This is a cheap but important grade of paper, used primarily in the production of newspapers. The pulp furnish is normally about 80 per cent mechanical and 20 per cent bleached chemical. These percentages are lower in the final product because around 5 per cent of clay is added as a filler, apart from the usual 10 per cent moisture content in an air-dry product. Consumption of newsprint is currently about 1·5 million tonnes, without any marked trend up or down. Of this total approximately 300 thousand tonnes is produced in Britain using domestic mechanical pulp, most of which is from domestic roundwood. Spruce is the favoured species, and larch is not accepted. For this reason newsprint has its own production activities in the model. The derivation of roundwood input coefficients for activities using this raw material are listed in Table 25. It is assumed that losses in pulping and papermaking total 10 per cent by weight (Eklund 1969).

Newsprint is also made by de-inking used paper, particularly over-issue and used newsprint, and uncoated magazine paper. Although these contain 20 per cent or more of chemical pulp it is realistic to allow for the addition of some new chemical pulp, unless best quality white waste paper forms part of the furnish. In the model it is assumed that the better of the two grades of waste paper distinguished, is usable for newsprint production by de-inking (in fact this is the reason for the division into two grades). The coefficients involved are included in Table 26, and an input of 1·06 tonnes implies that 10 per cent of the furnish is chemical pulp, because a 15 per cent loss in pulping is assumed. Table 26 also shows the remaining technical coefficients, from which it can be deduced that "other conifer" wood is limited to 20 per cent of the total, and each producing activity supplies ·11 tonnes of waste paper of grade 1. Production of newsprint in the United Kingdom from imported

TABLE 25

DERIVATION OF ROUNDWOOD COEFFICIENTS FOR NEWSPRINT

Activity definition, 1 tonne of newsprint from:	(1) Percent loss in barking (by vol)	(2) Oven-dry kg. p.m³	(3) Roundwood requirement per a.d. tonne newsprint, m³: Exc. loss in barking $\frac{900}{\cdot 94}/(2)$	(4) Inc. loss in barking (3)/(1)	(5) Adjusted for loss in paper, and furnish % (4) × ·83
Spruce size 1	14	375	2·55	2·97	2·47
" " 2	12	360	2·66	3·02	2·51
Other conifer " 1	17	390	2·45	2·95	2·45
" " " 2	15	410	2·34	2·75	2·28
" " " 3	15	410	2·34	2·75	2·28

Notes and Sources:
(1) Based on Forestry Commission *Forests Records* nos. 5, 8, 9, 10, 11, 14, 15.
(2) Based on figures supplied by Forestry Commission.
(3) 900 from 1000 kg. and 10% moisture; ·94 assumes 6% loss in pulping (Eklund 1969, Annex 4).
(5) ·83 from 80% of furnish and 4% loss in papermaking (Eklund 1969 Annex 6).

TABLE 26

INPUT AND OUTPUT COEFFICIENTS FOR NEWSPRINT

Constraint, period *n*	Activity, period *n*: 1 a.d. tonne of newsprint from: Spruce		Other conifer			Imported pulp	De-inked waste paper	RHS
	small	large	small	large	v. large			
Supply of small spruce (m³)	2·47							<0
" " large " "		2·51						<0
" " small other conifer "			2·45					<0
" " large " " "				2·28				<0
" " v. large " " "					2·28			<0
" " waste paper 1 (tonne)	−·11	−·11	−·11	−·11	−·11	−·11	−·11	<0
Use " " 1 "							1·06	<0
Max. % other conifer in furnish	−·2	−·2	·8	·8	·8			<0
Integrated capacity (tonne)	1	1	1	1	1			< cap.
Non-integrated capacity (tonne)						1		< "
De-inking " "							1	< "
Demand for newsprint "	1	1	1	1	1	1	1	< dem.

pulp has declined in recent years because of competition from Scandinavia, where integrated production is possible.

Printings and Writings

Alternative descriptions for this category are "cultural" and "graphic" paper. It comprises a variety of paper qualities and types, but the main properties looked for are uniformity of thickness and surface, with adequate strength and permanence. Whiteness, opacity and gloss are also often important, depending on the type of paper. In general the higher the proportion of chemical pulp as compared with mechanical pulp, the better the quality of paper, in terms of the properties listed.

One method of improving paper for printing is glazing or calendering, where the damp paper is passed between smooth hot rollers which increase the surface gloss. A more expensive process is coating, in which a layer of pigments and binders is applied to the surface of paper or board, either during the papermaking process ("on-machine coating") or at a later stage ("off-machine coating") (BPBMA 1965, p. 212). In this way the fibres in paper with a high proportion of mechanical pulp can be concealed, and the paper made suitable for good quality half-tone reproductions, for example. Present annual consumption of uncoated paper in the United Kingdom is about 900 thousand tonnes, and of coated paper nearly 400 thousand tonnes, with both trending upwards.

In the model, coated and uncoated papers are

TABLE 27

INPUT AND OUTPUT COEFFICIENTS FOR PRINTINGS AND WRITINGS, AND TISSUE (UNCONVERTED)

Constraint, period *n*	Activity, period *n*						
	Produce 1 a.d. tonne of:						RHS
	Uncoated printings and writings from:			Coated printings from imported pulp	Tissue from:		
	UK pulp		Imported pulp		UK pulp	Imported pulp	
	integ.	non-integ.					
Supply of chemical pulp (tonne)	·92	·92			1·0		<0
,, ,, waste paper 1 ,,	−·11	−·11	−·11				<0
,, ,, ,, ,, 2 ,,				−·11			<0
Integ. capacity, uncoated ,,	1						< cap.
Non-integ. ,, ,, ,,		1	1				< ,,
,, ,, coated ,,				1			< ,,
Integ. capacity, tissue (tonne)					1		< ,,
Non-integ. ,, ,, ,,						1	< ,,
Demand for uncoated p. & w. ,,	1	1	1				< dem.
,, ,, coated printings ,,				1			< ,,
,, ,, tissue ,,					1	1	< ,,

treated as separate products, although demand predictions for the two are made in conjunction with each other. The only integrated production in the United Kingdom is about 50 thousand tonnes of uncoated paper at Fort William in Scotland, although some of the pulp produced at the mill is sold to other paper makers. Non-integrated uncoated capacity is estimated at about 725 thousand tonnes annually, with non-integrated coated paper about 350 thousand tonnes. There are therefore three production activities for uncoated paper, integrated, and non-integrated both from United Kingdom pulp and from imported pulp. Coated paper production is assumed to be non-integrated. A coating machine could be installed at the Fort William mill but in terms of value added to uncoated paper it would make more sense to coat mechanical printings (i.e. paper with a high proportion of mechanical pulp, up to say 60 per cent). Technical coefficients for these four activities are shown in Table 27. The chemical pulp input to uncoated paper of ·92 tonnes pulp per tonne of paper, is derived from 98 per cent recovery of paper from pulp, and 10 per cent of additives such as clay, by weight. Each of the activities is assumed to yield 11 per cent of its own weight as waste paper, but coated waste is assigned to the lower quality waste paper because of its unsuitability for newsprint manufacture.

Tissue

For the purposes of the model this category comprises soft and hard tissue, and cellulose wadding. The main uses are for household and sanitary purposes, and for wrapping. Usually the main purpose of soft tissue is to absorb liquids, and therefore the paper is frequently creped but not sized. Total consumption of all types is now about 350 thousand tonnes annually and consumption of household tissue is growing rapidly.

Currently the only tissue manufactured in Britain is non-integrated production from imported chemical pulp. It could be produced in an integrated plant but the furnish used at Fort William mill, for example, would not be suitable. Another complication is that production and conversion of tissue (e.g. boxing of tissue handkerchiefs) are often combined in one production line. This is in fact more a problem for the calculation of net revenues than for physical inputs and output coefficients. In the model, allowance is made for non-integrated production of unconverted tissue, and also for integrated production although this is at present not a very realistic possibility, because it implies a chemical pulp mill with its problems of adequate wood supply and effluent disposal. For integrated production from chemical pulp, the coefficient is 1 tonne pulp per tonne of paper (Kimberly-Clark 1970) but since current capacity is zero, production cannot start unless new capacity is installed, as described at the end of this chapter. The technical coefficients for tissue-making activities are included in Table 27.

Fluting Medium (corrugating medium)

This is normally about ·225 mm. (·009 in.) thick and is therefore paper on the usual definitions, but may be described as paperboard in the trade. It is used as a corrugated sheet glued between two paper or paperboard facings or liners (usually kraft), in the manufacture of "corrugated fibreboard" packaging cases. Stronger cases can be made from multi-layer boards described for example as twin-flute and triple-flute, although terminology varies. Fluting medium is also used unlined or with only one liner, as wrapping and packaging material. Better quality fluting is made from semi-chemical hardwood pulp, including some waste paper, but it can also be made entirely from waste paper ("bogus fluting"). In the model, fluting is given separate production activities and demand requirements, because semi-chemical fluting is made in integrated plants in Britain, using broadleaved species. At present there are two plants, Ashton Paper Mill at Sudbrook near Chepstow in Monmouthshire, and a mill at Bowater's complex at Sittingbourne in north Kent.

In the production process the logs are first chipped and the material is then cooked in a solution of sodium sulphite ($Na\ SO_3$) for about 2 hours. The softened chips are then turned into pulp by a mechanical refining process. After "washing" the pulp to remove the cooking liquor, it is blended with pulp made from waste paper, and the mixture passes to a normal paper-making machine where the pulp is converted to a mat of fibres and dried between heated rollers. Corrugation of the paper is carried out where the packaging cases etc. are made. Consumption of corrugating medium is now approaching half a million tonnes annually, and represents about 20 per cent of the category "packaging and special papers" (as defined in this study) including fluting itself.

Manufacturing activities are defined as production of fluting from waste paper, and from broadleaved species including coppice. The complete set of input and output coefficients for one period is set out in Table 28.

The yield of pulp from unbarked hardwood logs is about 80 per cent, weight for weight (Robinson 1970), so that $(1/{\cdot}8) = 1{\cdot}25$ tonnes of wood are needed to produce 1 tonne of pulp (oven-dry weights). If the density is 430 kg. per cu. m. of oven-dry wood, the volume required is $(1{\cdot}25/{\cdot}43) = 2{\cdot}9$ cu. m., equivalent to 2·6 cu. m. per tonne of a.d. pulp. However, if 30 per cent of the furnish is waste paper, as is usual in practice, the wood input is reduced to 1·84 cu. m. Since one tonne of pulp contains ·3 tonnes of fibre originating from waste paper, an 85 per cent recovery of waste paper implies an initial weight of $({\cdot}3/{\cdot}85) = {\cdot}35$ tonnes waste paper (a.d.). Similarly the input of waste paper for manufacture of bogus fluting allows for 85 per cent recovery in pulping.

Other Packaging Paper (other than fluting medium)

This category comprises greaseproof and "parchment" papers, wrappings, liner paper and board for fluting medium, and industrial and special purpose papers such as wallpaper base and dye line paper. Most of the wrapping and liner paper is kraft or imitation kraft. (Kraft paper is strong brown paper made from sulphate pulp.) An indication of the relative importance by weight of the main types of paper in this category is as in Table 29. Estimates of the corresponding percentage breakdown in value terms, based on import prices, indicated a fairly similar pattern, although "other" paper would show a larger percentage because of some high-value

TABLE 28
INPUT AND OUTPUT COEFFICIENTS FOR FLUTING MEDIUM

Constraint, period n	Activity, period n				
	Produce 1 a.d. tonne of fluting medium from:				
	Semi-chemical pulp from:				
	Broad-leaved		Coppice	Wastepaper	RHS
	small	large			
Supply of small broadleaved m³	1·84				<0
,, ,, large ,, ,,		1·84			<0
,, ,, coppice ,,			1·84		<0
,, ,, wastepaper 2 tonne	−·4	−·4	−·4	−·4	<0
Use ,, 2 ,,	·35	·35	·35	1·18	<0
Capacity, semi-chemical ,,	1	1	1		$<$ cap.
,, wastepaper fluting ,,				1	$<$,,
Demand for fluting ,,	1	1	1	1	$<$ dem.

TABLE 29

ESTIMATED BREAKDOWN OF CONSUMPTION OF "OTHER PACKAGING PAPER"

Description		Apparent consumption 1970 th. tonnes	%
Greaseproof and "parchment"		105	5·6
Wrappings:	kraft	595	31·5
(inc. sacks)	other	118	6·2
Liner:	kraft	390	20·6
	other	292	15·4
Wallpaper base		117	6·2
Other		274	14·5
Total		1891	100·0

Source:
Based on BPBMA data; note that paper is defined as less than 220 g.p.m^2, which excludes some liner "board" used for the same purpose as liner paper.

special papers included under this heading.

In the United Kingdom the papers in this category are made only in non-integrated plants, and the raw materials needed are calculated as an average furnish. In terms of three components the composition is:

mechanical pulp	11 per cent	(·11)
chemical pulp	55 ,, ,,	(·57)
waste paper	34 ,, ,,	(·35)
	100 ,, ,,	

and the input coefficients per tonne of paper are very similar (shown backeted). In fact of these three only the waste paper coefficient is included in the matrix, referring to lower quality waste, although in principle domestic mechanical pulp could be used in the furnish. The coefficients for this activity, in each period, are therefore as shown in Table 30.

TABLE 30

INPUT AND OUTPUT COEFFICIENTS FOR "OTHER PACKAGING" PAPER

Constraint, period *n*		Activity, period *n*: Produce 1 a.d. tonne of "other packaging" paper
Supply waste paper 2	(tonne)	−·4
Use waste paper 2	,,	·35
Manufacturing capacity (non-integrated)	,,	1
Demand for packaging paper	,,	1

Paperboard

In Britain this definition generally refers to paper material weighing more than 220 grams per square metre, equivalent to a thickness of ·25 mm., although fluting medium is usually thinner than this but may be described as paperboard. In the model, however, fluting medium is included with packaging paper. The term "board" is often used as a synonym for paperboard, which may be divided into three categories (Curry 1970), containerboard, carton board, and solid bleach board. Some confusion with other products can arise here. For example, "fibreboard packing cases" are made from corrugated or solid containerboard and have no connection with fibreboard, the general name for building board, which comprises mainly hardboard and insulation board. Again the term "chipboard" is also used for some grades of packaging board, although in Britain "wood chipboard" is the common name for particle board based on wood.

In the United Kingdom about five-sixths by weight of the consumption of paperboard consists of boards used in packaging; this proportion is based on quantities before making up into e.g. packaging cases, which often contain fluting medium. The remaining consumption is of such types as boot and shoe board, roofing felt, and liner for plasterboard. Production of paperboard using domestic mechanical pulp is carried on by St. Anne's Board Mill Co. Ltd. at Bristol, and Thames Board Mills Ltd. at Workington in Cumberland. Production from waste paper and imported pulp is more widespread.

In the model there are two manufacturing activities per period, one using a fairly high proportion of (domestic) mechanical pulp, as at St. Anne's Board Mill, the other using an "average" furnish of which the domestic component is waste paper, although in principle all the wood fibre inputs could be from domestic sources. This is not a perfect representation of the actual situation but is regarded as the best available if all paperboard is treated as one commodity. The coefficients used are shown in Table 31. For integrated production the coefficients

TABLE 31

INPUT AND OUTPUT COEFFICIENTS FOR PAPERBOARD

Constraint, period *n*	Activity, period *n*: Produce 1 a.d. tonne paperboard from: "integrated" process	non-integrated process
Supply coniferous mechanical pulp (tonne)	·33	
Supply waste paper 2 (tonne)	−·4	−·4
Use ,, ,, 2 ,,	−·53	·77
Capacity integrated paperboard	1	
,, non-integrated ,,		1
Demand for paperboard	1	1

imply a furnish composition, allowing for losses in production, approximately as follows:

	%
chemical pulp	17
mechanical pulp	31
waste paper	45
fillers	7
	100

The chemical pulp is taken to be imported. Non-integrated production is assumed to have an average furnish with a higher percentage of waste paper:

	%
chemical pulp	19
mechanical pulp	7
waste paper	67
fillers	7
	100

Losses of pulps and waste paper inputs in processing are taken to be respectively 5 and 15 per cent.

Pitprops

"Pitprops are of round softwood, selected for quality and straightness, and air-dried to provide the maximum strength in use" (Willis 1968, p. 108). There is now little demand for props which are more than 2 metres (6½ feet) long and 16 cm. (6½ in.) top diameter under bark, because the larger props have mainly been replaced by steel supports (James 1966, p. 113). It is therefore reasonable to restrict pitprop-producing activities to the three types of small conifer, spruce, larch and other conifer. The coefficient is taken to be 1·1 cu. m. roundwood per cu. m. of pitprops, to allow for wastage in trimming and any other losses.

Existing Manufacturing Capacity

Processing of domestic or imported raw materials is limited by the capacity available at a given time. The definition of "capacity" is not unambiguous, since for example it depends on the number of shifts worked. The BPBMA definition is "the maximum daily, hourly or weekly saleable tonnage of the quality or qualities usually produced, multiplied by the maximum number of days, hours or weeks of scheduled operation during the year" (BPBMA 1968, p. 27). This definition assumes "usual operating conditions" and that adequate services are available. Recent output/capacity ratios have been as low as 85 per cent for newsprint and as high as 104 for kraft paper. Ratios exceeding 100 per cent occur where workers voluntarily agree to work through more weekends than are scheduled by national agreements.

In the model, estimates of available production capacity are needed for each period. They are incorporated as the RHS value in the capacity constraint row which is included for every final product except pitprops. The estimates used are based on the most recent production figures, adjusted if necessary to allow for output/capacity ratios different from 100 per cent. It is assumed that all existing capacity will be worn out or obsolete by the end of period 3 in the model (i.e. by 1985) and in most cases that the depreciation will be gradual over these 15 years. The actual figures used to approximate the rate of depreciation over the three periods are:

	1970 capacity × 5 ×
Period 1	·9
„ 2	·6
„ 3	·3

However, in cases where most or all of the capacity is represented by a few factories, this procedure has been varied. The estimates used are shown in Table 32 and the notes to the table indicate the procedures used.

New Manufacturing Capacity

Available manufacturing capacity can be expanded in any time period by means of activities defined as increasing capacity by one unit of production per year; however, since the capacity remains for a number of years, the coefficients must reflect this. In practice, increments would always represent a large number of units of production, but this is only important in relation to estimating the cost of expansion (Chapter 4). The coefficients for the capacity expansion activities have a negative sign in the appropriate capacity constraint row. Since the machinery and buildings can be expected to last for more than one time period, an activity normally has coefficients in more than one capacity row.

Installation is assumed to be at the mid-point of a time period, for which it is given a coefficient of −(·5 × length of period), representing the average capacity within the period. Alternatively the capacity can be considered to be installed at a uniform rate within a period, and two estimates of the multiplier (·5 above) are derived below, for a 5-year period.

	No construction time-lag	*1-year lag*
Years in operation: (maximum 25)	1 unit for 5 years	1 unit for 4 years
	1 „ 4 years	1 „ 3 years
	1 „ 3 years	1 „ 2 years
	1 „ 2 years	1 „ 1 year
	1 „ 1 year	
	15 years	10 years
	15/25 = ·6	10/25 = ·4

TABLE 32

MANUFACTURING CAPACITIES IN 1970 AND PERIODS 1 TO 3

Process and unit (tonnes exc. where stated)	(1) 1970 value (annual) th.	(2) Capacity (th.) in period: (1) × 5 × ·9	(3) (1) × 5 × ·6	(4) (1) × 5 × ·3 except where noted *
A. Sawmilling (m^3)	650	2925	1950	975
B. Newsprint:				
(i) integrated	300	1350	900	450
(ii) non-integrated	400	1800	1200	600
(iii) de-inking	100*	500	500	500
C. Uncoated p. and w.:				
(i) integrated	50*	250	250	250
(ii) non-integrated	725	3262	2175	1087
D. Coating printings, non-integrated	350	1575	1050	525
E. Fluting:				
(i) semi-chemical	115	5175	345	1725
(ii) other	260	1170	780	390
F. Tissues, non-integrated	340*	1530	1190	850
G. Other paper, non-integrated	1020	4590	3060	1530
H. Paperboard:				
(i) integrated	105*	525	525	525
(ii) non-integrated	1250	5625	3750	1875
I. Mechanical pulp (exc. newsprint)	50*	250	250	250
J. Chemical pulp, integrated	80*	400	400	400
K. Fibreboard	35	157	105	52
L. Particle board (m^3)	300	1350	900	450
M. Plywood (m^3)	30	135	90	45

Notes and Main Sources for 1970 value:
General—production, capacity, and output/capacity ratios for pulp and [paper products are given in the BPBMA *Reference Tables* (annual).

A. *Business Monitor P. 36* (Home-grown Timber) shows 1970 sawmill output as 646 th. m^3.
B. (i) 1970 estimate based on information from Bowaters.
(ii) 110 per cent of 1970 production (BPBMA) net of production from integrated and de-inking plants.
(iii) a rough estimate based on the *Financial Times* 13.3.68 (Reed Group), plus an allowance for Dixon's capacity. The plant is relatively new.
C. (i) Capacity refers to Wiggins Teape's Fort William Mill (see e.g. W.T. Directors' Report 1967). Future capacities shown imply the mill is functional until 1986.
(ii) 92 per cent of 1970 total output net of Fort William.
D. 92 per cent of 1970 output.
E. (i) Estimated from BPBMA figures.
(ii) Inferred from 1969 production of all fluting net of integrated production.
F. 1970 value from BPBMA data. As much capacity is recent, reduction over period is based on the factors 1·0, 0·7, 0·5 instead of 0·9, 0·6, 0·3.
G. From output of packaging and special papers, adjusted for fluting.
H. (i) Comprises capacity of St. Anne's Board Mill (Bristol) and Thames Board Mills (Workington). An approximate estimate calculated from:

St. Annes,	20 th. tonnes mech. pulp	30% of furnish = 65 th. tonnes
Thames,	30 „ „ „ „	75% „ „ = 40 „ „

(ii) 1970 production of paperboard adjusted for integrated production.
I. BPBMA figure adjusted for newsprint (1970).
J. See note C (i).
K. BPBMA, 1970 production.
L. Based on production shown in TTFUK *Yearbook of Timber Statistics 1969*.
M. See note L.

Similar but not identical results are obtained for longer periods, but a value of $-\cdot 5$ is a reasonable approximation in all cases.

The values of the coefficients in capacity rows for later periods depend on the average life assumed. In the present case 15 years is taken as the basic average operational life, and in many cases this means that the final capacity coefficient for a given activity is a fraction, as for the installation period. A check of the values is that the sum of the coefficients should equal 15. For example, plant installed in period 1 will have coefficients of -5 in periods 2 and 3, plus a coefficient of $-2{\cdot}5$ in periods 1 and 4, a total of 15. The values are summarised in Table 33.

Conversions of existing capacity are assumed to have a life of ten years and the coefficients applicable are shown bracketed in Table 33, if they differ from those for new capacity.

TABLE 33

COEFFICIENTS FOR CAPACITY INCREASES, WITH 15-YEAR LIFE*

Period of capacity	New capacity installed in period: 1	2	3	4	5	6	7
1	-2·5						
2	-5	-2·5					
3	-5(-2·5)	-5	-2·5				
4	-2·5(-)	-7·5(-2·5)	-10(-7·5)	-5			
5			-2·5(-)	-10(-5)	-5		
6					-10(-5)	-5	
7						-10(-5)	-7·5

* Bracketed figures apply to conversions of existing capacity (10-year life) where the coefficients differ from those for new capacity.

Chapter 4

CALCULATION OF NET REVENUES

This chapter gives an account of the estimation of discounted net revenues for the activities in the model. First the general principles of the model are recapitulated briefly, followed by descriptions of the procedures for estimating net revenues for existing and new plantations, primary manufacturing, new capacity and imports.

General Principles

The model is constructed with wood fibre-supplying activities providing the raw material for wood fibre-using activities. Since manufacturing is linked to these raw materials, the wood-supplying activities have negative net revenues, representing the cost of providing the material, and the wood-using activities have positive net revenues, excluding any costs already allowed for in the wood-supplying activities. The sale values of these "final products" is based on current import prices, and provision is made for varying these prices (relative to other prices) over time. Imports of final products are also given small but positive net revenues, on the argument that imports release domestic resources for profitable use elsewhere. The realism of this assumption will vary from time to time, depending on the level of employment in the United Kingdom, but the aim is to explore the competitive position of domestic production of wood (final) products in relation to the corresponding imports. Those raw materials which have separate importing activities, such as pulpwood and waste paper, are given negative net revenues, estimated from their current import prices.

All historical costs, such as establishment costs for existing plantations, and amortisation costs for installed machinery and plant, are excluded from net revenues. However, in general it is assumed that the management costs incurred in the past are a reasonable guide to the necessary amount to be spent in the future, although when the production period is so long it is in fact difficult to assess the most economic level of protection costs, for example.

Recalculation to Constant Prices

The estimates of costs and revenues, described later in this chapter, are based on recent time series data which are recorded at prices current at the time. In most cases these series have shown an upward movement in money terms, but part or all of this may be a reflection of changes in the general price level. As the latter changes at varying rates, it is helpful to express values at constant prices, taking some base year as a reference point. It is impossible to make an exact adjustment for general price changes, but an approximate correction can be made by dividing values at current prices by a broadly-based index of prices in the economy as a whole. In the present study the main price index used is the Index of Total Final Prices published by the National Institute of Economic and Social Research in the *National Institute Economic Review*, recalculated with 1967 equal to 100. In some estimates of future demands for wood products the GNP deflator is used instead (see Chapter 6). This can be obtained by dividing GNP at constant prices by GNP at current prices, but since the base year has changed twice, over the period 1948 to 1969, it is necessary to splice the different series together, on the basis of overlapping values. The same is done for the NIESR index. The resulting indices are listed in Table 34, together with the corresponding values of the retail price index, based on

TABLE 34

PRICE INDICES 1948–70 (1967 = 100)

Year	Index from NIESR Index of Total Final Prices	Index from GNP deflator	Retail price index (for comparison)
1948	54·0	—	49·5
49	55·5	51·8	51·2
50	57·2	51·9	53·0
51	64·2	56·0	58·2
52	68·0	61·2	63·4
53	68·2	62·6	65·1
54	69·1	63·8	66·0
55	71·8	65·8	69·4
56	75·7	69·5	72·7
57	78·3	72·5	75·4
58	80·1	77·4	77·7
59	80·7	78·7	78·2
60	81·7	80·1	79·0
61	83·9	82·7	81·7
62	86·6	85·5	85·1
63	88·0	87·3	86·8
64	90·2	89·6	89·6
65	94·0	93·1	93·8
66	97·5	96·4	97·6
67	100	100	100
68	105·0	102·6	104·7
69	109·9	106·3	110·4
70	118·4	—	117·4

Sources:
National Institute Economic Review.
Annual Abstract of Statistics.
LCES *The British Economy Key Statistics 1900–1970.*
Note:
The NIESR price index is the one used unless otherwise stated.

the London and Cambridge Economic Service, for comparison only. It is evident that the NIESR index suggests a smaller increase in the general price level from 1949 to 1967, than the GNP deflator index, but with the opposite tendency thereafter. The retail price index is frequently intermediate between the other two, especially in the early years of the series. In general the greater the distance from the base year the more likely are the series to diverge.

Net Discounted Revenues for Plantations

These net revenues are negative, representing the present value of costs incurred in establishing and/or maintaining the plantation, and in extracting the produce. The cost headings considered are:

Establishment, including protection (new plantations only)
Maintenance
Roading
Thinning and extraction
Felling ,, ,,
Rent (existing plantations) or land purchase (new plantations)
Terminal value of land (negative cost)

Costs which occur at a particular point in time (e.g. felling) are discounted back to the present according to the time period, whereas annual costs (e.g. rent) are discounted on the basis of the present value of an annuity over the time involved.

The distinction between establishment and maintenance periods in a plantation's life is arbitrary, but usually the first 5 years are regarded as the establishment period. This covers ground clearance, ploughing, draining, fencing, planting, weeding and beating-up (replacing trees which have died). The cost of protection from animals, fires, etc. is also mainly concentrated in this period and the subsequent 5 years. Maintenance of plantations usually refers to the keeping of drains and fences in good order, clearing fire-breaks, and brashing (removing the lower branches of young trees). Pruning of older trees is not widely practised nowadays, on the argument that the improvement in wood quality does not justify the cost.

Forest roads must be provided at the first thinning, or at felling if there is no thinning, in order to bring out the timber. If roads are already present they should be maintained, and the same applies to roads constructed to extract thinnings. For establishment of plantations it is often possible to make do with rough tracks or very temporary roadways, and in the model it is assumed that the overall establishment cost is adequate to cover any expenditure on access. Capital expenditure for road building is discounted from the mid-point of the time period of construction, and maintenance costs are annuitised from construction to the time period of felling.

Thinning costs include selecting and marking the trees as well as cutting and hauling the logs to the roadside, and transport to the final user. They are discounted according to the period of thinning. Felling implies clear felling, and apart from selection and marking, the cost items are similar to thinning, although the cost per unit volume is lower because of the larger logs.

Rent is charged for the land already occupied by plantations, on the ground that it has an alternative use or uses, such as sheep farming and grouse moors. This procedure follows from the restriction of the model to forest-related activities, rather than, e.g. upland land use as a whole. The fact that sheep farming is subsidised is regarded as an act of social policy similar to taxation of fuel, for example. In practice the difference is negligible, rent being typically less than 1 per cent of total discounted costs. After felling, land is assumed to be sold, at a price representing the discounted stream of future rents, derived from the usual formula:

capital value = annual value/rate of interest

but disregarding yield class, for example. Activities representing new planting must then buy back this (or other) land at the same price, but since it is included with the supply of roaded land, it has an advantage over activities involving planting on unroaded land.

For coppice, some differences occur because of the nature of the management system, and the location of coppice areas. Thinning, protection and roading are considered irrelevant, and maintenance is much lower than for plantations.

Estimation of Costs for Plantations

Costs for both state and private forests are based on those recorded by the Forestry Commission and published in their Annual Reports. The values obtained were checked against private contractors' quotations, as given in Hart (1966). The presentation of accounts in the Forestry Commission *Annual Reports* has changed occasionally, but those from 1959 to 1965 enable a consistent time series from 1958 to 1965 to be used (1958 because in 1959 the previous year's figures are given for comparison). The accounts for this period of eight years have a main division into "forestry operations", "nurseries" and "other", the latter representing expenditure in connection with private forestry, research and education. These items have been excluded from the present cost calculations, although it is arguable that research and education are a necessary part of total costs if the assumed future wood output is to be obtained. However, they represent only about 5 per cent of costs of forestry operations, excluding accumulated interest on capital.

In the accounts, overheads are allocated as subtotals to the various levels of organisation (Directorate and Headquarters, Conservancy, District and Forests) but for the purposes of the model, total overheads for each year are allocated to operations in proportion to direct costs. The grouping of operations used here is shown below, and is slightly different from that in the accounts:

Establishment of plantations:
- Preparation of ground including ploughing
- Planting including cost of plants (i.e. nursery costs are included here)
- New drains and fences
- Beating-up, including cost of plants
- Weeding and cleaning plantations
- Enrichment
- Protection (fire and other)

Maintenance of plantations:
- Maintenance of drains and fences
- Miscellaneous
- Protection (an allowance for established plantations of age class 1)

Harvesting (further divided into thinning and felling):
- Felling, extraction and processing
- Carriage and other expenditure

Roads:
- Maintenance
- Capital costs (from net additions to fixed assets in roads and bridges)

The details of the calculations to arrive at costs per unit of area, volume or length, are given in Appendix C. For establishment costs the general approach is to estimate cost per unit area by dividing each year's establishment costs (as listed above) by the area planted that year. In practice some of each year's expenditure is for past or future planting but the average for the time series should be realistic. Maintenance cost of plantations is based on the area of plantations more than 5 years old, in each year. Harvesting costs are divided on the basis of volumes thinned and felled by the Commission (some is extracted by private contractors) but in rather more detail than is obtainable from the published accounts. By referring to the source records it was possible to allocate selecting and marketing costs to thinning. The headings "thinning" and "felling' include carriage costs to the local forest depot and some simple processing, e.g. debarking. These processing costs are included, to compensate for the low average carriage cost, one which implies a fairly short haul, roughly 30 kilometres (20 miles). The figures for thinning and felling are expressed per unit volume, referring to Forestry Commission extraction and excluding volumes harvested by contractors.

Maintenance costs for roads are related to the total length of roads recorded as in use, and initial capital costs can be estimated from new roads completed each year and the expenditure recorded in the balance sheet; since roads are assumed to be maintained, they have no depreciation charge. The main problem is to decide how much road construction is necessary. The method used is to assume that the first three age classes have no existing roads, and therefore the capital cost must be incurred at felling or first thinning, whichever is the earlier. Maintenance cost is then incurred from roading year to felling year, if these are different. The roading density assumed necessary is 2·5 km. per sq. km. of plantation (4 miles per sq. mile) although in fact the optimum density is itself dependent on economic conditions. Plantations of age class 4 and above are assumed to be roaded already, at a density of 2 km. per sq. km. (about 3·2 miles per sq. mile), and maintenance costs on this density must be paid. It is recognised that this treatment is very approximate but on a per hectare basis the impact of roading capital costs is fairly small, at the densities mentioned above, only about 3 per cent of total discounted costs in many cases.

The costs estimated for operations are summarised in Table 35, in terms of constant prices, together with revised values assuming lower overhead costs, except for road construction, which appears separately in the accounts. The aim is to discover whether such cost reduction could make a substantial difference to the overall solution.

For coppice, cutting costs are taken to be the same as felling, protection and roading costs are ignored, and annual maintenance cost is estimated to be £1 per hectare, or £0·8 per hectare with reduced overheads. The rental value of £0·75 per hectare is based on the rents paid by hill farmers in Wales (University College of Wales, Aberystwyth, 1967). Taking the category "Livestock Rearing Farms—Poor Land", within each of the five size groups the area of "good land" was multiplied by 5 and the product added to the area of rough grazing, to give an estimate of total area in terms of rough grazing. Dividing the rent by this adjusted area resulted in a (weighted) average rent of £0·3 per acre or £0·75 per hectare.

To estimate costs for individual wood-producing activities, two special computer programmes were written, one for plantations already established, the other for new plantations. In this way the results for different interest rates, for example, could be obtained rapidly.

TABLE 35

AVERAGE COSTS OF FORESTRY OPERATIONS 1958–65, £ AT 1967 PRICES

	Including overheads as found (89% of direct costs)		Including overheads at 60% of direct costs	
	Metric	English	Metric	English
Establishment	370 p.ha	150 p.ac	312 p.ha	126 p.ac
Maintenance	2·27 ,,	0·92 ,,	1·92 ,,	0·78 ,,
Protection	11·7 ,,	4·8 ,,	10·0 ,,	4·1 ,,
Thinning	6·6 p.m³	0·19 p.ft³	5·6 p.m³	0·16 p.ft³
Felling	5·9 ,,	0·17 ,,	5·0 ,,	0·14 ,,
Road construction	3110 p.km	5007 p.mile	3110 p.km	5007 p.mile
Road maintenance	56 ,,	90 ,,	47 ,,	76 ,,

Source:
Adapted from Forestry Commission accounts, 1959–65.
Notes:
1 Protection costs shown apply only to established plantations of age class 1.
2 Road construction cost is not recalculated with lower overheads.

Transferring Plantable Land Between Time Periods

The method of including plantable land is to assume an initial amount of land is available, for example 100 thousand hectares for each of spruce, fir and pine. This is included in the RHS for the plantable land constraints in period 1; the corresponding constraints in periods 2 and 3 have RHS values of zero. For planting to occur, the activity has to "buy" the land and is not charged rent thereafter. Plantable land not used in a particular period is available for alternative uses such as sheep grazing, until the next period for which planting is an option. However, since a planting activity has to buy the land initially, it would be penalising planting unfairly to require it also to compete with a positive net discounted revenue from sheep grazing, calculated as a deferred annuity from one period to the next. Therefore for activities transferring land between time periods, the objective function value is zero.

Net Revenue (costs) for Domestic Wood Pulp and Waste Paper

Domestic mechanical and chemical pulp are given separate production activities with negative net revenues, so that the pulp can be distributed to different final uses if required (but mechanical pulp for newsprint is included with newsprint production). The net revenues consist of direct costs, which are here defined to comprise labour, maintenance materials, energy, and interest on working capital; wood fibre costs are allowed for in other (linked) activities, and depreciation is ignored, as a sunk cost.

Mechanical Pulp

Adapting figures given by Eklund (1969), the direct costs of mechanical pulp production, using the disc refiner method, should be £13·3 per tonne of a.d. pulp at an annual capacity of 50 thousand tonnes, or £11·8 per tonne at 100 thousand tonnes. On the basis of these figures, and discussion with United Kingdom producers, the direct cost per tonne of pulp is estimated as £13 per tonne, at 1967 prices, for a production scale of about 50 thousand tonnes per annum. This figure is used for both coniferous and broadleaved mechanical pulp.

Chemical Pulp

The report by Eklund also provides estimates of costs from bleached sulphate pulp, but Wiggins Teape Ltd. regarded his estimates as optimistically low for United Kingdom conditions. The figures used in the model are based on those suggested by Wiggins Teape Ltd., on the grounds that achieved costs are more likely to be useful as a guide to future action. At 1967 prices direct costs are estimated at £20 per tonne, to which must be added an allowance for imported hardwood chips (which constituted one third of the furnish at the time the model was constructed). At 1·5 tonnes of chips per tonne of final pulp, and an import price of about £7·75 per tonne of chips (1967 prices) the cost is £11·5 per tonne of pulp, giving a total net revenue of −£31·5. These figures are included in Table 36.

Waste Paper

The activities requiring a net revenue are transfers from supply to use, for each of the two grades, and also transfer from grade 1 to grade 2. The arrangement is illustrated in Chapter 3, Table 20. Net revenues for imports are dealt with separately later in the present chapter.

For domestic waste paper the net revenue consists of collection and sorting cost, and carriage to the final user. It is assumed that the price (ex-merchant, i.e. excluding carriage) is a reasonable guide to cost of collection and sorting. Prices for different types vary widely, as indicated overleaf (Francis, 1971):

Approximate 1970 prices for baled waste paper, ex-merchant

	£ p.tonne
Newspapers & magazines	14
Kraft liner	15
Mixed	11 to 11·50
Best white shavings	55

In tonnage, mixed paper accounts for about 60 per cent of the total and this is the basis for the net revenue for grade 2 paper as defined in the model. Adjusting to 1967 prices and allowing £2 per tonne for transport, the cost is taken to be £12 per tonne. The cost for grade 1 is based on newspapers, which adjusted for price changes and transport costs gives a figure of £14 per tonne. The carriage charge of £2 per tonne implies an average haul of about 30 kilometres each way.

The activity transferring grade 1 paper for use as grade 2 paper, has a cost of zero, because it is merely a device to ensure that all domestic waste paper of both grades is used before any imports come in. Although small quantities of waste paper are imported, the importing activities can also be regarded as increased recovery from domestic waste paper usage, at a higher cost than the current average.

Prices for Final Products and Imported Wood Pulp

The procedure used in the model involves valuing commodities at world prices, as far as these can be ascertained. They may be approximated by cost-insurance-freight import prices for the United Kingdom, although in some cases, such as printings and writings, the data are unsuitable. Domestically produced pulp and waste paper are respectively valued at direct cost of production and collection cost (as described in the previous section) but most of the wood pulp used in non-integrated paper and board manufacture in the United Kingdom is imported. For the purpose of calculating net revenues for these activities the pulp cost is also based on import price. Pulpwood and waste paper importing are given separate activities in the model and their net revenues are dealt with in a later section of this chapter.

Recent trends in c.i.f. import prices for the relevant products (including waste paper and pulpwood, for convenience) are shown in Figures 4.1 to 4.6 which refer to 1967 prices; the data from which they are constructed are in Appendix D. (The prices actually used in the model are included in Tables 36 and 37, and are discussed below.) The general impression from the graphs in Figures 4.1 to 4.6 is of falling import prices, but where the series go back before 1951, it is evident that in most cases the downward trend merely restores the position before the Korean War price increases of 1951. Most of the series also show a slight upturn after 1967, when sterling was devalued. Bearing in mind the United Kingdom balance of payments deficits in the years immediately preceding 1967, the recorded import price series from about 1964 onwards probably undervalue imports to some extent. Nevertheless it seems realistic to accept that these import prices have trended downwards in real terms. For the less processed commodities such as sawnwood the fall is a reflection of a general worsening of the terms of trade for raw materials in comparison with manufactures. For example, according to United Kingdom unit value indices for total exports and for imports of basic materials, the terms of trade (export/import prices) increased from 100 in 1961 to 112 in 1970. (Note that normally the terms of trade are calculated using an index of prices of *all* imports.)

For the more processed commodities such as printing and writing paper, the effect of economies of scale in major producing countries (especially Scandinavia) has probably been significant. An important question is whether import prices can be expected to change in the future, either as a whole or differentially within the wood products group. In general in this study it is assumed that import prices will remain at the values at which they have levelled out in the past five years, and also that relative price changes will not be important. Figures quoted in a recent cost/benefit study of forestry in Britain (Treasury 1972, p. 38) suggest that over the past fifty years unprocessed wood prices have increased in real terms at an average rate of around two per cent per year, although for newsprint the rate is zero. However, looking ahead the study suggests the most reasonable forecast is that wood prices will remain approximately constant in real terms, because the effects of increasing incomes and population will tend to be offset by competition from substitute materials such as plastics.

Price Ratios

If the terms of trade have moved against primary products one would expect the prices of the more processed wood products to have increased relatively to the less processed products. To investigate this point some recent time series of price ratios of different products were calculated, using average export unit values from 1955 to 1970 (FAO 1969 and 1971, Annex Tables 1C). Some of the ratios are plotted in Figure 4.7. Of the four shown, three appear more or less constant, but the ratio printings and writings/sawn softwood suggests a downward trend, which is the opposite of what would be expected from the generalisation about the terms of trade. Therefore although relative prices may alter in the future, recent historical data does not give much indication

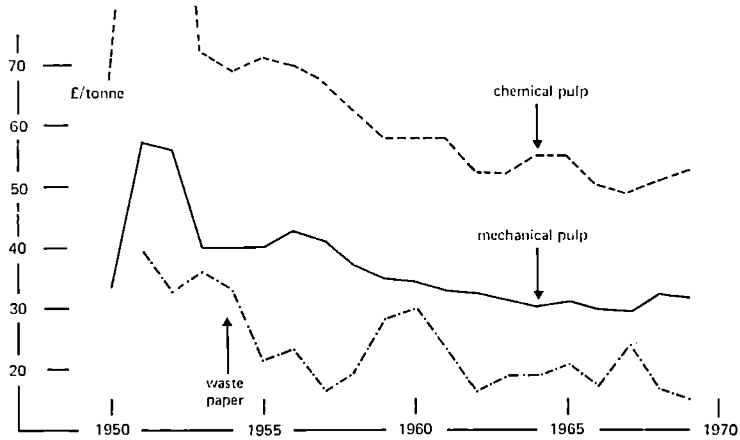


Figure 4.1 Average cif import prices for wood pulp and waste paper (1967 prices)

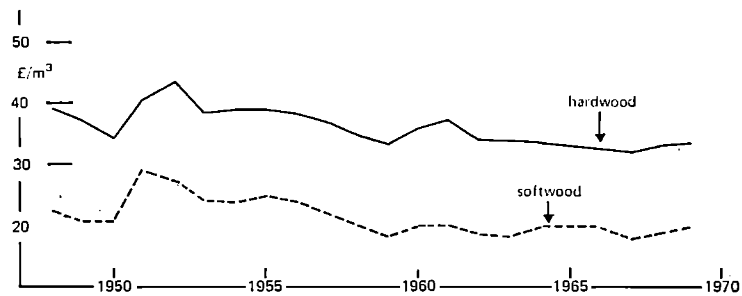


Figure 4.2 Average cif import prices for sawnwood (1967 prices)

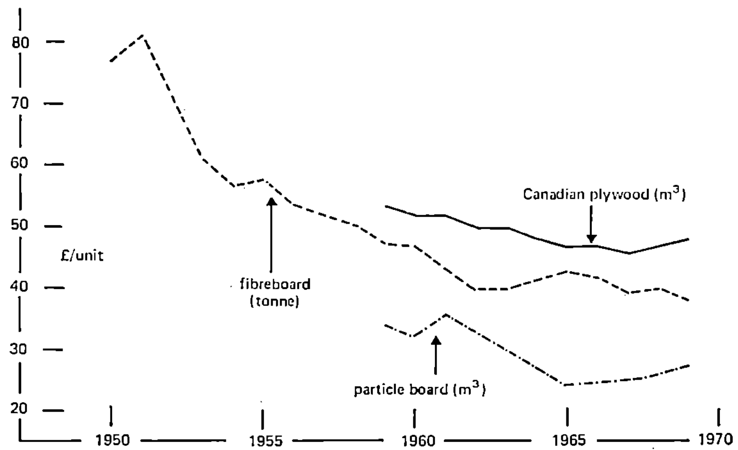


Figure 4.3 Average cif import prices for wood-based sheets (1967 prices)

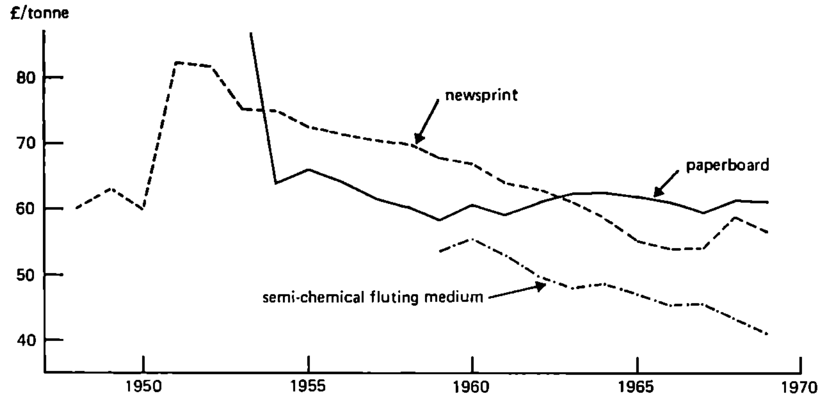


Figure 4.4 Average cif import prices for newsprint, paperboard and fluting medium (1967 prices)

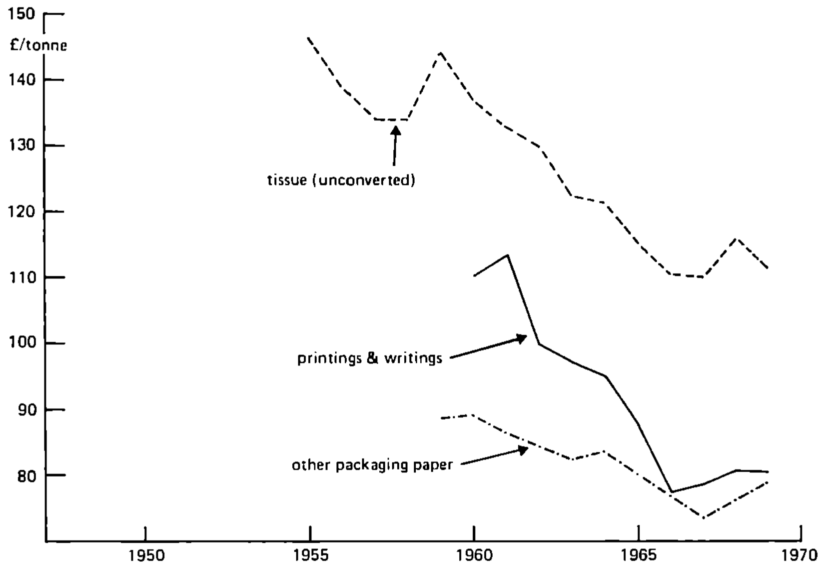


Figure 4.5 Average cif import prices for printings & writings, tissue, and other packaging paper (1967 prices)

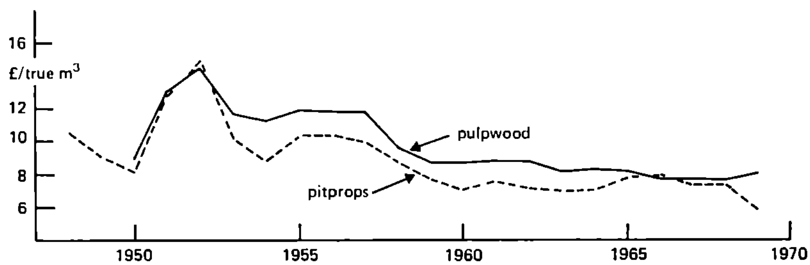


Figure 4.6 Average cif import prices for pitprops and pulpwood (1967 prices)

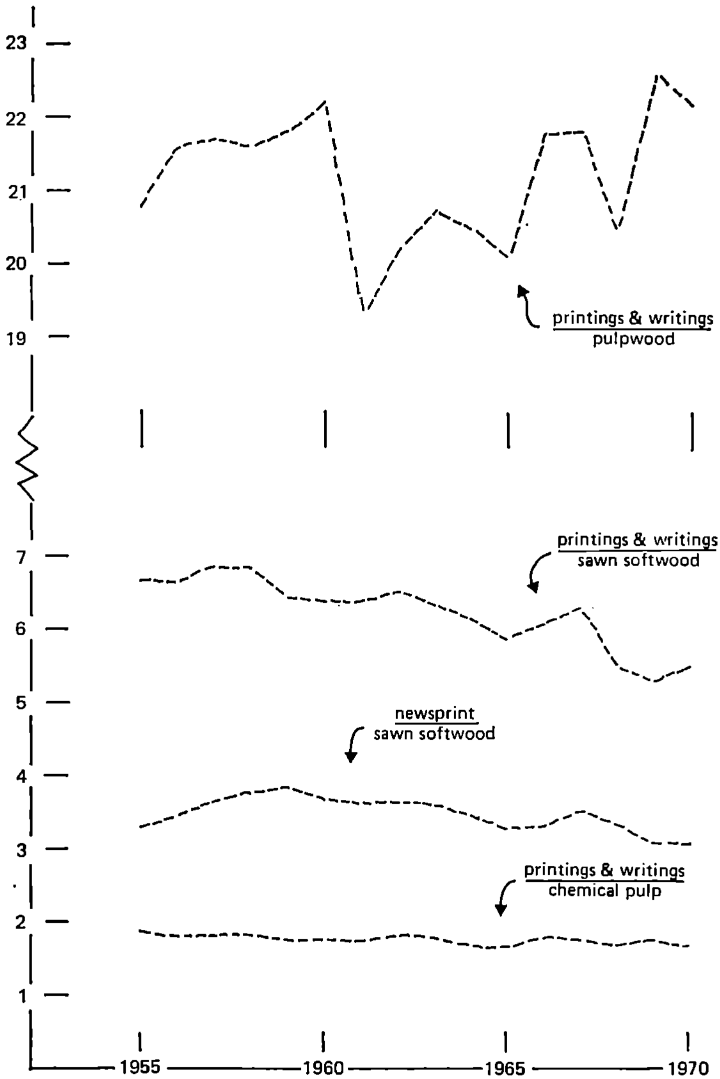


Figure 4.7 Ratios of average export prices

of the size or direction of such changes. These aspects are also discussed in Chapter 5.

In the following paragraphs the product prices used in the model are discussed briefly. Most of the import price series involved suggest a recent levelling off or reversal of the general downward trend, and for this reason most weight is attached to the more recent values rather than (say) an average for the whole data period. The values actually used are included in Tables 36 and 37.

Wood Pulps

Mechanical pulp prices (at 1967 prices) have stabilised at just above £30 per tonne and the value used is £32. Chemical pulp includes all types but the main categories are fairly similar in price. For example, for the first half of 1969 the agreed import prices for dry bleached softwood sulphite and sulphate pulps were respectively £62·25 and £64·25 per long ton (Johnsen *et al.* 1969, p. 5). Hardwood pulps tend to be about £5 per ton cheaper but this is offset by higher prices for the dissolving grades (about £75 per ton at that time). The figure used in the model is £52 per tonne.

Sawnwood

Here import prices are well documented over a long period and from Figure 4.2 it is clear that if the price index used is realistic, there is little difference between 1950 and 1969 values. The figures used are £20 per cu. m. for softwood and £33 per cu. m. for hardwood.

Wood Sheets

Any plywood manufactured from United Kingdom softwood logs is likely to be of constructional grade, with a price below the average for all imports. The import price of Canadian plywood should be a realistic valuation (Carruthers 1969), and on this basis the sale price is taken to be £48 per cu. m. These figures are only available from 1959, and the same is true for particle board. The import price series used is for wood chipboard only (excluding flaxboard, although prices are similar) and the predicted price for the model is £30 per cu. m., rather higher than the most recent values (at 1967 prices) but the trend is upwards (see Figure 4.3). Fibreboard import prices cover hardboard and insulation board and for this reason are expressed per tonne. The price adopted is £40 per tonne.

Newsprint

This is one of the more homogeneous of the products defined in the model, with a long import price series. On the basis of recent values the price is taken as £56 per tonne. The price series is included in Figure 4.4, with the series for fluting medium and paper-board, for convenience of the scale on the ordinate.

Printings and Writings

In this case the import data are inadequate as a basis for the product price, since the bulk of imports is the cheaper grades such as mechanical printings. Also the break-down into prices for coated and uncoated paper is only possible since 1967. The prices used in the model are therefore based on some domestic paper mill quotations for various grades. Apart from coating, prices may differ for one or more of the following reasons:

(a) Paper may be in reels or sheets
(b) Paper density varies
(c) There are reductions for large quantity

For these reasons the price estimates used must be regarded as approximations. For medium density paper in 25 tonne lots, the average of reel and sheet prices, adjusted to 1967 prices, is about £139 per tonne for coated printings, and about £125 for uncoated paper. These compare with import prices of about £75 per tonne for uncoated printings and writings in 1967 and 1969, and an average of about £120 for coated printings, for the same two years.

Tissue

For the past few years the import price for unconverted tissue has moved between about £110 and £115 per tonne, at 1967 prices, and therefore the price used in the model is £112·5 per tonne.

Fluting Medium

Import prices for semi-chemical fluting (corrugating) medium are only available from 1959 on, with a gap in 1968. These figures indicate a price of £40 per tonne, and this is used also for the activity defined as producing fluting medium from waste paper ("bogus fluting"), although in fact the quality of this product is somewhat lower than the semi-chemical materials.

Other Packaging and Special Paper

Because this category excludes fluting medium, it is only possible to estimate important prices since 1959, again with a gap in 1968. Average price fell until 1967 (see Figure 4.5) but in view of the rise since then the price is estimated as £80 per tonne.

Paperboard

The recent import data suggest a price of £60 per tonne, but the grades imported are usually rather better quality than the average (Fussell 1970). For this reason the sale value is taken to be £55 per tonne.

Pitprops

Prices for roundwood are usually quoted per piled cubic fathom or cubic metre, but here they are converted to true measure using an adjustment factor of ·7 (1 piled cu. m. = ·7 true cu. m.). Over the past ten years import prices (at 1967 prices) have remained fairly uniform at about £7·5 per true cu. m., and this is the valuation used. As would be expected the import price series for pulpwood (included in Figure 4.6) is very similar to that for pitprops, since both consist of small roundwood.

Direct Costs of Manufacturing

As already mentioned, direct costs are here defined to comprise labour, maintenance materials, energy and interest on working capital. In practice the labour and interest charges will be more or less fixed and therefore on a per tonne basis these costs will vary according to the level of output. For many of the products considered, estimates of direct (and other) costs are included in a report by Eklund (1969) where the figures are taken to refer to 1968 prices. They have been supplemented by discussions with UK producers, although many felt unable to comment on cost estimates except in a general way. Also, firms' accounts are not usually arranged in a way that makes these particular comparisons easy. For this reason source references for direct costs are not always so explicit as elsewhere in the study. The estimates used in the model are included in Tables 36 and 37, and their basis is discussed below, for the different final products in turn.

Sawnwood

Eklund suggests costs for a new sawmill with a capacity of about 18 thousand cu. m. sawnwood per 8-hour shift, using a profile chipper and double band saw. Direct costs vary little according to the number of shifts, and the breakdown is approximately:

	£ p.m³ (1968 prices)
Labour	·97
Materials exc. wood	·65
Electricity	·24
Interest on working capital	·54
	2·40 (about £2·28 at 1967 prices)

Allowing for the fact that many existing mills will not be as efficient as this, a direct cost of £3 per cu. m. sawnwood is allowed, for both types of sawnwood.

Plywood

At present there is no plywood made in the United Kingdom from domestic logs. Eklund gives some estimates of production costs for a plant using a 4-foot lathe, with a capacity of 15 thousand cu. m. plywood per shift. Assuming a 1-shift operation, in case log supply is a problem, the cost breakdown is:

	£ p.m³
Labour	6·0
Other operating costs	16·0
Interest on working capital	2·2
	24·2 (about £23 at 1967 prices)

To avoid exaggeration the direct cost allowed is £24 per cu. m.

Particle Board

In this case the costs suggested by Eklund refer to 3-shift working for two alternative capacities, 30 thousand and 100 thousand cu. m. annually. The cost structures are somewhat different:

	Annual capacity (th.m³)	
	30	100
	£ p.m³	
Chemicals	2·4	2·4
Fuel	2·3	2·2
Labour	3·9	1·9
Misc. and interest	1·6	1·4
	10·2	7·9

On the basis of these figures, and discussions with British producers, an estimate of £9 per cu. m. is allowed for direct costs.

Fibreboard

For this product costs have been derived from a 1963 report by Defibrator AB, updated to allow for price changes, and in conjunction with some data from United Kingdom producers. Defibrator suggest that the minimum economic size of plant is one with a capacity of about 25 thousand tonnes of hardboard per annum, or rather higher for insulation board. The former figure can be achieved with a daily capacity of about 80 tonnes and 300 day working. Taking an exchange rate of 14·5 Swedish Kroner to £1, the estimates are:

	£ p.tonne (1963 prices)
Chemicals and repair materials	1·5
Energy and water	3·8
Labour	4·9
Misc. and interest	·9
	11·1 (about £12·6 at 1967 prices)

From these calculations the direct cost used in the model is £13 per tonne.

Newsprint

This commodity is considered by Eklund, who deals with the alternatives of a new (integrated) mill or expansion of an existing one. In terms of direct costs the difference is confined to labour, where the expanded mill is able to use some existing resources. For the new mill, costs are as follows:

	£ p.tonne (1968 prices)
Labour	2·9
Energy	9·4
Maintenance materials	3·1
Misc. and interest	2·1
	17.5

The ratio of energy to labour cost is surprisingly high, but the total seems realistic (Robinson 1971). Adjusting to 1967 prices, a value of £17 is incorporated in the model for all newsprint-production activities, including de-inking. For commercial reasons the only published information on this process is of a general technical nature.

Printings and Writings

From the point of view of direct costs this category requires four different estimates, for the activities listed below. The figures arrived at are derived from information supplied by a number of paper mills. For production of uncoated paper using United Kingdom-produced pulp (from Fort William mill), pulp production costs have already been allowed for.

Activity	£ p.tonne
Uncoated paper from United Kingdom pulp (integrated)	32
Uncoated paper from United Kingdom pulp (non-integrated)	33
Uncoated paper from imported pulp (non-integrated)	40
Coated paper from imported pulp (non-integrated)	52

The figure of £33 for the second activity (above) is intended to try to ensure that UK-produced pulp is used before imported pulp, in non-integrated production. The increase in cost of £1 over integrated production is not meant to imply that this is necessarily a realistic estimate for the cost of drying and baling the pulp.

Tissue

Despite helpful co-operation from Kimberly-Clark Ltd., the figures for tissue are probably the most approximate of the cost estimates. This is because the usual method of manufacture combines the production of tissue with its conversion to boxed handkerchiefs, etc. To include these converting stages in the net revenue calculations would inflate the values for tissue by comparison with other products defined in the model. However, the product price for the average production mix of tissue, at 1967 prices and ex-factory, was estimated to be about £250 per tonne, exactly twice the import price. On this basis the direct costs for unconverted tissue production are estimated at half those for converted tissue, or £49. This figure is also used in the very hypothetical activity representing integrated production of tissue, using United Kingdom pulp, but of course the non-integrated production has the cost of imported pulp added to direct costs.

Fluting Medium

Here direct costs are based on pricing of physical inputs listed by Ashton Paper Mill Ltd. (Ashton Paper Mill 1970), in conjunction with comments by Bowaters (Robinson 1971). The estimate, adjusted to 1967 prices, is £19 per tonne, and this figure is used for both semi-chemical and waste paper-based fluting.

Packaging Paper and Paperboard

In both cases an estimate of £17 per tonne is used, related to costs for other paper making especially newsprint.

Net Revenues for Final Products

The net revenues can be deduced from the product prices and direct costs discussed above, in conjunction with input coefficients for imported pulp. The results are summarised in Tables 36 and 37, with the imported pulp coefficients included in Table 37 (column 2). In Table 36 most of the figures are described as £ per true cu. m., but this is only to make it clear that pitprops are not being expressed on a piled basis. These net revenues shown are the amounts available to provide amortisation of capital, profit, and in some cases pulp or waste paper inputs, whose costs are incorporated elsewhere in the matrix. It is noticeable that the estimated net revenue for non-integrated newsprint production (£1·5 per tonne) is far too small to provide for amortisation and profit, a result which tallies with recent closures of newsprint mills in the United Kingdom. The net revenues shown in the Tables are retained for all periods but discounted as described in a later section of this Chapter.

TABLE 36
NET REVENUES FOR ACTIVITIES PRODUCING SAWNWOOD, WOOD SHEETS AND PITPROPS, 1967 PRICES

Product	(1) Sale price	(2) Direct costs	(3) Net revenue (1)–(2)	(4) Approx. scale (annual output)
	£/true m³			
1. Coniferous sawnwood	20	3	17	10–20 th.m³ (1–2 shifts)
2. Broadleaved sawnwood	33	3	30	,,
3. Plywood (constructional)	48	24	24	15 th.m³ (1-shift)
4. Particle board	30	9	21	50 th.m³ (3-shifts)
5. Pitprops	7·5	·5	7	not applic.
	£/tonne			
6. Fibreboard	40	13	27	25 th.tonnes

Net Revenues for Importing Activities

Each final product in the model has an import activity which forms an alternative source of supply, and in most cases the major part of supplies. In addition, the two grades of waste paper, and pulpwood are allocated activities, with the imported pulpwood contributing to the supply of small sprucewood. The waste paper importing activities are mainly intended to show how the production pat-

TABLE 37

NET REVENUES FOR ACTIVITIES PRODUCING PULP, PAPER AND PAPERBOARD, 1967 PRICES

Product	(1) Sale price £/tonne	(2) Imported pulp: amount tonnes/tonne of product	(3) Imported pulp: cost £/tonne of input	(4) Other direct costs	(5) Total direct costs (2)×(3) +(4)	(6) Net Revenue (1)−(5)	(7) Approx. scale (annual output) th.tonnes
				£/tonne	£/tonne	£/tonne	
1. Mechanical pulp (integrated)	—			12	13	−13	50
2. Chemical ,, ,,	—	1·5 (BL chips)	7·75	20	31·5	−31·5	80
3. Newsprint							
(a) integrated	56	chem. ·21	52	17	28	28	150
(b) non-integrated	56	chem. ·21	52	17	54·5	1·5	150
		mech. ·83	32				
(c) de-inking	56	chem. ·1	52	17	22	34	60
4. Uncoated printing & writings							
(a) integrated	125			32	32	93	50
(b) non-integrated but U.K. pulp	125			33	33	92	70
(c) non-integrated	125	chem. ·92	52	40	87·5	37·5	70
5. Coated printings (non-integrated)	139	chem. ·87	52	52	97·5	41·5	100
6. Tissue (unconverted)							
(a) integrated (hypothetical)	112·5			49	49	63·5	50
(b) non-integrated	112·5	chem. 1·0	52	49	101	11·5	50
7. Fluting medium							
(a) semi-chemical	40			19	19	21	70
(b) waste paper-based	40			19	19	21	70
8. Other packaging paper	80	chem. ·57	52	17	33	30	70
		mech. ·11	32				
9. Paperboard							
(a) "integrated"	55	chem. ·18	52	17	26·5	28·5	60
(b) "non-integrated"	55	chem. ·19	52	17	30	25	70
		mech. ·07	32				

tern might change if the domestic recovery were greater, although at an increased cost.

Imports of final products are given positive net revenues, on the grounds that imports benefit the economy by freeing domestic resources for use elsewhere. In theory their net revenue represents the importers' profit per unit of product imported, where profit is the return on capital. In practice a small positive value is allocated to the objective function of each importing activity, and the stability of the solution explored when the values are changed, using parametric programming. With this method, the valuation of domestically-produced wood products at world prices, is incorporated in the objective function values for the production activities, rather than in the values for imports of the products.

The practical procedure used was to take an initial set of values equal to 1 per cent of the net revenue for each domestic production activity. This seems to imply that the higher are import prices, the greater the benefit to the United Kingdom economy, but of course with world-pricing the net revenues for domestic production would also become higher. The 1 per cent values can be inferred from Tables 36 and 37, but for convenience are reproduced in Table 38, together with prices for waste paper and pulpwood. As explained previously, these "intermediate" products are given negative net revenues. In the case of pulpwood the net revenue is the estimated future price, at 1967 prices, and at £8 per true cu. m. is £0·05 above the sale value credited to pitprops (see Figure 4.6).

Only small quantities of waste paper are imported and therefore average price is not a reliable indicator. In the model "import" prices are taken to be domestic collection cost plus 20 per cent, which for grade 1 results in a price of £16·8 per tonne; this is in fact quite similar to recent import values, as indicated in Figure 4.1. For grade 2 the corresponding value is £14·4 per tonne.

TABLE 38

NET REVENUES FOR IMPORTING ACTIVITIES

Final product	Unit	Net revenue (initial) £ per unit
Coniferous sawnwood	m^3	·2
Broad-leaved sawnwood	,,	·33
Plywood	,,	·48
Particle board	,,	·3
Fibreboard	tonne	·4
Newsprint	,,	·56
Uncoated printings & writings	,,	1·25
Coated printings	,,	1·39
Tissue	,,	1·12
Fluting medium	,,	·4
Other packaging paper	,,	·8
Paperboard	,,	·55
Pitprops	m^3	·07
Intermediate product		**Net revenue**
Pulpwood	m^3	−8·0
Waste paper grade 1	tonne	−16·8
,, ,, ,, 2	,,	−14·4

Costs of Capacity Expansion

Each manufacturing process can "buy" additional capacity through activities representing expansion, as described at the end of Chapter 3. The cost per unit of product of such expansion will vary with the scale, and this is the aspect of the model where the linear assumption is least likely to be realistic. The method adopted is to use a capital cost per unit, representative (as far as can be estimated) of the minimum economic size of plant. The latter is not a very precise concept, but normally a graph of capital cost per unit plotted against capacity shows an initial steep fall, followed by a gradual flattening of the curve. Thus after a certain point economies of scale in construction become small. The figures are affected by the number of shifts assumed, more or less proportionally. For example, double-shift working will normally halve capital costs per unit as compared with single-shift, although this may not be true for total costs. The main sources for the data are the report by Eklund (1969), the graphs of investment cost per tonne of pulp or paper, in Eklund and Kirjasniemi (1969), and discussions with United Kingdom producers. For fibreboard, only the capital cost of the pressing and drying installation is required; this is taken to be one third of the total cost of an integrated plant (Vellani 1971); the total cost referred to is based on figures in the paper by Defibrator AB (1963).

The estimates used in the model are listed in Table 39. Undoubtedly they are approximate figures, but an advantage of the linear programming approach is that it gives an indication of the sensitivity of the solution to a particular objective function value. If it is insensitive then it is probably not worth while trying to improve its accuracy.

An activity is included representing conversion of a non-integrated paper mill from newsprint to printings and writings. Here the net revenue is a guess, representing an exploration of this possibility.

TABLE 39
NET REVENUES (COSTS) FOR CAPACITY EXPANSION, 1967 PRICES

Mill to produce:		Net revenue capital cost	Notes*	Main source(s)
		£ per unit		
Sawnwood	m^3	-13	2-shift	Eklund 1969
Plywood	,,	-30	1-shift	,,
Particle board	,,	-50	3-shift	,,
Fibreboard	tonne	-23	press line only	Defibrator 1963; Vellani 1971
Mechanical pulp (refined groundwood)	,,	-42	no drier	Eklund 1969
Chemical pulp	tonne	-115		,,
Newsprint	,,			
(a) integrated	,,	-80	inc. groundwood	,,
(b) de-inking	,,	-240		Financial Times 1968
Uncoated printings & writings:				
(a) integrated	tonne	-200	chemical pulp × 1·75	Eklund & Kirjasniemi 1969
(b) non-integrated	,,	-115		,, ,,
Coated printings		-130	uncoated × 1·11	,, ,,
Tissue (unconverted)				
(a) integrated	tonne	-210	non-integ. × 1·75	Kimberly-Clark Ltd.
(b) non-integrated	,,	-120		,, ,,
Fluting medium				
(a) semi-chemical	,,	-100		Eklund & Kirjasniemi 1969; Savage 1970
(b) waste paper	,,	-80		
Packaging paper (non-integrated)	,,	-120		Eklund & Kirjasniemi 1969
Paperboard				
(a) integrated	,,	-90	Exc. groundwood	St. Anne's Board Mill Ltd.
(b) non-integrated	,,	-110		Eklund & Kirjasniemi 1969
Convert newsprint to uncoated printings & writings	tonne	-40		

* All pulp and paper mills are assumed to work 3 shifts.

Discount Rate and Discounting Factors

The two discount rates chosen are 5 and 10 per cent. The rationale behind the choice has been discussed in the Introduction and will not be repeated here. Discounting is made to the mid-point of each time period, and the factors used are set out in Table 40.

TABLE 40
DISCOUNTING FACTORS

Period	1	2	3	4	5	6	7
Mid-point (years from present)	2·5	7·5	12·5	20	30	40	52·5
Discount rate, per cent	discounting factors						
5	·885	·694	·543	·377	·231	·142	·077
10	·788	·489	·304	·149	·057	·022	·006

Chapter 5

DEMAND FORECASTING

Introduction

The linear programming model used in this study requires estimates of future consumption levels for each of the thirteen "final products" distinguished. They are included in the model as values in the Right Hand Side of the matrix, corresponding to the demand constraint rows which are present for each time period. (For convenience the term "demand" is used inter-changeably with "consumption" implying a given set of conditions such as price, unless the contrary is made clear). Since imports of final products are given a positive coefficient in the objective function (discounted net revenue) the future demands must be maxima, otherwise the solution will be unbounded. Ideally these demand values should be consistent with the future product prices assumed in the estimation of net revenues. In practice this is impossible to assess precisely, but since the prices used are based on recent values, it is sensible to make the consumption levels consistent with recent trends, at least in the initial time periods. They can also be treated as starting points for parametric analysis of the RHS, to test the sensitivity of the solution.

The accuracy of any forecast becomes increasingly doubtful the further ahead the time period to which it applies. In the present study, forecasts of wood consumption are required up to the year 2030, in order to evaluate the benefits from establishing new plantations over the next fifteen years. Obviously any such forecasts must be extremely speculative, but they are nevertheless implicit if new planting is to be considered in an economic context. In the present study they are based on extrapolation of time trends in consumption, in most cases using data from about 1950 to 1970. However, price and income elasticities were also estimated, where suitable figures were available. As the resulting consumption estimates are used as totals for periods of which the shortest are five years, there is no attempt to deal with cyclical aspects which may be important from year to year. Capital investment in wood-processing plant is allowed for in each time period, and as the depreciation period allowed is fifteen years, manufacturing capacity can be varied more easily than wood-producing capacity. Nevertheless the longer-range demand forecasts are not independent of the manufacturing aspect, because the future capital investment and manufacturing costs affect the profitability of the forestry activities such as planting. This may affect the resulting balance between domestic production and imports, for example.

The present chapter contains a discussion of the factors likely to affect UK consumption of wood, and a brief description of the approach actually used in the forecasts. The results for individual products are summarised in Chapter 6.

Factors Affecting Future Wood Consumption

The main factors likely to affect future wood fibre consumption are shown diagrammatically in Figure 5.1, where the letters P and F refer to present and future respectively, used in a general sense. The arrows in the flow chart show the main direction of influence, and the signs show whether the influence is positive or negative. For example, improvements in technology are likely to affect the future cost of electricity, and the more advanced is technology, the lower the cost. The use of the description wood *fibre* rather than wood, in Figure 5.1, is relevant to recycling. The greater the recovery of waste paper and other wood residues, the greater the amount of wood fibre used but the less the volume of new timber needed.

From the flow chart it can be seen that consumption is postulated to depend on the price of wood relative to the price of substitutes, and on the absolute level of income and population. In terms of a conventional price-quantity diagram, a change in price may come about through a shift of either the demand schedule or the supply schedule, or a combination of the two. The aggregate demand curve may be shifted by a change in income or population or both, and by the development of substitutes for wood. Increased income or population is likely to move the demand curve to the right, while the effect of substitutes is to make the demand curve more elastic, and possibly to shift the curve to the left, depending on the situation. For example, in the replacement of wooden pitprops by steel props, the substitute (steel) is not merely price-competitive with timber props but is actually essential for mechanised coal production. In Figure 5.1 this aspect is covered by the box referring to new production techniques, which in general will tend to reduce wood consumption, partly through more efficient use of the raw material.

The supply schedule for wood (excluding re-cycled fibre) is unavoidably concerned with time, because of the long production period involved in forestry. Nearly all the wood to be used in the world over the next thirty years, for example, will come from trees already planted, but the supply schedule for a

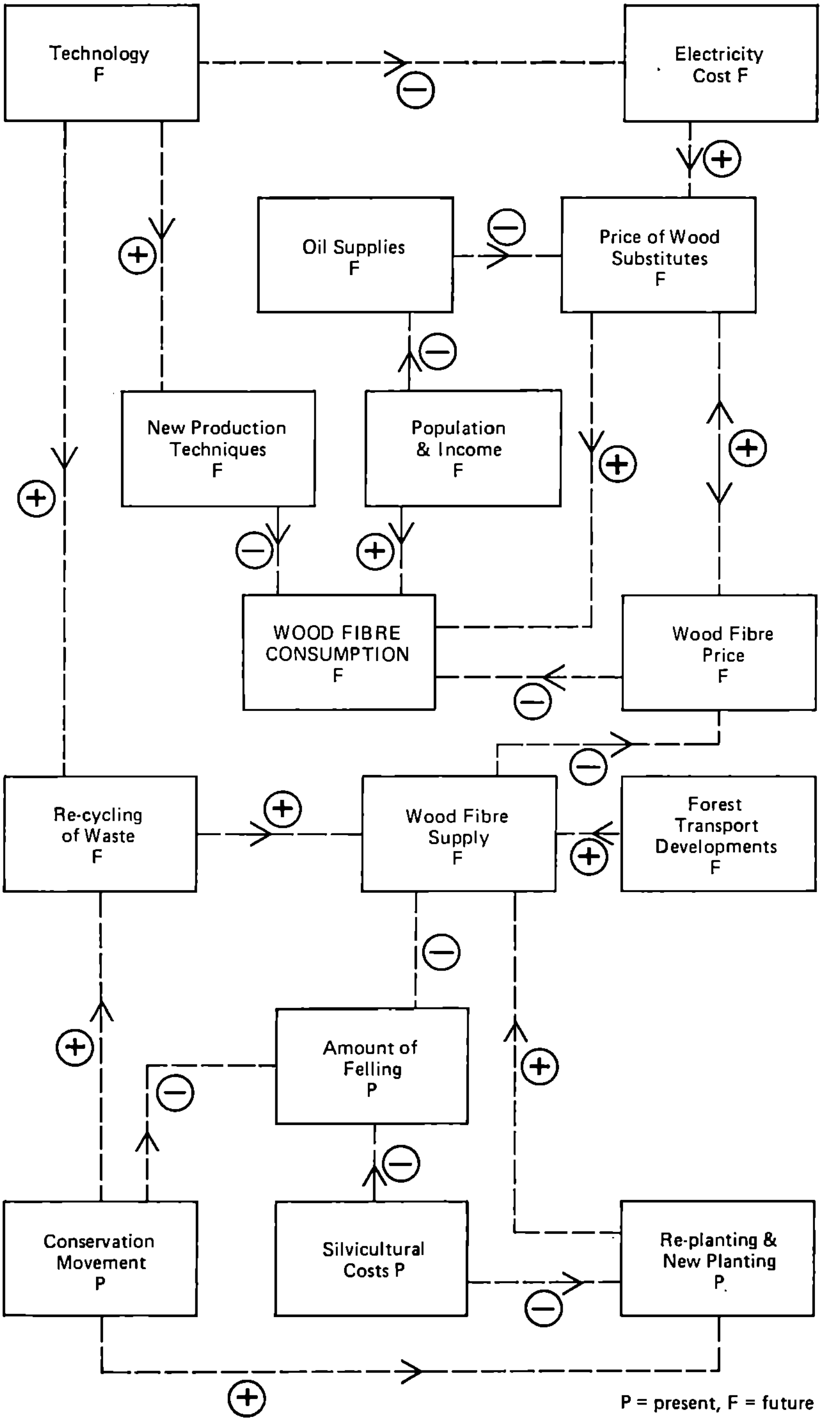


Figure 5.1 Factors affecting future wood consumption

particular future year or period is not a vertical line because the higher the price the greater the area of forest which becomes economically accessible. Also the management systems in normally accessible forests can be varied, but increased wood output in one period is often at the expense of output later. These facts give some flexibility to short-run supply but it remains true that long-run supply and price (for example, fifty years ahead) depend partly on current policies regarding afforestation or re-afforestation.

Forests, particularly coniferous forests, are not the only suppliers of cellulose suitable for paper-making (as distinct from structural wood), but they predominate in the more developed areas of the world. However, alternative sources of fibre such as bamboo could prove important in the future because it reaches maturity in about 3 years, and yields several tons of fibrous raw material per hectare (FAO 1954, p. 63).

In the present model the net revenue estimates used to measure the profitability of production of various "final products" are based on the assumption of a continuation of current world prices as far as these can be ascertained. This implies constancy of relative prices both within the wood products sector, and between wood products and other commodities. The future consumption levels or demands postulated should be consistent with these prices, but of any two different estimates at least one must be wrong. In dealing with this aspect two alternatives of a general nature have been considered. One is the possibility of continuing growth in consumption of many paper products, which can only occur if supplies are available. The other is the possibility of rapid and extensive substitution of wood by other raw materials. In the model these alternatives are incorporated as two sets of RHS values, representing "large" and "small" future demands. The "large" demands are perhaps more likely to be consistent with constant prices, but competition from other materials could also lead to consumption falls without marked price increases.

The likelihood of substitution of wood by other materials has been advocated particularly by Dawkins (1969), who argues that over the next fifty years wood will be reduced to the status of a luxury good. The main competitive materials are seen as derivatives of the elements aluminium, iron, silicon and calcium (for structural uses in particular) together with plastics based on oil. Although the world supply of easily-tapped oil may be exhausted within the next thirty years (Warman 1971), other fossil hydrocarbons such as coal are much more abundant although the average cost of extraction is usually higher. An alternative source of cellulosic derivatives is the carbon in limestone ($CaCO_3$) and the hydrogen in water (H_2O). Carbon dioxide (CO_2) is obtained as a by-product of cement manufacture, and from it carbon monoxide can be produced by reduction with hydrogen, itself the product of electrolysis of water. Combination of carbon monoxide with hydrogen permits the synthesis of organic products as methyl alcohol (CH_3OH) from which various polymers are obtainable. Most of these processes are endothermic, so that to be economic at current prices for plastics, they would require cheap energy supplies, probably from nuclear power.

To put the quantities involved in perspective, in 1967 the million tons of plastics used in Britain derived from 0·6 per cent of total oil consumption. For the whole consumption of paper and board to be made from plastics would have taken 2·4 per cent of oil consumption, which is less than the annual increase in petroleum usage (Dawkins *op. cit.*). However, at current prices it is more economic to use wood pulp. Apart from this possible replacement of wood as the raw material for conventional paper, there is the prospect of change in the nature of the requirements. For example, data storage will increasingly be based on magnetic or photographic processes rather than paper.

Methodology

In general the factors most likely to affect demand for a commodity are price, income and population. Some estimates of elasticities for these variables were made where practicable, but the forecasts actually used in the RHS are based mainly on extrapolations of time trends in total annual consumption. With this approach the independent variable time represents the combined effect of a number of unspecified factors, and the idea of a causal connection is largely absent. Some of these unspecified variables, such as income, may be relatively easy to include explicity, but it is then necessary to specify the future development of the variable. If this is postulated to be similar to its recent development, the advantage of specifying it separately may be rather small.

The income implied in this discussion is of necessity an aggregate such as Gross National Product (GNP). When a product is used mainly by one industry there may be enough data to justify using the output of that industry as a better measure of buyers' income. For example, with some products consumption per unit of GNP, or of construction industry output, showed regular trends over the past 15 to 20 years.

In the case of prices, where there are no close substitutes the price of the product itself may not be the most useful one to investigate. For example,

TABLE 41

IMPORTANCE OF UNITED KINGDOM TRADE IN WOOD PRODUCTS, 1968

	(1) Value of imports US $ millions	(2)	(3) UK as % of world $\frac{(1)\times 100}{(2)}$	(4) UK imports as % of production in Europe + N. America*
	UK	World		
Coniferous sawnwood	451	3005	15·0	5·8
Non-coniferous sawnwood	77	449	17·1	2·6
Plywood and veneers	156	747	20·9	5·4**
Particle board	23	92	25·0	3·3
Fibreboard	29	125	23·2	·8
Roundwood and sleepers	43	2093	2·1	·1
Total wood pulp	368	1921	19·2	4·0
Newsprint	102	1403	7·3	3·5
Printing and writing paper	43	465	9·2	1·1
Other paper and board	*247*	*1721*	*14·4*	*2·7*
Total	1539	12021	12·8	—

Source: FAO *Yearbook of Forest Products 1969.*

* exc. USSR; based on quantities.

**exc. veneers.

the price of newspapers is probably more relevant to newsprint consumption than is the price of newsprint. Where possible, measures of delivered price are preferable to c.i.f. import prices, because changes in the latter may not be reflected very closely in the prices paid by users. For estimates involving prices of wood products, it is assumed that recorded prices are determined by world conditions and not by changes in the United Kingdom market. This is particularly realistic for the very small portion of wood supplied from domestic forests, and it is probably also reasonable to assume that changes in United Kingdom demand do not affect world prices. On average, United Kingdom imports represent about 13 per cent of world imports of forest products, but for some products the proportion is as high as a quarter (Table 41). In general it is the wood-based panel products which represent a high proportion, offset by low percentages for roundwood and for printing and writing paper (including newsprint). However, quantities traded internationally are a small proportion of total supplies. Table 41 shows that United Kingdom imports in relation to production in Europe and North America, did not exceed 6 per cent in 1968.

Population change may be taken into account by the use of per capita data, but the procedure does not necessarily provide a satisfactory correction (McKillop 1967, p. 41). It is also difficult to forecast population, as demonstrated by recent changes in official United Kingdom forecasts to the end of the century. Thus in most cases total rather than per capita data have been used.

Income elasticities as calculated were usually found to be positive and not easily offset by other factors such as a negative own price elasticity in conjunction with a predicted price increase. Consequently if income is assumed to continue to rise, consumption increases indefinitely. In any case the estimated elasticities are only likely to be valid for small ranges of the independent variables. The use of a trend curve can avoid these problems, but is restricted to cases where a reasonably regular pattern exists in the past data. Some justification of the trend curve approach is found in the empirical fact that many product histories have followed recognisable curves during their growth periods (Harrison and Pearce 1971, p. 2). On the other hand it must be recognised that several functions may fit the historical data very well, but extrapolation results in widely different predictions. This is true of many of the products discussed in Chapter 6.

The main trend curves used in the analysis are the linear, quadratic and cumulative lognormal functions. With the first two, the dependent variable is sometimes transformed to logarithms (base e), giving semi-log equations. The quadratic function is used only where the coefficient of the squared term is negative, i.e.

$$y = a + bt - ct^2 \quad \text{where } y = \text{consumption per year}, \; t = \text{time in years}$$

This implies that a maximum consumption is reached, at $t = -b/2c$.

Although the coefficient of a linear equation is constant, the corresponding percentage growth rate is not. With a positive coefficient, the growth rate is positive but declines with time and approaches zero.

If the coefficient is negative the growth rate is also negative and becomes more so as time increases, approaching minus infinity as consumption tends to zero. For the quadratic form mentioned above, the growth rate falls at a constant rate until it reaches zero at the maximum value of y (consumption) and is negative thereafter, again approaching minus infinity as y tends to zero.

The lognormal curve used is the cumulative density function of the lognormal distribution and is therefore positively skew. It is sigmoid in shape, implying an initial slow rate of growth, followed by a rapid rate and then a slowing down again as an upper asymptote or "saturation level" is approached. Other sigmoid curves tried were the logistic and the Gompertz functions. The relative merits of these curves in demand analysis are discussed by Bain (1964), who concludes that the lognormal is more flexible and therefore preferable. In the present study it is used mainly with GNP as the independent variable, rather than time itself. This form has the advantage that the implied income elasticity declines as income increases, a property which agrees with past data of paper and board consumption (FAO 1960, p. 99).

In comparing alternative trend curves the main criterion was the value of the (corrected) coefficient of multiple determination (R^2), together with the Durbin-Watson statistic as an indicator of the behaviour of residuals. Where logarithmic transformations were used the value of R^2 was made comparable to the non-transformed case. For example, with the semi-logarithmic form:

$$\ln y = a + bx - cx^2$$

the value of R^2 is calculated as the squared correlation coefficient between y and $e^{a+bx-cx^2}$.

Population and GNP Values Used

Where used, the population figures are the mid-year *de facto* estimates prepared by the Registrar-General. This means that the figures refer to the number of people actually present in the United Kingdom at the time, excluding British forces serving overseas, for example.

For income, the published values of Gross National Product at factor cost and current prices were deflated by the NIESR index of total final prices, referred to in Chapter 4. For comparison an alternative series was prepared based on the GNP deflator, splicing the published series where necessary. In some cases these were found to give rather better estimates of lognormal demand functions, as described in the next Chapter. One difference between the GNP series is in the most recent years, where the NIESR price index indicates a higher general level of prices than does the GNP deflator. The figures obtained are listed in Table 42.

TABLE 42

VALUES FOR UNITED KINGDOM POPULATION AND GROSS NATIONAL PRODUCT

Year	Population	Gross National Product		
	million	Current prices (factor cost)	1967 prices (deflated by NIESR price index) £ million	1963 prices (deflated by GNP deflator)
1948	49·62	10397	19236	
49	49·93	11136	20065	18762
50	50·18	11695	20446	19674
51	50·29	12850	20015	20018
52	50·431	14005	20596	19967
53	50·592	14951	21923	20847
54	50·765	15981	23128	21860
55	50·947	16936	23643	22483
56	51·184	18338	24333	23033
57	51·430	19392	24932	23349
58	51·652	20408	25510	23005
59	51·956	21411	26498	23759
60	52·372	22794	27900	24877
61	52·807	24391	29072	25771
62	53·314	25563	29553	26106
63	53·637	27218	30931	27150
64	54·008	29373	32563	28569
65	54·361	31364	33365	29363
66	54·654	33006	33851	29880
67	54·978	34805	34805	30412
68	55·283	36686	34925	31276
69	55·534	38601	35114	31695
70	55·711	42730	36485	

Sources:
1 *Annual Abstract of Statistics.*
2 Price indices shown in Table 34.

Note:
The GNP figures using the NIESR price index imply a compound growth rate of about 2·7 per cent, and those using the GNP deflator about 2·4 per cent.

Chapter 6

DEMAND FORECASTS FOR INDIVIDUAL PRODUCTS

This Chapter contains results of applying to individual products the methods discussed in the previous Chapter. The general approach is to record the recent consumption levels and any price data which are available, and examine the implications of fitting various trend curves to the data. In some cases estimates of price and income elasticities are possible. The products are discussed in the usual order adopted in this study, as follows:

Sawnwood
Wood-based sheets
Newsprint
Printings and writings
Tissue
Packaging paper and paperboard
Pitwood

Sawnwood

At present imports of sawn softwood and hardwood (including some hardwood logs for sawing in the United Kingdom) constitute about a third by value of wood products imports, and 2·5 per cent of total imports. Annual consumption of sawn softwood is currently about 8–9 million cu. m., and hardwood about 1·4 million cu. m., but with differing trends in recent years (Figures 6.1 and 6.2). Consumption and price index data for sawnwood are included in Table 43 for the period 1948 or 1950 to 1969.

According to the 1963 Census of Production about 90 per cent of both soft and hard sawnwood is used in construction, or more precisely the four industries defined as Construction, Shop and Office Fitting, Furniture and Bedding. Furniture output is closely correlated with that of the construction industry* and is only a small fraction of it, and it is therefore reasonable to make some analysis of sawnwood consumption in relation to construction industry output. This is a more comprehensive measure of activity than gross domestic fixed capital formation in construction, which excludes the value of repairs. Estimates of the output of the construction industry in the United Kingdom are given in Table 43 at

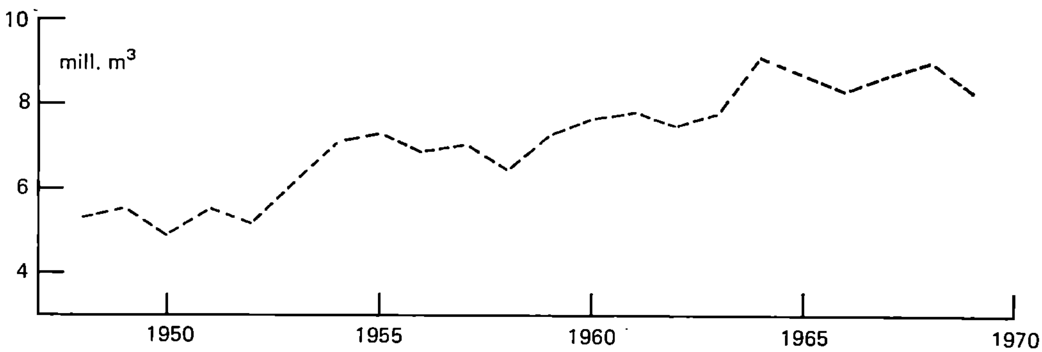


Figure 6.1 Consumption of sawn softwood

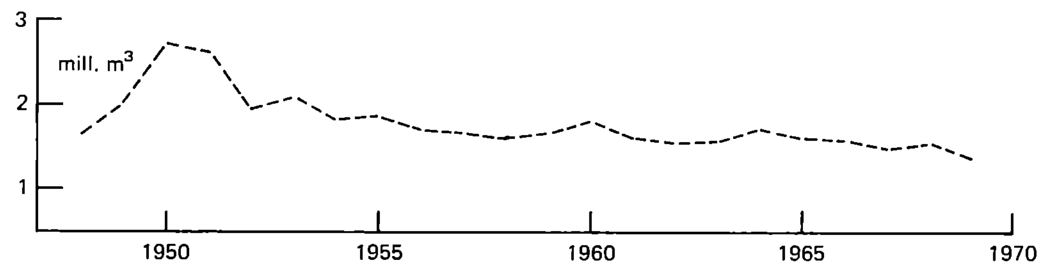


Figure 6.2 Consumption of hardwood

* For 1956–69 the correlation coefficient is ·95.

TABLE 43
CONSUMPTION AND PRICE DATA FOR SAWNWOOD

Year	Consumption		Sawnwood Price Indices				UK Construction Industry					Sawnwood consumption per unit of construction industry output	
							Value of output			Price indices		(1)/(8)	(2)/(8)
	Sawn softwood	Hardwood	Imported softwood (*delivered*) Current prices	Imported softwood (*delivered*) 1967 prices	Imported hardwood (*ex-wharf*) Current prices	Imported hardwood (*ex-wharf*) 1967 prices	Current prices	1967 prices	As % of GNP	(*1967 prices*) Construction materials	(*1967 prices*) Construction output	Sawn softwood	Hardwood
	th. m^3		1967=100		1967=100		£ m.	£ m.	%	1967=100		m^3/£ th.	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1948	5303	1713	—	—	—	—	1158	2144	—	—	—	2·47	·80
1949	5502	2025	—	—	—	—	1227	2211	—	—	102·9	2·49	·92
1950	4953	2749	55·9	97·7	60	105	1300	2272	11·1	106·1	108·8	2·18	1·21
1951	5508	2664	83·4	129·9	82	127	1441	2245	11·2	112·0	104·1	2·45	1·19
1952	5253	1964	91·8	135·0	92·1	135·4	1632	2401	11·7	112·5	105·8	2·19	·82
1953	6183	2141	83·7	122·7	87·2	127·9	1786	2618	11·9	109·5	103·0	2·36	·82
1954	7066	1842	84·2	121·9	83·7	121·1	1887	2730	11·8	108·8	101·7	2·59	·68
1955	7310	1893	91·5	127·4	87·3	121·6	1902	2649	11·2	109·8	103·7	2·76	·72
1956	6893	1745	92·2	121·9	86·9	114·9	2118	2798	11·5	108·9	102·1	2·46	·62
1957	7033	1719	90·7	115·8	88·3	112·8	2186	2792	11·2	109·2	102·3	2·52	·62
1958	6455	1611	85·7	107·1	87·0	108·7	2222	2778	10·9	107·4	101·0	2·32	·58
1959	7324	1719	80·6	99·9	86·8	107·6	2444	3026	11·4	105·5	98·2	2·42	·57
1960	7738	1798	87·9	107·6	91·6	112·1	2628	3217	11·5	106·0	98·0	2·41	·56
1961	7881	1704	89·2	106·3	94·3	112·4	2898	3454	11·9	106·0	98·8	2·28	·49
1962	7577	1567	87·5	101·2	91·8	106·1	3071	3550	12·0	104·7	99·1	2·13	·44
1963	7871	1575	88·2	100·2	92·1	106·5	3174	3606	11·7	104·2	100·6	2·18	·44
1964	9221	1745	95·4	105·8	94·1	106·9	3687	4089	12·6	104·6	100·1	2·26	·43
1965	8792	1698	99·6	106·0	96·0	106·4	3936	4188	12·6	103·5	99·8	2·10	·41
1966	8412	1566	100·0	102·6	97·8	104·0	4127	4234	12·5	102·1	100·7	1·99	·37
1967	8834	1508	100·0	100·0	100·0	100·0	4408	4408	12·7	100·0	100·0	2·00	·34
1968	9094	1570	110·8	105·4	116·0	110·4	4678	4453	12·7	99·2	98·5	2·04	·35
1969	8376	1392	116·8	106·3	122·5	111·4	4801	4367	12·4	98·2	98·0	1·92	·32

Sources:
(1), (2), (3) and (5) from Timber Trade Federation of the UK *Yearbook of Timber Statistics 1969*.
(7) *Annual Abstract of Statistics* and Gov. of N. Ireland *Digest of Statistics*.
(10) Department of the Environment *Monthly Bulletin of Construction Statistics*.
(11) *Annual Abstract of Statistics*, i.e. based on the (then) Board of Trade index of building costs, and (pre-1954) the price index of "output of building and civil engineering other than repairs".

current and constant prices, and as a percentage of GNP (col. (9)). For the latter it is clear from the table that in general the values for the 1960's are higher than for the 1950's, and most recently have averaged about 12·5 per cent.

Elasticities

Some estimates of price and output elasticities were made, using price indices for sawnwood and wood-based sheets, and construction industry output. The approach was similar to that used by Baxter and Rees (1963) in their study of industries' demand for electricity in Britain, and includes the assumption that firms act to minimise costs. An alternative model assuming profit maximisation was also tried, where demand for an input (such as sawn softwood) is a function of its own price, those of substitute inputs and the price of construction output. In this case substitute inputs would be hardwood, wood sheets, and construction raw materials as a whole. Unfortunately it is difficult to derive a satisfactory price index for construction, since the amount of output is not readily measurable in physical terms. The price and output data used are given in Table 43.

In general the results from these models were difficult to interpret in a manner consistent with the underlying theory. For example, the price elasticity for sawn softwood was usually positive. Where construction industry output was included as an explanatory variable it normally overshadowed price effects.

Consumption Trends

The graphs of total consumption (Figures 6.1 and 6.2) suggest a static or declining consumption in the future, and this seems likely to continue, for two main reasons. Firstly, there is no technical problem in replacing most of the constructional uses of timber by substitute materials such as metals, for which the resource base is much more extensive than that of timber. Secondly, the price of sawnwood has risen relatively to that of other construction materials, particularly since the 1967 devaluation. For example, taking 1963 as 100, the price index of construction materials had risen to 119 by 1969, but for imported sawn softwood and hardwood it had reached 133 (undeflated indices).

For these reasons predictions for sawnwood consumption are based on the assumption of gradual replacement of timber by substitutes. For softwood the graph (Figure 6.1) suggests a quadratic, and ordinary and semi-logarithmic quadratics improved the value of $\bar{R}^2$ compared with a linear regression particularly when using 3-year average data, which is reasonable as the figures refer to apparent consumption. For hardwood a linear downward trend is indicated (Figure 6.2). The equations for these trends are summarised in Table 44, equations (1), (2), and (3), together with information on maximisation where applicable.

Forecasts obtained by extrapolation of these trends are included in Table 45, annually for the first ten years and in 5-year or period totals thereafter. They are also shown diagrammatically in Figures 6.7 and 6.8.

An alternative approach is to work from the trends in consumption per unit of construction industry output (shown in the last two columns of Table 43). As Figures 6.3 and 6.4 indicate, there is some regularity in recent changes in these ratios, especially for hardwood. Starting at 1956 for softwood, the series is best approximated by a linear trend (equation (4) in Table 44). The corresponding relationship for hardwood, from 1952, is excellently fitted by a negative exponential curve (equation (5)). Forecasts of wood consumption obviously depend on the predicted output of the construction industry. As already noted, this has recently averaged about 12·5 per cent of GNP. Assuming this percentage is maintained, and that GNP continues to grow at an annual rate of 2·5 per cent (the approximate average for the past two decades), the resulting sawnwood consumption forecasts are included in Table 45 and in Figures 6.7 and 6.8. For softwood it is clearly important which of the three forecasts is accepted, whereas for hardwood the two are fairly similar. For comparison, the ECE have estimated sawn softwood consumption in the British Isles (including Eire) at 10 million cu. m. in 1975 and 1980, and sawn hardwood at 1·9 million cu. m (ECE/FAO 1969, pp. 24 and 29). The latter figure is well in excess of both the estimates suggested here, even allowing for the consumption in the Irish Republic.

Wood-based Sheets (plywood, particle board, fibreboard)

The recent consumption trends of these three types of rigid sheet are shown in Table 46 and in Figures 6.9 to 6.11. Data for particle board are available only from 1959, the first year that imports were itemised separately. It can be seen that plywood consumption has shown a fairly consistent upward trend since 1950, but that of fibreboard has levelled off since 1960. Particle board consumption has grown extremely rapidly since 1959, although with a check in 1969. This is generally a thicker sheet than plywood or hardboard but the three types are to some extent substitutes. In this respect there is a case for analysing demand for wood sheets as a whole, and this is one of the approaches used here. Converting plywood and particle board to a weight basis and adding

TABLE 44

TIME TREND EQUATIONS FOR SAWNWOOD

Equation	R^2 %	$D-W$ statistic	n	Implying maximisation: in year	at consumption
Total consumption (y) th.m³					
Softwood (3 year average data, 1951–68)					
(1) $y=5331+285{\cdot}1x-4{\cdot}61x^2$					
(72·4) (3·7)	88·7	1·21	18	1981	9744
(2) $\ln y=8{\cdot}584+{\cdot}04792x-{\cdot}00109x^2$					
(·01) (·00053)	88·0	1·08	18	1972	9051
Hardwood (1952–69)					
(3) $y=1975{\cdot}4-28{\cdot}07x$					
(4·55)	68·5	1·69	18	Not applicable	
Consumption per unit of construction industry output				when applied to construction industry output prediction	
(y) m³ p.£ th. at 1967 prices					
Softwood (1956–69)					
(4) $y=2{\cdot}539-{\cdot}0425x$					
(·0046)	86·8	2·28	14	1974	8599
Hardwood (1952–69)					
(5) $\ln y={\cdot}1521-{\cdot}0549x$					
(·0019)	98·0	2·53	18	Not applicable	

Note:
$x=1,2,3\ldots n.$

Figure 6.3 Consumption of sawn softwood per unit of construction output (1967 prices)

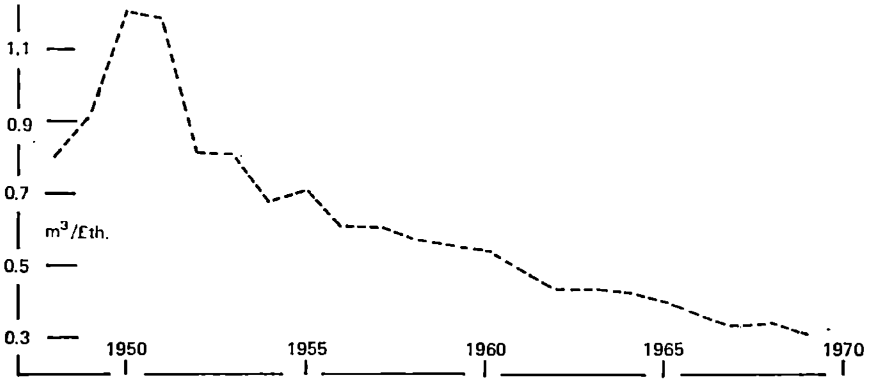


Figure 6.4 Consumption of hardwood per unit of construction output (1967 prices)

them to fibreboard, gives an estimate of total wood-based sheets consumption, and also enables market shares to be calculated. These percentages, and total consumption, are given in Table 46 and shown in Figures 6.12 and 6.13. Plywood's share has remained roughly constant at about half the total, with particle board increasing at the expense of fibreboard. On a value basis, plywood's share would probably be nearer two-thirds.

Elasticities

If one type of wood sheet is a substitute for another, it should be possible to estimate cross price elasticities. This was attempted using the three product prices and construction output, as independent variables. The results were difficult to interpret, since price elasticities often had the "wrong" sign. Unfortunately, if particle board is included as it should be, only data from 1959 can be used, giving 11 readings and 6 degrees of freedom.

Elasticities for the consumption of total wood sheets were also estimated, using a composite weighted price index based on import prices. This indicated that price lagged one year is more important than current price, the elasticity for the lagged price being −2·6 in conjunction with that for construction industry output (unlagged) of ·52.

In the following sections the analysis of market shares is dealt with first, followed by predictions based on consideration of each wood sheet product separately. The consumption forecasts from these two approaches are brought together in Tables 49 and 51.

Predictions from Market Shares

The graph of total panels consumption (Figure 6.12) suggests a roughly linear upward trend but an estimate of the probable eventual slackening in consumption can be obtained by fitting a semi-log quadratic to the data (equation (1) in Table 47). The market shares within this total are shown in Figure 6.13 from which it is clear that each trend is

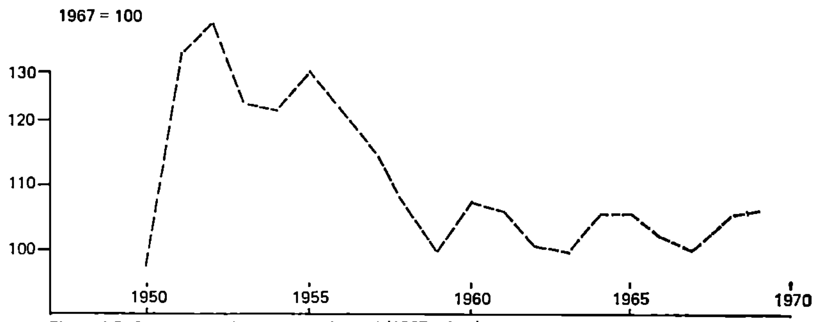


Figure 6.5 Price index of imported softwood (1967 prices)

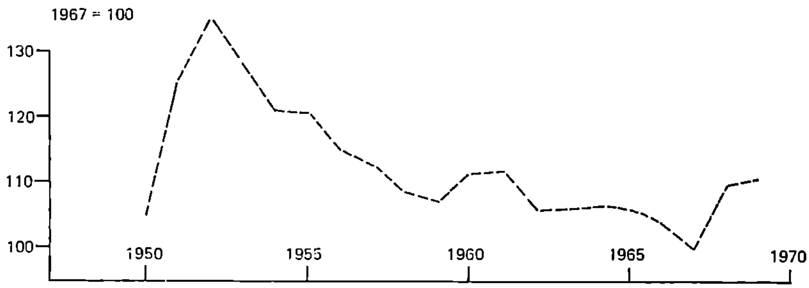


Figure 6.6 Price index of imported hardwood (1967 prices)

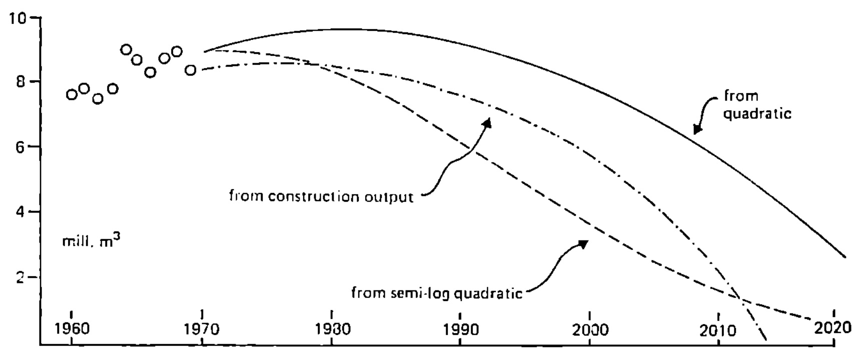


Figure 6.7 Consumption forecasts for sawn softwood

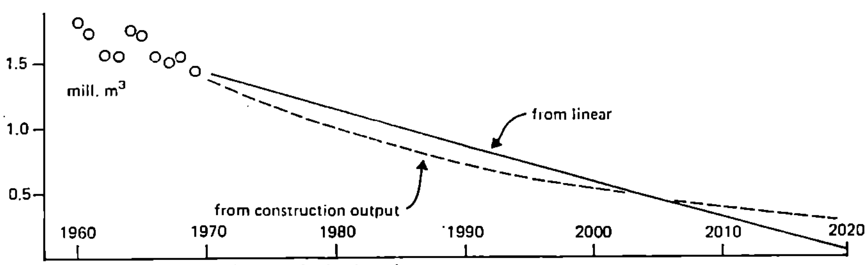


Figure 6.8 Consumption forecasts for hardwood

TABLE 45

SAWNWOOD CONSUMPTION FORECASTS

Period no. in model (length in years)	Year or years	Consumption estimate from: Sawn softwood: Quadratic	Sawn softwood: Semi-log quadratic	Sawn softwood: Per unit of construction	Sawn hardwood: Linear	Sawn hardwood: Per unit of construction
		(1)	(2)	(4)	(3)	(5)
		thous. cu. m.				
	1971	9288	9042	8573	1414	1321
	72	9375	9051	8586	1386	1282
	73	9453	9041	8595	1358	1244
1 (5)	74	9522	9011	8599	1330	1206
	75	9581	8962	8597	1302	1171
	(1971–75)	(47219)	(45108)	(42950)	(6790)	(6224)
	1976	9631	8894	8590	1274	1136
	77	9672	8806	8578	1246	1102
	78	9704	8701	8559	1218	1069
2 (5)	79	9727	8578	8535	1189	1037
	80	9740	8439	8503	1161	1007
	(1976–80)	(48474)	(43418)	(42766)	(6088)	(5351)
3 (5)	1981–85	48579	39584	41792	5386	4601
4 (10)	1986–90	47532	34183	39824	4685	3956
	1991–95	45333	27959	36617	3982	3402
5 (10)	1996–2005	79463	37556	57144	5859	5439
6 (10)	2006–15	56852	18321	21190	3053	4021
7 (15)	2016–30	25425	8713	—	474	4154

Notes:
1. Bracketed figures at heads of columns are equation numbers from Table 44.
2. Consumption from construction output assumes construction is 12·5 per cent of GNP, which grows at 2·5 per cent per year.

roughly linear. Fitting a linear trend to fibreboard's share implies zero consumption after 1981, which seems unlikely, but a semi-log trend is equally good in terms of $\bar{R}^2$, and this is the formulation used, in conjunction with linear trends for the shares of plywood and particle board. These equations are summarised in Table 47.

The results of applying these market share equations ((2), (3) and (4)) to that for total sheets (equation (1)) are included in Tables 49 and 51 to facilitate comparison of forecasts for each product; Table 49 also shows the predictions for total wood sheets, in weight terms.

Plywood (including blockboard)

Figure 6.9 shows that plywood consumption has increased more or less linearly over the past two decades, with some indication of a faster growth rate from 1958 onwards. The deflated wholesale price index of imported plywood (delivered) has varied in a rather contrary way, with a steep fall from 1951 until about 1956, since when it has been fairly constant (Figure 6.14). It is therefore not surprising that price is a poor explanatory variable for determining plywood consumption over this period, although the price elasticity has the expected negative sign. On the other hand construction industry output explains 95 per cent of the variation in plywood consumption, with an output elasticity of about 2. Little is gained by adding the price index as a second independent variable. In the case of plywood, the delivered price index is not very closely correlated with the average import price, the linear correlation being only ·81, implying that the import price explains only about 64 per cent of the variation in delivered price.

As might be expected from the relationship between plywood consumption and construction output, consumption per unit of construction output shows an upward, fairly uniform trend (Fig. 6.15)

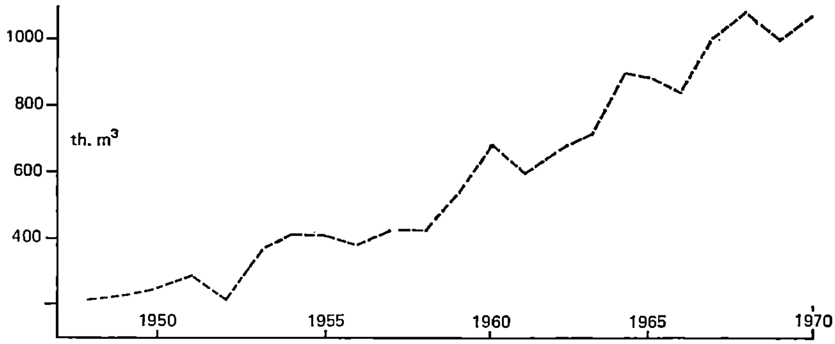


Figure 6.9 Consumption of plywood

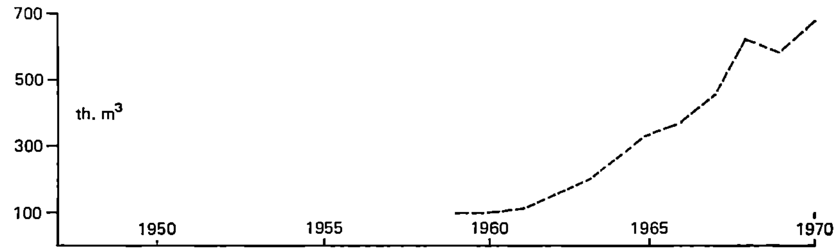


Figure 6.10 Consumption of particle board

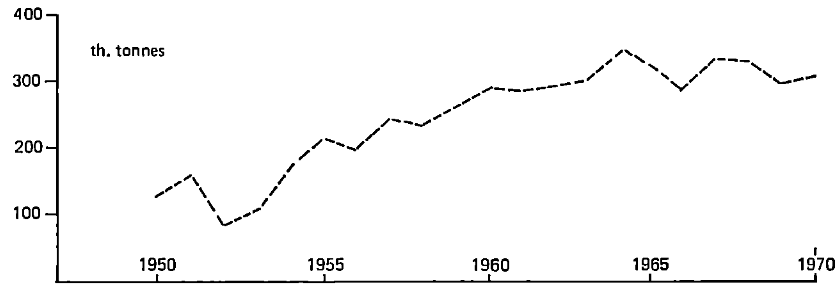


Figure 6.11 Consumption of fibreboard

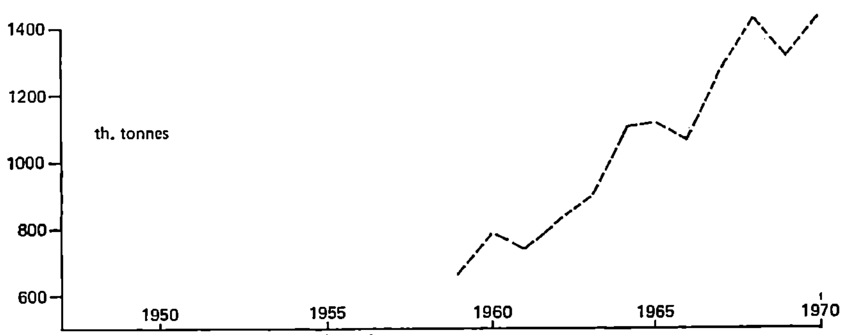


Figure 6.12 Consumption of total panels

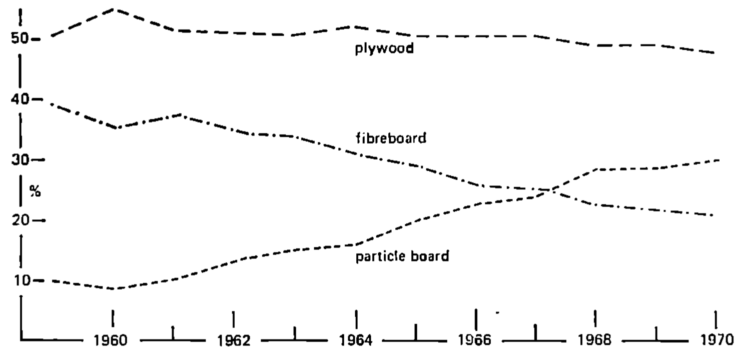


Figure 6.13 Market sharos for wood-based sheets

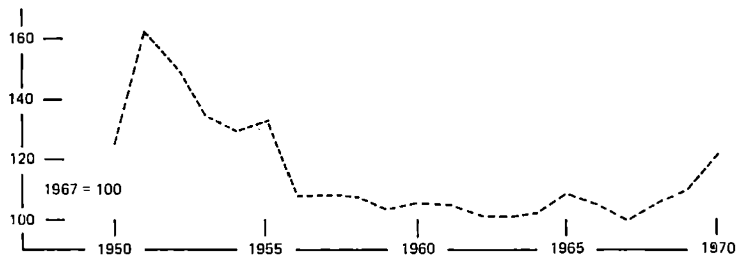


Figure 6.14 Price index for plywood (delivered) (1967 prices)

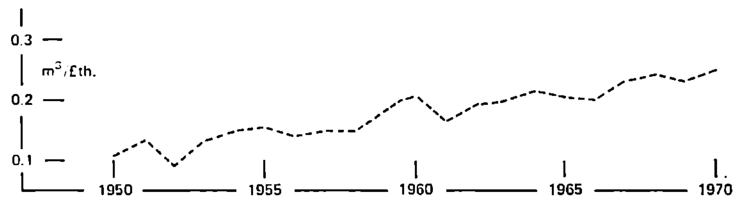


Figure 6.15 Consumption of plywood per unit of construction output (1967 prices)

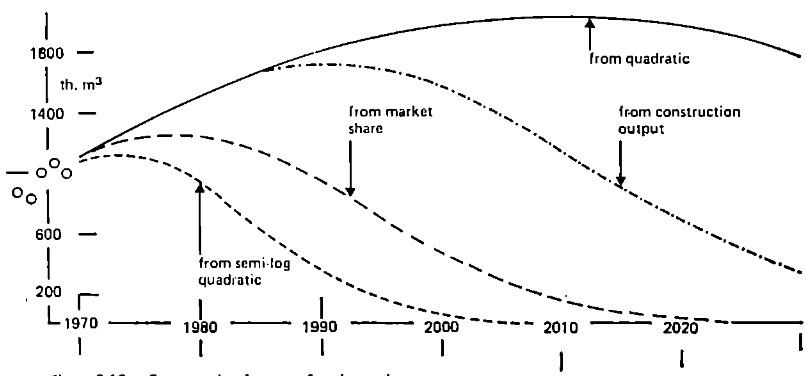


Figure 6.16 Consumption forecasts for plywood

TABLE 46

CONSUMPTION AND PRICE DATA FOR WOOD-BASED SHEETS

Year	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Apparent consumption					Market shares, %			Price series (1967 prices)		
	Plywood									Av. import price	
	Annual	Per unit of construction output 1967 prices	Particle board	Fibre-board	Total wood sheets	Plywood $\frac{(1)\times100}{1\cdot54\times(5)}$	Particle board $\frac{(3)\times100}{1\cdot54\times(5)}$	Fibre-board $\frac{(4)\times100}{(5)}$	Index for imported plywood (delivered) 1967=100	Particle board	Fibre-board
	th. m³	m³/£.th	th. m³	th. tonnes						£/m³	£/tonne
1950	251	·11		128					125·2		76·1
1951	284	·13		168					163·1		80·9
1952	223	·09		86					152·6		71·3
1953	339	·13		110					135·2		61·2
1954	415	·15		176					129·5		56·7
1955	411	·16		220					133·0		57·7
1956	379	·14		201					108·2		53·7
1957	428	·15		247					108·7		52·0
1958	427	·15		236					107·9		50·4
1959	536	·18	106	267	684	51·0	10·0	39·0	103·6	34·2	47·4
1960	678	·21	106	287	796	55·4	8·6	36·0	106·5	32·4	47·1
1961	600	·17	120	282	750	52·0	10·4	37·6	105·8	35·8	43·3
1962	671	·19	167	295	840	51·9	12·9	35·2	102·1	32·8	40·3
1963	718	·20	211	310	914	51·1	15·0	33·9	101·4	30·2	40·1
1964	903	·22	279	351	1119	52·4	16·2	31·4	102·4	26·9	41·7
1965	885	·21	345	328	1128	51·0	19·9	29·1	109·0	23·9	42·7
1966	847	·20	375	284	1078	51·1	22·6	26·3	105·8	24·5	41·9
1967	1012	·23	467	330	1291	50·9	23·5	25·6	100	25·0	39·6
1968	1087	·24	628	328	1442	49·0	28·3	22·7	106·1	25·7	40·2
1969	1007	·23	591	297	1335	49·0	28·7	22·2	109·9	27·1	38·3
1970	1081	·25	680	313	1457	48·2	30·3	21·5	122		

Sources:
(1) and (3) from TTFUK *Year Book of Timber Statistics 1970.*
(4) from BPBMA *Reference Tables* and (pre-1954) from production data supplied by BPBMA, in conjunction with *Annual Statement of Trade.*
(9) from TTFUK *Year Book of Timber Statistics* various years; pre-1954 values estimated from average import price.
(10) and (11) from *Annual Statement of Trade.*

TABLE 47

TIME TREND EQUATIONS FOR TOTAL WOOD SHEETS CONSUMPTION AND MARKET SHARES

Equation	$\bar{R}^2$ %	*D-W* statistic	Implying maximisation: in year	Implying maximisation: at consumption
Total wood sheets consumption (y) th. tonnes				
(1) $\ln y = 6{\cdot}427 + {\cdot}0956x - {\cdot}00192x^2$ $({\cdot}025) \quad ({\cdot}0018)$	93·4	2·31	1983	2031
Market share (y)%			(when applied to total sheets consumption trend)	
Plywood				
(2) $y = 53{\cdot}8 - {\cdot}438x$ $({\cdot}10)$	60·3	2·58	1978	1276 th. m³
Particle board				
(3) $y = 5{\cdot}09 + 2{\cdot}11x$ $({\cdot}12)$	96·6	1·84	1988	1750 th. m³
Fibreboard				
(4) $\ln y = 3{\cdot}77 - {\cdot}060x$ $({\cdot}0035)$	96·4	·97	1967	317 th. tonnes

Note:
$x = 1,2,3 \ldots 12.$

The price elasticity in this formulation is about $-1{\cdot}6$, and lagging the price one year improves the $\bar{R}^2$ but the elasticity is very similar.

If plywood consumption continued to grow at the average rate since 1958 (about 50 thousand cu. m. per year) consumption would reach about 4 million cu. m. by the year 2030, an increase of 300 per cent. However, it seems more probable that consumption growth will gradually slacken, under the influence of competition from substitutes and the limited supply of plylogs. Already in the last few years consumption has remained fairly static, although similar situations have occurred before, for example in the mid-1950's.

On the assumption that some turndown in consumption will occur, quadratic functions were fitted to the trend data, for both total consumption and consumption per unit of construction output. A log-normal function was also tried but although very high values of $\bar{R}^2$ were obtained, it was not possible to discriminate between saturation consumption levels as different as 1·6 million cu. m. and 2·8 million cu. m. per year. For the quadratic trends, a very good fit to the earlier part of the time series is obtained by a semi-log equation for total consumption from 1950–69. This implies maximisation about the year 2000 at a consumption of approximately 3 million cu. m., three times the present level, but because the fit to the most recent data is poor, the prediction even for 1970 is about 90 thousand cu. m. too high. From this point of view much better fits are obtained working with 3-year average data from 1957 to 1959, but unfortunately the forecast is very different depending on whether the ordinary or semi-log version is used. The results are summarised in Table 48, equations (1) and (2); obviously the squared term is much more significant in the semi-log version.

With consumption per unit of construction output, only the semi-log formulation resulted in a negative coefficient for the squared term. (Equation (3) in Table 49 opposite refers to 3-year average data; the result for annual data is very similar except for the value of $\bar{R}^2$). Plywood consumption depends on the level of output of the construction industry, which as in the case of sawnwood is taken to be 12·5 per cent of GNP, the latter increasing at 2·5 per cent per annum. The consumption implications of these trend equations are summarised in Table 48 below.

The ECE/FAO forecasts for plywood consumption in the British Isles are 1370 and 1550 thousand cu. m. in 1975 and 1980 respectively, very similar to those obtained here from the quadratic and per unit of construction trends (ECE/FAO 1969, p. 43).

TABLE 48

CONSUMPTION FORECASTS FOR PLYWOOD AND TOTAL WOOD SHEETS

Period no. in model (length in years)	Year or years	Plywood consumption estimate from: Quadratic (see Table 49) (1)	Semi-log quadratic (see Table 49) (2)	Per unit of construction (see Table 49) (3)	Market share (see Table 47) (2)	Total wood sheets consumption (quadratic) (see Table 47) (1)
		th. m³	th. m³	th. m³	th. m³	th. tonnes
	1971	1166	1112	1140	1141	1548
1 (5)	1972	1210	1126	1187	1175	1617
	1973	1255	1132	1234	1204	1683
	1974	1297	1129	1280	1229	1745
	1975	1339	1118	1325	1249	1802
	(1971–75)	(6267)	(5617)	(6166)	(5998)	(8395)
	1976	1379	1098	1369	1263	1854
	1977	1418	1071	1411	1272	1900
2 (5)	1978	1456	1036	1451	1276	1940
	1979	1493	995	1489	1274	1973
	1980	1528	948	1525	1266	1999
	(1976–80)	(7273)	(5148)	(7245)	(6351)	(9666)
3 (5)	1981–85	8131	3912	8077	6044	10116
4 (10)	1986–90	8841	2464	8541	5187	9624
	1991–95	9401	1287	8569	4024	8325
5 (10)	1996–2005	19890	757	15520	4624	11226
6 (10)	2006–15	20350	74	11436	1579	4838
7 (15)	2016–30	28787	4	8852	409	1644

Notes:
(1) Bracketed numbers at head of columns are equation numbers from tables indicated.
(2) Consumption from construction output assumes construction is 12·5 per cent of GNP, which grows at 2·5 per cent per year.

TABLE 49

TIME TREND EQUATIONS FOR UNITED KINGDOM PLYWOOD

Equation	$\bar{R}^2$ %	*D-W* statistic	*n*	Implying maximisation: in year	Implying maximisation: at consumption
Total consumption (y) th. m³					th. m³
(3-year av. data 1957–69)					
(1) $y = 347{\cdot}8 + 63{\cdot}44x - {\cdot}594x^2$	99·3	1·94	13	2009	2040
(5·8) (·40)					
(2) $\ln y = 5{\cdot}91 + {\cdot}1307x - {\cdot}00381x^2$	99·2	1·77	13	1973	1132
(·0087) (·00062)					
Consumption per unit of construction industry output (y) m³ per £ th. at 1967 prices.					
(3-year av. data 1950–69)					
(3) $\ln y = -2{\cdot}288 + {\cdot}0637x - {\cdot}00106x^2$	97·5	1·52	20	1991*	1726*
(·0064) (·0003)					

* when applied to construction output estimated as 12·5 per cent of GNP, the latter growing at 2·5 per cent per year.
Note: $x = 1,2,3 \ldots n$.

Particle Board

Figure 6.10 shows that consumption since 1959 increased slowly at first, followed by a rapid rise, broken temporarily in 1969. The only price series available is average import price, which since 1959 has fallen more rapidly (in real terms) than plywood, but very little more than fibreboard.

The fall relative to plywood may be one reason for the rapid increase in total consumption and also in market share, but attempts to quantify this price effect in terms of cross-elasticities were not very successful.

Taking particle board in isolation, price appears to explain about 70 per cent of consumption, but as soon as construction output is added as an independent variable the price effect is swamped.

The shape of the consumption trend suggests a sigmoid growth curve, and therefore a semi-log quadratic curve was fitted, using 3-year average data for 1967–69. The fit is extremely close, and predicts maximisation in 1979 at about 1315 cu. m., roughly twice present consumption. In per capita terms this would probably represent ·0225 cu. m. per head, well below even the 1969 level in West Germany, which was about ·056 cu. m. per head (Ollman 1971, p. 35). The prediction from market shares, mentioned above, implies maximisation in 1988 at about 2·5 times the present level. Again this would be well below the current level in Germany, and is certainly not unreasonably high. The semi-log equation is included in Table 50 and the forecasts in Table 51.

TABLE 50

TIME TREND EQUATIONS FOR PARTICLE BOARD AND FIBREBOARD

Equation	$\bar{R}^2$ %	*D-W* statistic	*n*	Implying maximisation: in year	Implying maximisation: at consumption
Particle board					
Total consumption (y) th. *m*³					th. m³
(3–year average data 1960–69)					
(1) $\ln y = 4{\cdot}388 + {\cdot}277x - {\cdot}00687x^2$	99·7	1·74	10	1979	1316
(·017) (·0015)					
Fibreboard					th. tonnes
Total consumption (y) th. tonnes					
(annual data 1952–69)					
(2) $y = 61{\cdot}23 + 36{\cdot}16x - 1{\cdot}257x^2$	43·1	2·17	18	1965	320
(3·78) (·19)					
(3) $\ln y = 4{\cdot}452 + {\cdot}2039x - {\cdot}00763x^2$	90·4	1·23	18	1964	335
(·023) (·0012)					
(4) $\ln y = 4{\cdot}380 + {\cdot}799 \ln x - {\cdot}1068(\ln x)^2$	94·8	2·40	18	1993	356
(·10) (·0009)					

Note:
$x = 1,2,3 \ldots n$.

TABLE 51

PARTICLE BOARD AND FIBREBOARD CONSUMPTION FORECASTS

Period no. in model (length in years)	Year or years	Consumption estimates					
		Particle board, th. cu. m.			Fibreboard, th. tonnes		
		Semi-log quadratic (1) in T 50	Market share (3) in T 47	Log normal	Semi-log quadratic (3) in T 50	Double log quadratic (4) in T 50	Market share (4) in T 47
1 (5)	1971	832	771	611	239	335	307
	1972	925	854	670	214	338	300
	1973	1013	937	733	189	340	293
	1974	1095	1021	792	165	342	284
	1975	1168	1104	859	141	344	274
	(1971–75)	(5033)	(4688)	(3665)	(948)	(1699)	(1458)
2 (5)	1976	1228	1185	925	119	345	264
	1977	1274	1264	992	99	347	253
	1978	1304	1340	1057	81	348	241
	1979	1316	1412	1125	65	349	229
	1980	1310	1478	1191	52	350	217
	(1976–80)	(6432)	(6679)	(5290)	(416)	(1740)	(1204)
3 (5)	1981–85	5887	8155	6900	126	1764	896
4 (10)	1986–90	3857	8707	8295	26	1774	603
	1991–95	1809	8230	9300	4	1778	367
5 (10)	1996–2005	754	12192	20185	—	3545	306
6 (10)	2006–15	28	5769	20990	—	3510	169
7 (15)	2016–30	—	2108	31500	—	5172	—

Notes:
(1) Bracketed figures at heads of columns refer to equation number in stated Table.
(2) Particle board quantities can be converted to th. tonnes by multiplying by ·65.

The sigmoid curves which do not imply a downturn beyond a maximum, the lognormal, logistic and Gompertz functions, were fitted to the data. The results using construction output as the independent variable were better than those using time, but visually none appeared to give a very satisfactory continuation of the existing consumption series. As in the case of plywood it was difficult to distinguish between a wide range of (consumption) saturation levels, all of which gave similar values of $\bar{R}^2$ in the regression. A saturation level of 2100 thousand cu. m. per year appeared marginally the best and results from this lognormal were used as demand constraints in some runs. The consumption growth curve implied by the lognormal curve is included in Figure 6.17; the values shown are based on construction output at 12·5 per cent of a GNP increasing at 2·5 per cent per annum, but converted to a time scale. The corresponding consumption forecasts are included in Table 51. ECE/FAO forecasts for British Isles consumption in 1975 and 1980 are 1186 and 1478 thousand cu. m. respectively, very similar to the estimates based on market shares (ECE/FAO 1969, p. 48).

Fibreboard

Consumption increased up to about 1964, since when it has remained fairly constant at about 300 thousand tonnes annually (Figure 6.11). No index of delivered prices is available, but as shown in Chapter 4, average import prices have been fairly constant in real terms in the 1960s following the fairly steep decline during the 1950s. A significant proportion of the total fibreboard is used in the vehicle building industry, and this may be one reason why a regression of consumption on average import price and construction output for 1950 to 1969, indicated that price is the more important explanatory variable, although together explaining only 80 per cent of consumption. Price and output elasticities were estimated as −1·4 and ·12 respectively.

The usual quadratic functions were fitted to the consumption data, starting at 1952, and ordinary and double log formulations gave the best results, as shown by the summary statistics in Table 50. Extrapolation yields vastly different results and although visually the ordinary quadratic seems a better fit to the most recent data, it seems improbable that

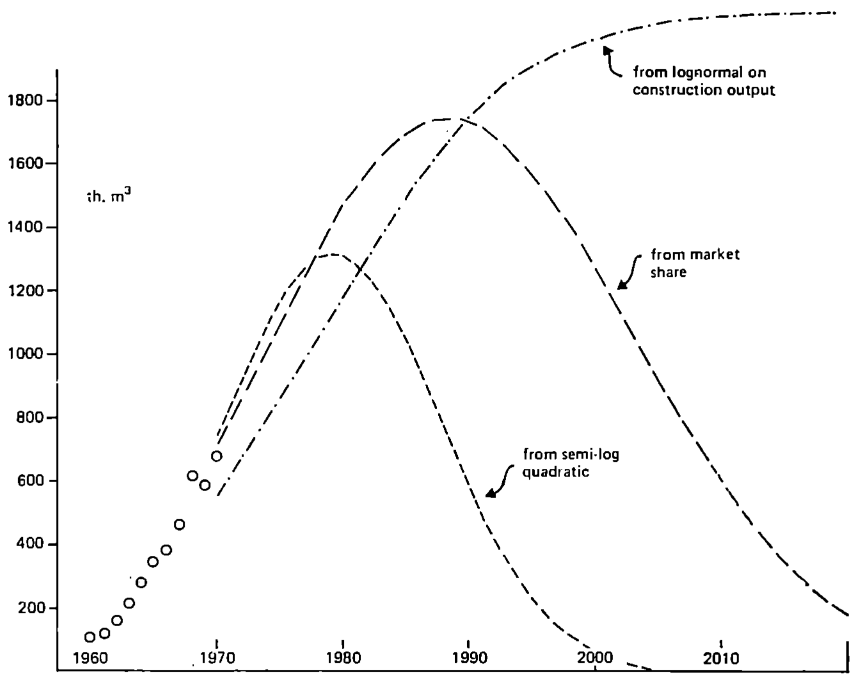


Figure 6.17 Consumption forecasts for particle board

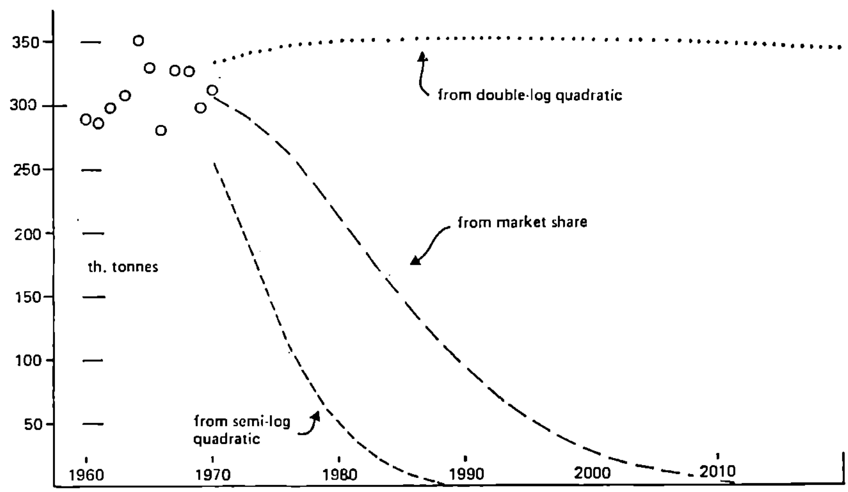


Figure 6.18 Consumption forecasts for fibreboard

TABLE 52
CONSUMPTION AND PRICE DATA FOR NEWSPRINT AND NEWSPAPERS

Year	Newsprint consumption: Total th. tonnes (1)	Newsprint consumption: Per head kg. (2)	Newsprint consumption: Per unit of GNP (1967 prices) kg./£ th. (3)	Consumers' expenditure on newspapers £ million: Current prices (4)	Consumers' expenditure on newspapers £ million: 1967 prices (5)	Newsprint average import price £/tonne: Current prices (6)	Newsprint average import price £/tonne: 1967 prices (7)	Newspaper price index (5)/(1) £ p. tonne (8)	Advertising expenditure in newspapers £ million: Current prices (9)	Advertising expenditure in newspapers £ million: 1967 prices (10)	Advertising expenditure in newspapers as % of GNP (11)
1948	401·8	28·1	20·9	60	111	32·6	60·4	2765	14	25	·13
1949	583·7	11·7	29·1	70	126	34·9	62·8	2160	20	36	·18
1950	653·3	13·0	32·0	71	124	34·3	59·9	1900	24	41	·20
1951	601·9	12·0	30·1	83	129	52·7	82·0	2148	25	39	·20
1952	655·2	13·0	31·8	92	135	55·3	81·3	2065	30	44	·21
1953	803·9	15·9	36·7	96	141	51·4	75·3	1752	38	56	·26
1954	837·9	16·5	36·2	99	143	51·7	74·8	1710	45	65	·28
1955	890·1	17·5	37·7	99	138	52·0	72·4	1549	53	73	·31
1956	972·2	19·0	39·9	114	151	54·0	71·3	1549	58	77	·32
1957	1013·4	19·7	40·6	121	155	55·2	70·5	1525	62	80	·32
1958	1058·0	20·5	41·5	137	171	55·9	69·9	1619	68	84	·33
1959	1149·9	22·1	43·3	131	162	54·8	67·8	1412	77	96	·36
1960	1308·1	25·0	46·9	134	164	54·6	66·9	1254	98	120	·43
1961	1272·5	24·1	43·8	150	179	53·5	63·8	1405	101	120	·41
1962	1368·9	25·7	46·3	157	182	54·2	62·7	1326	103	119	·40
1963	1330·1	24·8	43·0	161	183	53·8	61·2	1376	113	128	·41
1964	1379·6	25·5	42·4	173	192	53·0	58·7	1390	113	125	·38
1965	1404·7	25·8	42·1	196	209	51·9	55·2	1484	114	121	·36
1966	1380·9	25·3	40·8	204	209	52·6	54·0	1515	109	112	·33
1967	1340·9	24·4	38·5	209	209	54·1	54·1	1559	103	103	·30
1968	1445·6	26·2	41·8	242	228	62·0	58·5	1579	119	112	·32
1969	1550·7	27·9	44·6	244	220	62·3	56·1	1416	111	100	·29

Notes:
1. Estimates of advertising revenue (9) exclude that from classified advertisements.
2. Legion estimates for 1960–63 are not comparable because of changes in press coverage, and values in (9) are estimated from regression of Legion data on EIU data, 1957–59 and 1964–65.

Sources:
(1), (4) from *Annual Abstract of Statistics.*
(6) from *Annual Statement of Trade.*
(9) from *Advertising Statistical Review* (Legion Publishing Co. Ltd.).

consumption will be zero after 1981, which is the implication. The consumption predictions from the logarithmic functions are included in Table 51. In contrast ECE forecasts are for a continuing rise inc onsumption, at 430 and 470 thousand tonnes in 1975 and 1980 respectively, including the Irish Republic.

Newsprint

Basic data on recent trends in newsprint consumption are given in Table 52, for the period 1948–69. Consumption has risen from around half a million tonnes at the beginning of the period, to about 1·5 million tonnes currently. The graph in Figure 6.19 shows two reasonably distinct periods, a steeper rise up to about 1960, followed by a more gradual upward trend. Consumption per head shows a similar pattern (Figure 6.20), but consumption per unit of (deflated) GNP shows a declining trend from 1960 to 1967, reversed only in the past few years (Figure 6.21).

In attempting to explain these changes through the usual factors of income, population and prices it should be recognised that at present there is no realistic substitute material for newsprint (apart from other communications media) and the price of newsprint itself may be less relevant to consumption than the price of newspapers. For this reason a price index for newspapers was constructed by dividing deflated consumers' expenditure on newspapers, by the weight of newsprint consumed. In recent years this index may be slightly exaggerated because of the popularity of thinner sheets i.e. *ceteris paribus* the same weight of newsprint will represent a higher sale revenue. A graph of the index shows a generally steep fall from 1948 to about 1960, followed by a gradual upward trend (Figure 6.22).

On this argument it follows that a prediction of newsprint consumption from price changes requires a prediction of the price of newspapers. In the time available it was not possible to deal with this problem in detail, but since for national newspapers advertising revenue is about half the total (EIU 1966, pt. II, Table 13), the level of advertising expenditure in newspapers should affect the sale price. The EIU report referred to covers only the national press, from 1957 to 1965. To obtain a longer time series, and include the provincial press, estimates of advertising expenditure were extracted from the Advertising Statistical Review (Legion Publishing Co. Ltd.) and are shown in Table 52 and Figure 6.23. Unfortunately the figures exclude classified advertising, which is important for all groups of newspapers except popular morning dailies. It is

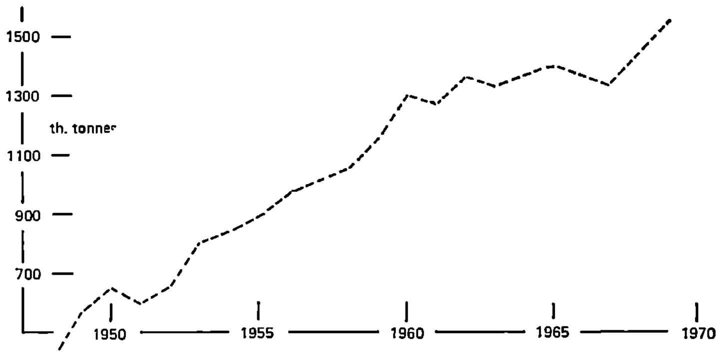


Figure 6.19 Consumption of newsprint

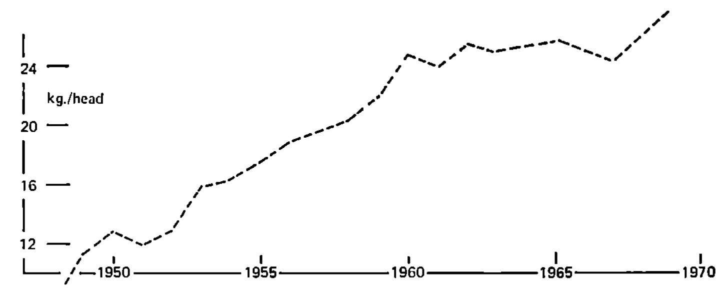


Figure 6.20 Consumption of newsprint per head

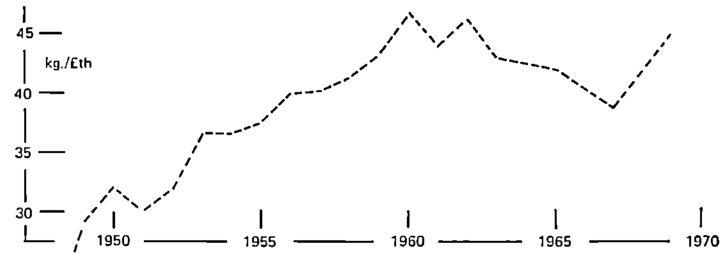


Figure 6.21 Consumption of newsprint per unit of GNP (1967 prices)

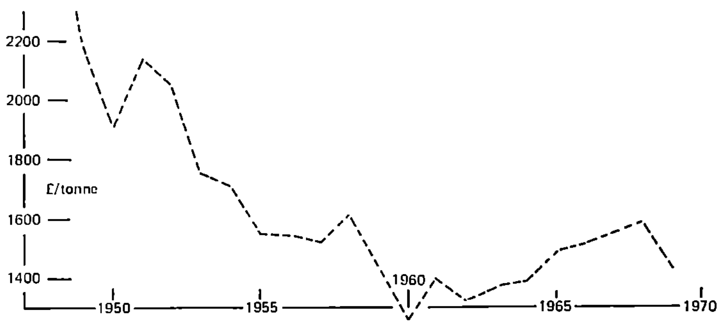


Figure 6.22 Price index of newspapers (1967 prices)

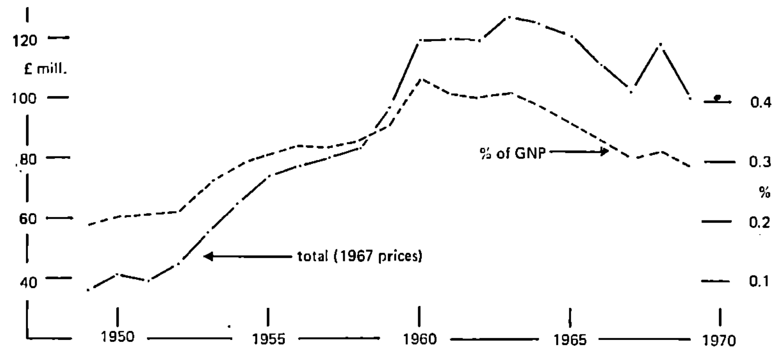


Figure 6.23 Newspaper advertising revenue

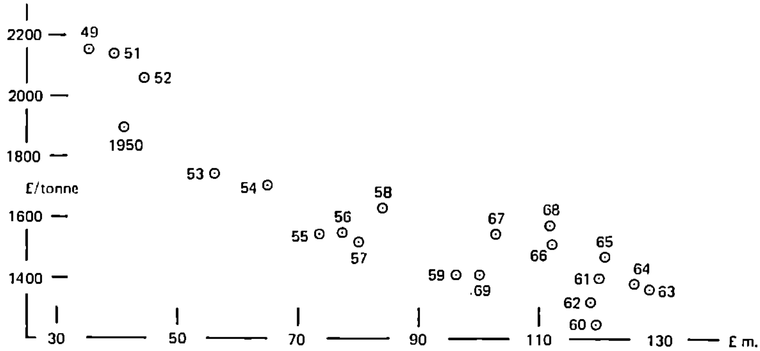


Figure 6.24 Newspaper price index (y) on newspaper advertising revenue (x) (1967 prices)

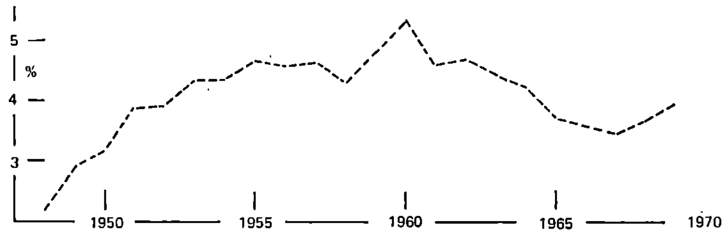


Figure 6.25 Newsprint price/newspaper price index

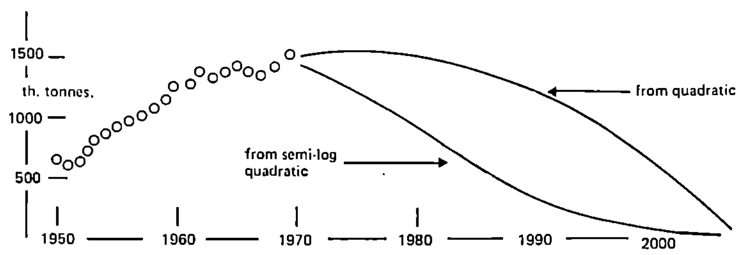


Figure 6.26 Consumption forecasts for newsprint

or was also increasing its percentage share of total advertising revenue. For example, in 1965 classified advertisements represented just over half total advertising revenue for London evening papers (EIU 1966, pt. II, Table 11).

The graph (Figure 6.23) indicates that advertising revenue at constant prices maximised about 1963 but as a proportion of GNP it maximised about 1960, since when the decline has been fairly consistent. It is probably relevant that commercial television coverage of Britain was completed in 1959.

If the newspaper price index is plotted against advertising expenditure as estimated, the resulting graph shows the expected relationship (Figure 6.24), although if the figures for 1959–69 only are taken, the trend is not evident. Overall, the relationship is approximated well by a rectangular hyperbola:

$$y = 1055 + 41235/x \qquad \bar{R}^2 = 94{\cdot}5\%$$

where y = newspaper price index, £ p. tonne 1967 prices and x = advertising expenditure in newspapers, £ in 1967 prices

If the apparent decline in newspaper advertising revenue continues, the result should be an increasing newspaper price index, the actual figure depending on the trend assumed for advertising. For example, a linear decline in the revenue as a percentage of GNP, results in a zero revenue about 1987, but a semi-logarithmic formulation gives almost as good an $\bar{R}^2$ and never becomes zero:

$$\ln y = -{\cdot}767 - {\cdot}0457x \qquad \bar{R}^2 = 88{\cdot}8\%$$

where y = advertising expenditure in newspapers as percent of GNP and x = time, 1960 = 1, 1969 = 10

Extrapolations of this type imply a future rate of increase of GNP similar to that of the data period, about 2·5 per cent annually. The main conclusion is that there is some reason to believe that the newspaper price index will rise in the future, but better data on revenue from classified advertisements might change this view. These results also indicate where further research could be useful. For example, the level of advertising revenue and newsprint consumption (or newspaper circulation) are likely to be mutually determining and the equations just given would then not be identified. A recursive or iterative model could be suitable here (see for example Riihinen 1962 and 1971).

Changes in the price of newsprint do not appear to have a very consistent influence on newspaper price (Figure 6.25). During the 1950s the values show a positive relationship, as seems reasonable, but in the 1960s it becomes negative. These differences are consistent with the diminishing importance of newsprint as a proportion of total newspaper costs. For example, in 1957 newsprint and ink were found to be about 43 per cent of total costs for the popular (national) press, but by 1965 this figure had fallen to about 35 per cent (EIU 1966, pt. II, Table 14). A downward trend was also shown for the quality newspapers, at rather lower proportions.

Elasticities

Price, population and income elasticities of consumption were calculated by the usual double-log linear equations, and the results are summarised in Table 53. Population and income were not included together because of the high correlation between them (·99). It is clear that much more satisfactory results are obtained by including two independent variables, but the choice between income and population as the partner to price, is not so obvious. The number of potential readers appears a plausible explanatory variable, but a population elasticity of 5 seems very high and probably includes income effects. The similarity of results for total and per capita data suggests that income may be the more realistic variable. Inclusion of a trend term as a third independent variable effectively eliminates income or population, because of the high correlation between time and both these variables, but there seems no gain in replacing them in this way. Estimates of point elasticities such as these may be meaningful for short and medium term projections (say 5 years) but they are unlikely to remain constant. For example, within the period 1948–69, price elasticities for the first half of the period (1948–58) are approximately −1, but for 1959–69 the estimates are roughly −·7, differing somewhat depending on whether income or population is the second independent variable.

These elasticity estimates are a reflection of the general trends over the data period involved. At first newsprint consumption rose rapidly and the newspaper price index fell rapidly, followed by a levelling off in both cases, while population grew gradually. Population and income can confidently be expected to increase in the future, and there is some reason to believe that the price index will also increase (see above). In this situation application of the calculated elasticities to predicted changes in income and price should give estimates of future consumption. However, it was found that using income and price as independent variables, newsprint consumption increased indefinitely once GNP grew faster than about 2 per cent per annum. This "break-even" percentage which would have been even lower if the more recent price elasticity estimates of −·7, had been used.

TABLE 53

ELASTICITIES OF CONSUMPTION FOR NEWSPRINT

Independent variable(s)	Elasticities: Price	Income (constant prices)	Popln.	$\bar{R}^2$ %	D-W statistic	Correlation coefficient (indep. variables)
Total consumption						
Price	-1·78 (·16)	—	—	84·9	·49	—
Income	—	1·70 (·14)	—	88·1	·50	—
Population	—	—	9·18 (1·0)	79·7	·34	—
Price and Income	-·96 (·08)	1·02 (·07)	—	98·7	1·55	-·76
Price and Popln.	-1·14 (·06)	—	5·06 (·35)	98·9	1·84	-·69
Consumption per head						
Price	-1·66 (·13)	—	—	87·9	·58	—
Income	—	1·86 (·16)	—	86·3	·52	—
Price, and Income per head	-·96 (·08)	1·01 (·09)	—	98·4	1·56	-·78

Notes:
1 Price is newspaper price index, not newsprint price.
2 Income is GNP deflated to 1967 prices by NIESR price index.
3 Population is U.K. *de facto* mid-year.

Consumption Trends

In the short run newspapers are likely to find their main competition in alternative news media such as television, particularly if newspaper prices rise in the future, relative to other prices. In the longer run, perhaps ten to twenty years, the physical transportation of newspapers to households may be replaced by "printing" within the household, by a unit connected to the television set. This already is being achieved at the prototype stage. The "paper" is unlikely to be newsprint although it might be based on mechanical pulp, and there would be a strong incentive for it to be re-usable. This argument suggests that newsprint consumption is more likely to decline than to grow. For this reason quadratic trend curves were fitted to the consumption data for 1948–69, including various logarithmic transformations. All the equations gave excellent values of $\bar{R}^2$ (around 97 per cent) but only the ordinary and a semi-log form gave negative coefficients for the squared term, implying a maximum consumption. This was also true for consumption per head. These results are given in Table 54, with some details on maximisation. The bracketed figures are where maximisation has already occurred.

The consumption levels predicted for these equations are shown in Table 55, annually for the first ten years and by period totals subsequently. According to equation (1), total consumption will maximise in 1975–6 and decline gradually thereafter, reaching a million tonnes annually by about 1995.

The semi-log equation (2) implies that consumption maximised in 1968 and as usual with this formulation, the decline from the maximum is more rapid but y never becomes negative. In view of the sharp rise in consumption from 1967 to 1969, the first equation looks more plausible. The forecasts from these equations are also shown in Figure 6.26.

The predictions for consumption per head fairly rapidly become inconsistent with the corresponding total consumption and probable population growth. For example, in 1980 the population required to make columns (equations) (1) and (3) consistent is 1513000/·0234, or about 65 millions, which seems improbable. This more rapid fall in the estimate for per capita consumption is a reflection of the data base, with total newsprint consumption levelling off in the 1960s, but a continuing growth in population.

In contrast with the suggestion of a downturn in consumption, made here, the ECE predicts increasing consumption in the British Isles, reaching 1780 thousand tonnes in 1975 and 2010 thousand tonnes in 1980 (ECE/FAO 1969, p. 68).

TABLE 54

QUADRATIC TREND EQUATIONS FOR NEWSPRINT

Equation	$\bar{R}^2$ %	D-W statistic	Implying maximisation: in year	at consumption
Annual data 1948–69				th. tonnes
Total consumption (y) th. tonnes				
(1) $y = 336{\cdot}9 + 86{\cdot}2x - 1{\cdot}53x^2$ (8·1) (·34)	97·1	1·35	1975	1549
(2) $\ln y = 6{\cdot}02 + {\cdot}1216x - {\cdot}00294x^2$ (·009) (·0004)	96·9	1·81	(1968)	(1446)
Consumption per head (y) kg.				kg./head
(3) $y = 6{\cdot}87 + 1{\cdot}702x - {\cdot}0364x^2$ (·15) (·0065)	96·5	1·38	(1970)	(26·8)
(4) $\ln y = 2{\cdot}116 + {\cdot}119x - {\cdot}00306x^2$ (·009) (·0004)	96·3	1·80	(1966)	(26·4)

Note:
$x = 1,2,3 \ldots 22$.

TABLE 55

NEWSPRINT CONSUMPTION FORECASTS

Period no. in model (length in years)	Year or years	Consumption estimate from: Quadratic (1) thous. tonnes	Semi-log quadratic (2) thous. tonnes	Quadratic kg. p. head (3)	Semi-log quadratic p. head (4)
1 (5)	1971	1523	1400	26·8	24·8
	1972	1534	1368	26·7	24·0
	1973	1542	1330	26·5	23·1
	1974	1547	1286	26·3	22·2
	1975	1549	1235	26·0	21·1
	(1971–75)	(7695)	(6619)	av(26·4)	av(23·0)
2 (5)	1976	1548	1180	25·6	20·0
	1977	1544	1120	25·2	18·8
	1978	1536	1057	24·7	17·5
	1979	1526	992	24·1	16·3
	1980	1513	925	23·4	15·0
	(1976–80)	(7667)	(5274)	av(24·6)	av(17·5)
				mid-period average	
3 (5)	1981–5	7255	3634	20·9	11·5
4 (10)	1986–90	6460	2165	15·4	6·4
	1991–95	5280	1115	8·1	3·1
5 (10)	1996–2005	5500	689	·8	·8
6 (10)	2006–15	89	82	—	·1

Note:
The bracketed figures at the head of columns are equation numbers from Table 54.

Printings and Writings

As defined here, this category excludes newsprint. Data on consumption and some prices are given in Table 56. Total consumption, shown in Fig. 6.27, has increased more or less continuously since 1950, from about 700 thousand tonnes to 1¼ million tonnes currently. This upward trend is also true of consumption per head (Figure 6.28), but because GNP has risen faster than population, the

TABLE 56

CONSUMPTION AND PRICE DATA FOR PRINTINGS AND WRITINGS (EXC. NEWSPRINT)

Year	Apparent consumption			Consumption of coated paper as % of total	Average import price (1967 prices) £/tonne	Price index of manufactured stationery (1967 prices) 1967=100
	Total th. tonnes	Per head kg.	Per unit of GNP kg/£th.			
1950	677·2	13·5	33·1			113·5
1951	738·0	14·7	36·9			151·2
1952	588·7	11·7	28·6			136·5
1953	663·3	13·1	30·3			113·9
1954	754·3	14·9	32·6		very	113·5
1955	849·0	16·7	36·0		small	114·9
1956	799·4	15·6	33·0		quantities	115·8
1957	778·7	15·1	31·4		pre-1960	111·5
1958	808·5	15·7	31·7			109·0
1959	791·2	15·5	29·8			108·4
1960	938·5	17·9	33·6	pre-1962	110·1	107·8
1961	928·0	17·6	31·9	n.a.	113·6	107·3
1962	880·3	16·5	29·8	19·1	99·7	107·1
1963	938·3	17·5	30·3	20·7	97·3	105·9
1964	1036·7	19·2	31·8	21·2	95·4	103·8
1965	1062·7	19·6	31·9	21·5	87·7	102·2
1966	1138·4	20·8	33·6	22·7	77·1	102·3
1967	1158·1	21·1	33·3	24·9	78·6	100
1968	1171·2	21·2	33·5	28·0	80·6	100·3
1969	1226·6	22·1	34·9	29·1	80·3	101·6
1970	1259·9	22·6	34·5	28·7		105·9

Sources:
1 Apparent consumption and import price from BPBMA *Reference Tables* and (pre-1954) from information supplied by BPBMA.
2 Coated paper percentage derived from information from BPBMA.
3 Price index from *Annual Abstract of Statistics.*

consumption per unit of GNP has remained fairly constant at about 30–35 kg. per £ thousand (1967 prices) (Figure 6·29). From 1962 onwards it is possible to separate consumption of coated and uncoated paper, and of these, coated has increased more consistently than uncoated, reaching nearly 400 thousand tonnes (Figure 6.31). This is reflected in the market share percentages, included in Table 56 and shown in Figure 6.32.

Elasticities

Although plastic printing paper is available it is at present comparatively expensive, and used mainly for purposes where water-resistance or durability are particularly important. Therefore over the time period considered here, wood fibre has been for practical purposes the only raw material, and in estimating elasticities the price of the converted product is more relevant than that of the paper as such. A price index of manufactured stationery is available and is shown in Table 56 and in Figure 6.30. This index is more likely to be representative of uncoated than of coated paper, but the former represents about 70 per cent of consumption.

It was found that a significant estimate of price elasticity, in conjunction with income (GNP), was obtained by lagging price 1 year. The results were:

Price elasticity −·63 (price index lagged 1 year)
Income elasticity ·96

Income can confidently be predicted to increase in the future, and there is some evidence in the last few years that the price index is also rising, relatively to other prices (see Figure 6.30). If these elasticities remained constant, and assuming GNP rises in the future at 2·5 per cent per annum, the price index would have to rise at nearly 4 per cent to prevent indefinite expansion of consumption.

Consumption Trends

Simple extrapolation of all the recent trends implies a continually rising consumption of printings and writings, and especially of coated printings. For the reasons discussed in Chapter 5, this prediction is considered unrealistic for the long run, but for shorter-term forecasts, linear trends were fitted to the consumption data from 1962 to 1970, for coated and uncoated paper separately. The equations are in Table 57 ((2) and (3)) and the resulting forecasts are shown in Table 58 and Figures 6.33 and 6.34 for the first five time periods in the model. Using the total

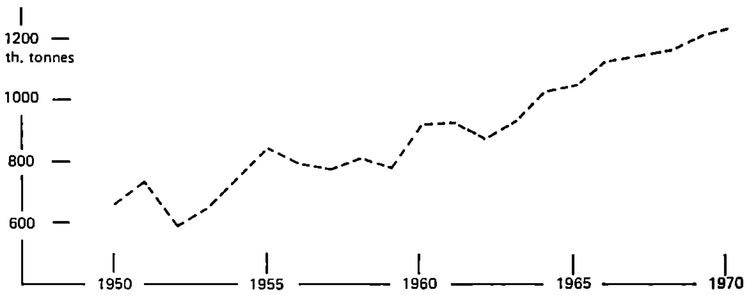


Figure 6.27 Consumption of printings & writings (exc. newsprint)

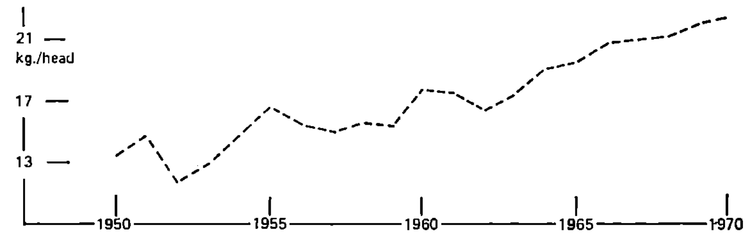


Figure 6.28 Consumption of printings & writings per head

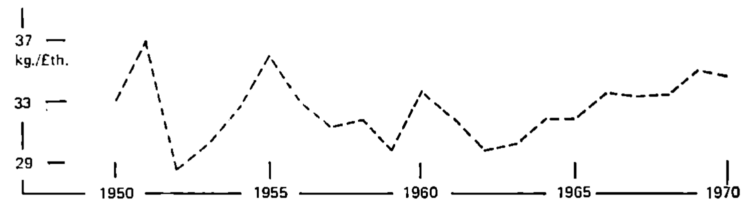


Figure 6.29 Consumption of printings & writings per unit of GNP

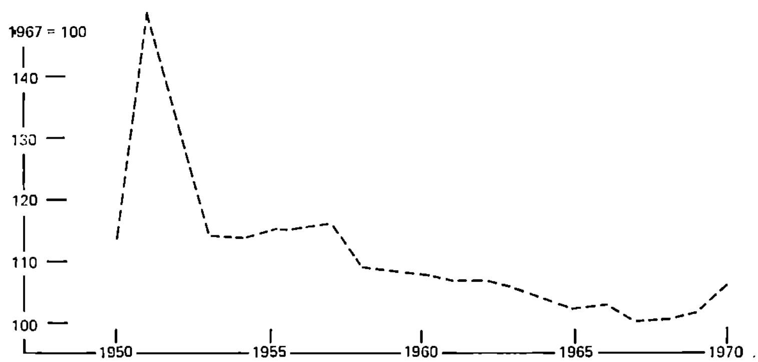


Figure 6.30 Price index of manufactured stationery (1967 prices)

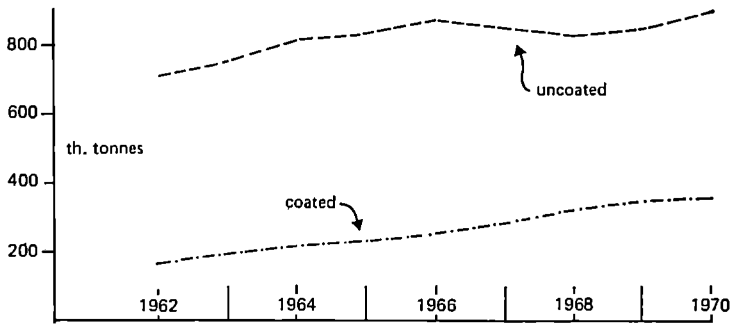


Figure 6.31 Consumption of coated and uncoated paper

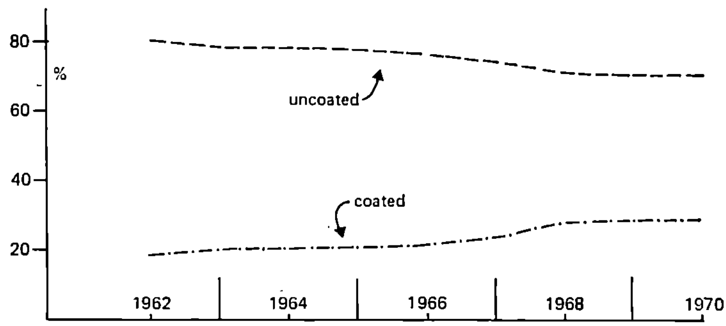


Figure 6.32 Market shares for coated and uncoated paper

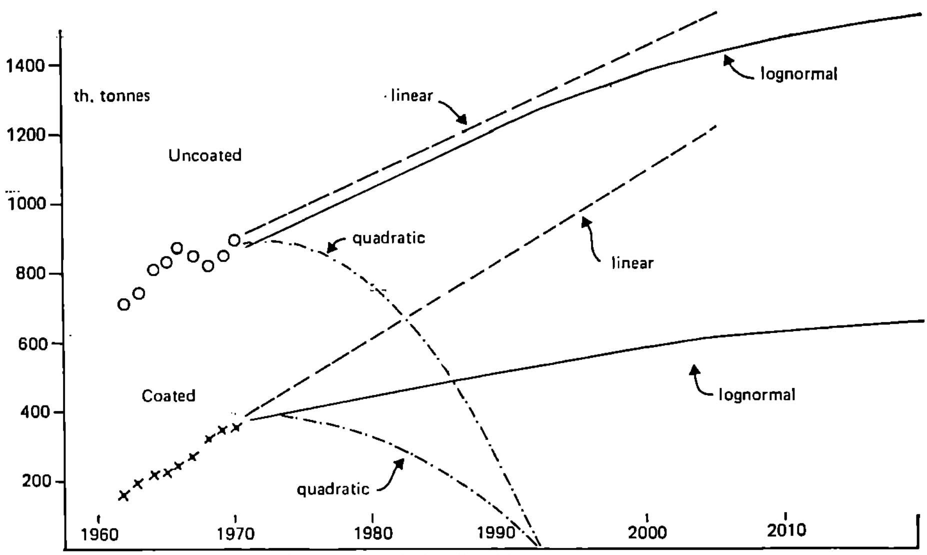


Figure 6.33 Consumption forecasts for printings & writings

Figure 6.34 **Consumption of tissue (unconverted)**

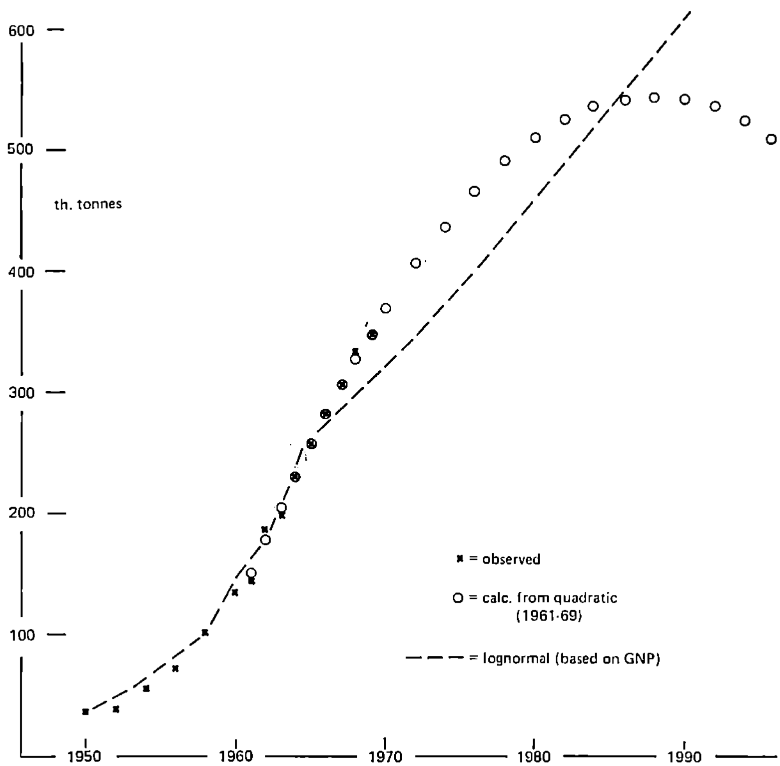


Figure 6.35 **Observed and predicted consumption of tissue**

consumption data over the same period, a quadratic trend function can also be fitted which implies an eventual downturn in demand, but maximisation is in 1973, which seems improbably early (see Table 57; equation (1)). However, the forecasts are given in Table 58, and in Figures 6.33 and 6.34, using a breakdown of 70 per cent uncoated and 30 per cent coated. These values are used as RHS values in conjunction with parametric variation of the RHS.

Over the data period as a whole (from 1950) there is some indication of a sigmoid trend in total consumption but fitting a semi-logarithmic quadratic

TABLE 57
TIME TREND EQUATIONS FOR PRINTINGS AND WRITINGS

Equation	$\bar{R}^2$ %	D-W statistic	Implying maximisation: in year	Implying maximisation: at consumption
Total consumption (y) th. tonnes (annual data 1962–70)				th. tonnes
Printings and writings				
(1) $y = 806{\cdot}3 + 79{\cdot}45x - 3{\cdot}375x^2$ (10·5) (1·02)	98·0	2·48	1973	1274
Uncoated paper				
(2) $y = 728{\cdot}3 + 18{\cdot}95x$ (4·5)	67·5	·92	not applic.	
Coated paper				
(3) $y = 139{\cdot}3 + 25{\cdot}11x$ (1·06)	98·6	1·45	" "	

Note:
$x = 1,2,3, \ldots 9.$

TABLE 58
CONSUMPTION FORECASTS FOR PRINTINGS AND WRITINGS

Period no. in model (length in years)	Year or years	Consumption estimate from: Lognormal on GNP (1963 prices) uncoated	Lognormal on GNP (1963 prices) coated	Quadratic uncoated (1)	Quadratic coated (1)	Linear uncoated (2)	Linear coated (3)
		thous. tonnes					
1 (5)	1971	874	374	884	379	918	390
	1972	894	383	890	382	937	415
	1973	912	391	892	382	956	441
	1974	935	401	888	381	975	466
	1975	956	410	880	377	993	491
	(1971–75)	(4571)	(1959)	(4434)	(1901)	(4779)	(2203)
2 (5)	1976	981	420	867	372	1013	516
	1977	1001	429	849	364	1032	541
	1978	1020	437	827	354	1051	566
	1979	1041	446	800	343	1069	591
	1980	1060	455	768	329	1088	616
	(1976–80)	(5103)	(2187)	(4111)	(1762)	(5253)	(2830)
3 (5)	1981–85	5597	2398	3198	1371	5726	3458
4 (10)	1986–90	6055	2595	1694	726	6200	4087
	1991–95	6461	2769	124	53	6674	4714
5 (10)	1996–2005	13920	5965	—	—	7384	5655
6 (10)	2006–15	14886	6379				
7 (15)	2016–30	23373	10017				

Notes:
1 The lognormal and quadratic figures are from total consumption split into uncoated and coated in the ratio 70:30.
2 The bracketed figures at the head of some of the columns are equation numbers from Table 57.
3 It is regarded as unrealistic to extrapolate the linear trends beyond period 5.

function resulted in positive coefficients for both the independent variables. On the other hand, fitting a lognormal curve with GNP as the independent variable, gave very high values of $\bar{R}^2$, particularly when using GNP at 1963 prices (based on the GNP deflator, as described in Chapter 4) rather than 1967 prices. On this basis a saturation level of 2·3 million tonnes gave marginally the best fit, and also a smooth continuation of the existing series. These forecasts are shown in Figure 6.33, converted to a time basis, on the assumption of 2·5 per cent annual growth in GNP, and the usual 70:30 split between uncoated and coated paper. It should be noted that the graph does not include all of period 7.

Comparing the estimates in Table 58, there is fairly close agreement between the lognormal and linear series for uncoated paper, over the first three periods, although initially the linear trend suggests higher values. This is because the linear trend as fitted to the historical data, rather exaggerates the more recent consumption levels, and in fact has a fairly low $\bar{R}^2$. By period 2 the linear trend for coated paper is well ahead of the estimate, partly because of its linearity and also because of the fact that its percentage share is rising above 30.

For example, by 1980 it is about 36 per cent, which on American experience is the maximum for coated paper. ECE forecasts, referred to for other product groups treated in this Chapter, suggest that consumption in the British Isles will rise even more rapidly than the linear trends shown in Table 58. They predict consumption of 1950 and 2440 thousand tonnes in 1975 and 1980 respectively, taking coated and uncoated paper together (ECE/FAO 1969, p. 72). These compare with about 1480 and 1700 thousand tonnes, obtained by adding the linear trends for the two types of paper in these years, although consumption in the Irish Republic is excluded.

Tissue

This category is defined rather widely to include all household paper such as kitchen rolls, cellulose

TABLE 59

CONSUMPTION AND PRICE DATA FOR TISSUE (UNCONVERTED)

Year	Apparent consumption: Total th. tonnes	Apparent consumption: Per head kg.	Apparent consumption: Per unit of Gross National Product (1967 prices) kg/£.th.	Wholesale price index (1967 prices) 1967=100
1948	32	·65	—	
1949	33	·66	1·65	
1950	37	·74	1·79	
1951	49	·97	2·46	
1952	39	·77	1·91	
1953	42	·83	1·91	
1954	57	1·1	2·45	
1955	68	1·3	2·90	
1956	71	1·4	2·93	
1957	85	1·6	3·43	
1958	102	2·0	3·99	
1959	110	2·1	4·16	
1960	135	2·6	4·84	
1961	145	2·7	5·00	
1962	185	3·5	6·25	
1963	202	3·8	6·52	109·9
1964	230	4·3	7·05	109·6
1965	256	4·7	7·68	107·5
1966	283	5·2	8·37	104·9
1967	304·0	5·53	8·73	100
1968	330·3	5·97	9·46	103·8
1969	346·8	6·25	9·89	101·1

Sources:
1 Consumption data from United Kingdom production and net imports of unconverted tissue.
2 United Kingdom production data from BPBMA *Reference Tables* (1954–on) and from BPBMA (1948–53 incl.).
3 Net imports from *Annual Statement of Trade*, including estimates as noted below.
4 Wholesale price index from *Business Monitor*.

Notes:
1 Figures before 1967 incorporate various estimates because of lack of detail in import statistics.
2 1960–66 import figures include estimated imports of creped tissue, taken as 80 per cent of imports of "paper and paperboard, corrugated, (with or without flat surface sheets), creped, crinkled, embossed or perforated, in rolls or sheets, not cut to size or shape, weighing not more than 220 g/m²".

wadding, filter, blotting, and cigarette paper, as well as the grades normally termed tissue. At present this group is still a relatively small part of total paper consumption, about 7 per cent by weight, but it has been one of the fastest-growing sectors in recent years. Consumption figures before 1967 have been estimated from United Kingdom production together with net imports, but pre-1967 the latter incorporate a number of estimates and assumptions because the published data do not always distinguish tissue from other types of paper. However, the general trend is believed to be as shown in Table 59 and Figure 6.34. If the figures are correct, consumption has doubled roughly every six years since 1948, although with some slackening in the last few years. Converted tissue consumption (consisting of boxed handkerchiefs, kitchen and toilet rolls, and so on) is very similar in weight but much higher in value terms.

The trends in consumption per head and per unit of GNP, consistent with the estimated totals, are included in Table 59 but are not shown in graphs. As with other products, the patterns are similar to that for total consumption. Since tissue is a relatively new product, with few close substitutes, the price of the converted tissue is probably more relevant to elasticity estimates than is the price of the unconverted. Unfortunately the main price series available are for the unconverted product. (The import price has been given in Chapter 4 (Figure 4.5) and a wholesale price index is shown in Table 59, from its starting date in 1963.) For this reason elasticity estimates have not been attempted.

The growth pattern in consumption suggests a sigmoid curve, but fitting a semi-logarithmic quadratic trend curve gave a positive coefficient for the squared term. Logistic, Gompertz and lognormal curves were also fitted to the data, using time and GNP as alternative independent variables; of these a lognormal curve based on GNP, and a saturation consumption level of 1·1 million tonnes, gave the best result. However, it underestimates the growth in consumption over the most recent years, which have shown below-average rates of GNP. This suggests a time trend is also present, although in the lognormal estimations, time as an independent variable was much inferior to GNP. The result is that predicted consumption for the next few years is actually less than the most recent values, unless an improbably high growth rate of GNP is assumed. This particular problem can be avoided if a quadratic trend curve is fitted to the data from 1961 on. The equation is:

$$y = 118{\cdot}56 + \underset{(2{\cdot}35)}{30{\cdot}45x} - \underset{(\cdot 23)}{\cdot 543x^2} \qquad \text{where } x = 1 = 1961 \text{ and } n = 9$$

$$\bar{R}^2 = 99{\cdot}7\%$$

The equation implies maximisation in 1988 at a consumption level of about 545 thousand tonnes annually, and a decline thereafter.

The forecasts from these equations are shown in Table 60 and Figure 6.35, where the lognormal estimates assume a growth rate in GNP averaging 2·5 per cent per year. Both the forecasts are used as RHS values.

TABLE 60

CONSUMPTION FORECASTS FOR TISSUE

Period no. in model (length in years)	Year or years	Consumption estimate from: Lognormal on GNP	Quadratic
		--- thous. tonnes ---	
1 (5)	1971	348	388
	1972	370	406
	1973	392	422
	1974	416	438
	1975	440	453
	(1971–75)	(1966)	(2107)
2 (5)	1976	463	467
	1977	488	479
	1978	514	490
	1979	538	501
	1980	563	510
	(1976–80)	(2566)	(2447)
3 (5)	1981–85	3182	2651
4 (10)	1986–90	3760	2720
	1991–95	4275	2652
5 (10)	1996–2005	9685	4558
6 (10)	2006–15	10545	2658
7 (15)	2016–30	16365	288

Note:
The saturation level for the lognormal curve is 1·1 million tonnes annually.

Packaging Paper and Paperboard

This heading covers three final products in the model: fluting medium, other packaging paper, and paperboard. As noted in Chapter 3, "other packaging paper" includes special papers such as dye-line, but about half by weight consists of kraft paper of various types (see Table 29). Demands for these three final products are discussed together because all are mainly or entirely used in packaging, often combined with one another. Data on consumption since 1950 are given in Table 61 where fluting medium is not separated from other packaging paper. Full consumption data for fluting are not available until 1965, and are shown in Table 62.

TABLE 61

CONSUMPTION AND PRICE DATA FOR PACKAGING PAPER AND PAPERBOARD

Year	Apparent consumption of:						Wholesale price indices, 1967 prices	
	Packaging paper (inc. fluting medium)			Paperboard				
	Total	Per head	Per unit of GNP kg/£th.	Total th. tonnes	Per head kg	Per unit of GNP kg/£th.	Paper bags	Cardboard boxes etc.
							1967 = 100	
1950	721	14·4	35·3	949	18·9	46·4	126	55
1951	873	17·4	43·6	1071	21·3	53·5	178	150
1952	590	11·7	28·7	791	15·7	38·4	156	135
1953	707	14·0	32·3	941	18·6	42·9	119	114
1954	937	18·5	40·5	1168	23·0	50·5	122	119
1955	1054	20·7	44·6	1270	24·9	53·9	123	120
1956	1006	19·7	41·4	1187	23·2	49·0	115	119
1957	1115	21·7	44·7	1249	24·3	50·4	114	115
1958	1163	22·5	45·6	1283	24·8	50·3	112	110
1959	1321	25·4	49·8	1321	25·4	49·8	108	106
1960	1460	27·9	52·3	1447	27·6	51·9	109	105
1961	1496	28·3	51·5	1438	27·2	49·5	112	105
1962	1535	28·8	52·0	1417	26·6	48·0	110	104
1963	1665	31·0	53·8	1484	27·7	48·0	110	103
1964	1820	33·7	55·9	1580	29·3	48·5	109	103
1965	1838	33·8	55·1	1580	29·1	47·4	108	105
1966	1912	35·0	56·5	1558	28·5	46·0	105	102
1967	2038	37·1	58·5	1547	28·1	44·5	100	100
1968	2212	40·0	63·3	1650	29·8	47·3	100	98
1969	2287	41·2	65·1	1665	30·0	47·4	99	101
1970	2375	42·6	65·1	1582	28·4	43·4	103	106

Sources:
1 Consumption data from BPBMA *Reference Tables* and (pre-1954) from BPBMA and *Annual Statement of Trade*.
2 Price indices from *Trade and Industry* (formerly *Board of Trade Journal*).

Two wholesale price indices relevant to these products are available, one for paper bags, the other for "cardboard boxes, cartons and fibreboard packing cases", where the term fibreboard has no connection with the wood sheet product discussed earlier in the Chapter. Although the second price index mentioned appears most applicable to paperboard, the "fibreboard packing cases" consist of a mixture of fluting medium and liner board or paper.

The consumption data in the Tables are graphed in Figures 6.36 to 6.38, from which it can be seen that paperboard consumption has been overtaken by packaging (and special) paper, even excluding fluting medium. Consumption of semi-chemical fluting has increased but total fluting has remained fairly constant. Since paperboard consumption over the same period has also been relatively static, the proportion of fluting to paperboard has remained at about 30 per cent, whereas the corresponding figure for packaging paper (including fluting itself) seems to have fallen slightly (Table 62).

The price indices of Table 61 are shown in Figure 6.39, where some of the values around 1951 are off the scale. The changes in the series for paperboard closely parallel those in the import price both of paperboard (Figure 4.4) and of packaging paper including fluting (not shown), although as Figure 6.39 shows, the two wholesale series are not vastly different. The wood-based packaging materials are meeting increasing competition from other materials, especially plastics. However, the choice is not always a straightforward one between two materials which are used in the same way. For example, there has been some replacement of corrugated packaging cases by shrink-wrap plastic film, which utilises the rigidity of the containers being transported, so that extra rigidity is unnecessary. For this reason the price of the converted product should still be of importance for elasticities.

Elasticities

Using the data from 1953 to 1969, to avoid the extreme price levels recorded in 1951–52, price and income elasticities were estimated by the usual logarithmic equations. It was found that generally the price variable had to be lagged one year to obtain a negative elasticity, and the value of $\bar{R}^2$ also improved. The results for income and lagged prices are summarised in Table 63. It is evident that the addition of a price variable to income increases the

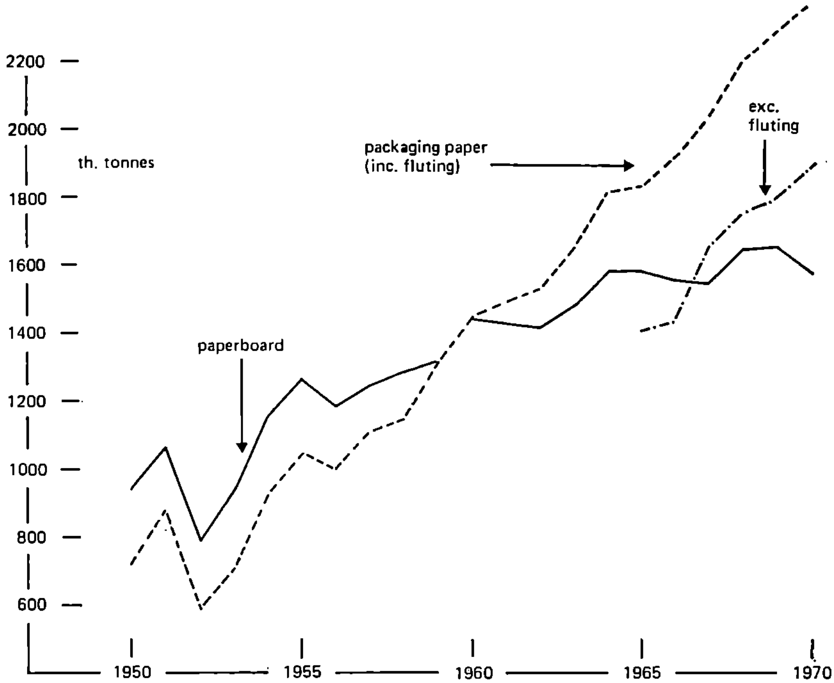


Figure 6.36 Consumption of packaging paper and paperboard

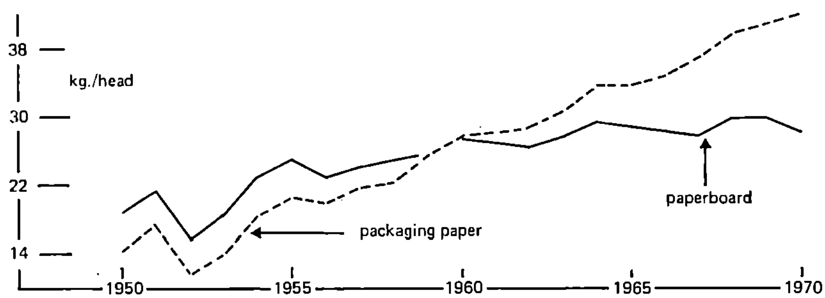


Figure 6.37 Consumption of packaging paper and paperboard per head

value of $\bar{R}^2$ (quite substantially in the case of paperboard) and improves the Durbin-Watson statistic.

As would be expected it also lowers the estimate of the income elasticity. In general the elasticities from the price indices have better significance levels than those from the import prices; they are also consistently more negative, which is reasonable as the paper or board is only part of the cost of the converted product.

Consumption Trends

Total consumption of packaging paper appears set on a linear upward trend (Figure 6.36) and consumption is rising faster than population and GNP (Figures 6.37 and 6.38); clearly this cannot continue indefinitely and therefore a lognormal curve was fitted to the total consumption data. As usual some very high values of $\bar{R}^2$ were obtained with widely differing saturation levels, but marginally the best fit came from a saturation consumption of 4 million tonnes, based on GNP at 1963 prices. GNP at 1967 prices gave nearly as good a fit but time was much poorer. It also proved possible to achieve a moderation in consumption by fitting quadratic trend curves to the data for consumption per unit of GNP from 1952 onwards. The equations are shown in

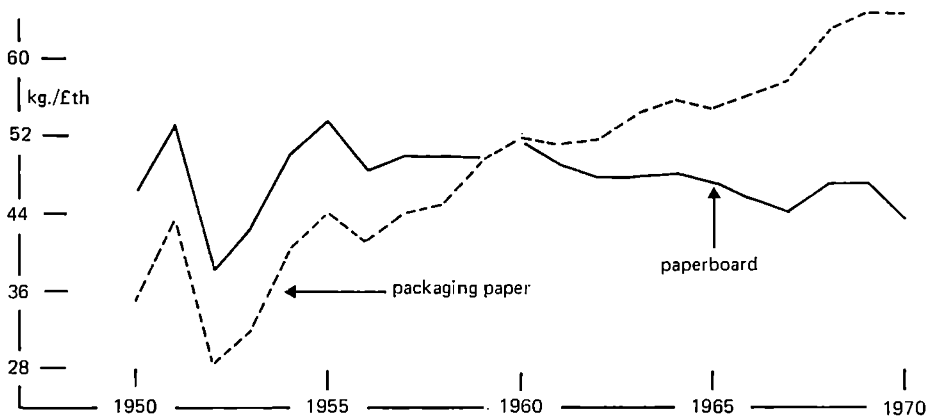


Figure 6.38 **Consumption of packaging paper and paperboard per unit of GNP**

Table 64 together with the dates and quantities when maximisation occurs. Because total GNP is assumed to increase continuously, the date of maximum total consumption is later than that of consumption per unit of GNP.

For paperboard, the consumption trend indicates a gradual slackening of growth, and sigmoid curves appear inappropriate. Quadratic trend curves were fitted to the 3-year average data from 1955 to 1969, giving equations (3) and (4) in Table 64. Consumption per unit of GNP is trending downwards, at about ·45 kg. per £ thousand per year. However, this does not reach a rate of decline of 2·5 per cent until after 60 years, so that on the usual assumptions made here, consumption increases indefinitely.

Pitwood

In the United Kingdom this is wood used directly by the coal mining industry, and demand is related to the size of that industry and to the possibility or necessity of substitution. Since 1947 the industry has consisted of only one "firm", the National Coal Board, and with this degree of centralisation of decision-making it is not useful to try to estimate price or output elasticities.

During the past twenty years coal output has generally been over 200 million tonnes but recently it has fallen to around 150 million (Table 66). About 95 per cent is deep-mined coal, for which some form of pit support is required. Within total coal production the percentage obtained by mechanised cutting has increased from a negligible proportion in 1949 to over 90 per cent at present. Mechanisation favours the use of steel props, and thus consumption of wooden pit-props has fallen steadily. Sawn softwood consumption has also fallen, although less consistently, but hardwood has increased since 1949 although it was higher in the intervening years. The overall result has been a

TABLE 62

CONSUMPTION DATA FOR FLUTING MEDIUM AND OTHER PACKAGING PAPER

Year	Apparent consumption of: Fluting medium — Semi-chemical	Fluting medium — Other	Fluting medium — Total	Other packaging paper	Total fluting medium as % of: Total packaging paper	Total fluting medium as % of: Paperboard
	th. tonnes	th. tonnes	th. tonnes	th. tonnes		
1962	107					
1963	136					
1964	173					
1965	177	255	429	1409	23·3	27·1
1966	191	286	477	1435	25·0	30·6
1967	199	175	374	1664	18·4	24·2
1968	233	217	450	1762	20·3	27·3
1969	278	212	490	1797	21·4	29·4
1970	310	124	484	1891	20·4	30·6

Source: BPBMA *Monthly Bulletin* (February issues).

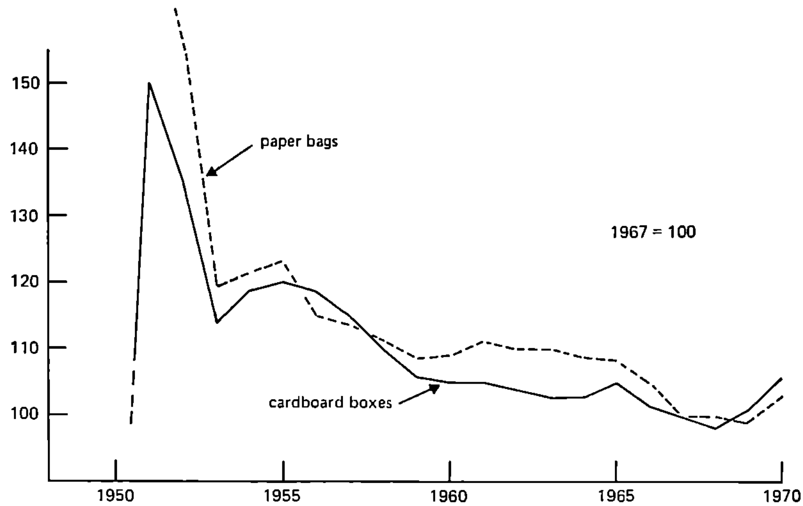


Figure 6.39 Wholesale price indices for paper bags and for cardboard boxes etc. (1967 prices)

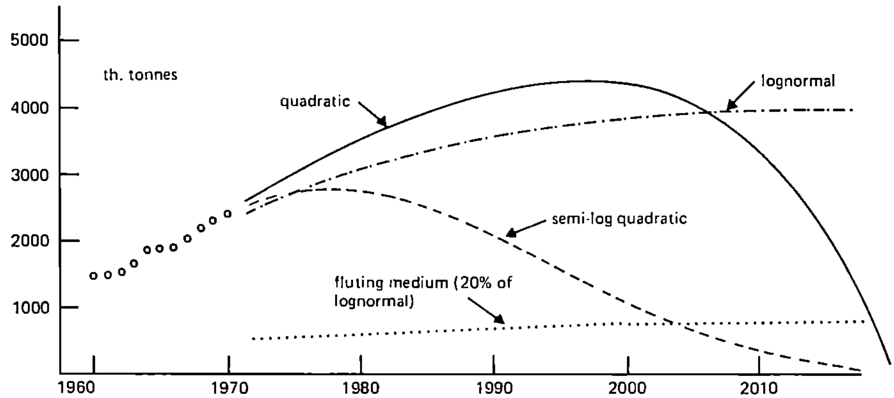


Figure 6.40 Consumption forecasts for packaging paper

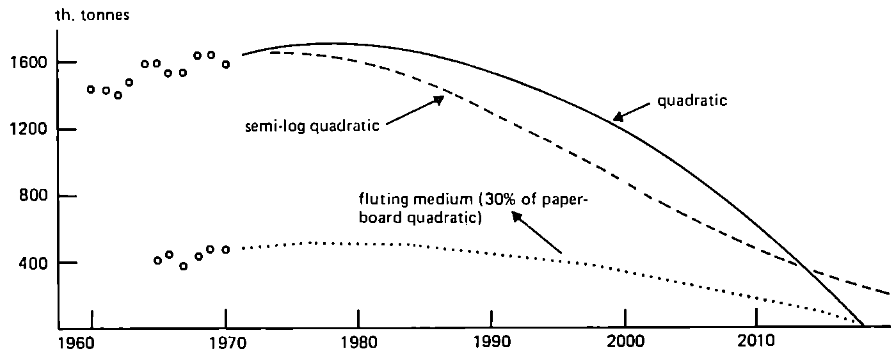


Figure 6.41 Consumption forecasts for paperboard

TABLE 63

PRICE AND INCOME ELASTICITIES FOR PACKAGING PAPER AND PAPERBOARD

Independent variable(s)	Elasticity (standard error)			$\bar{R}^2$ %	*D-W* statistic	Correlation coefficient (independent variables)
	Income	Price index	Import price			
1. *Packaging paper*						
(a) Income	2·04 (·10)	—	—	96·4	1·06	—
(b) Paper bags price index lagged 1 year	—	−4·46 (·49)	—	84·6	·87	—
(c) Import price lag 1	—	—	−1·87 (·80)	97·3	1·57	—
(d) (a) and (b)	1·52 (·11)	−1·09 (·27)	—	99·0	2·4	−·89
(e) (a) and (c)	1·15 (·39)	—	−·75 (·38)	98·2	1·54	−·99
2. *Paperboard*						
(a) Income	·88 (·08)	—	—	87·8	1·28	—
(b) Cardboard boxes price index lag 1	—	−1·67 (·16)	—	87·1	1·67	—
(c) Import price lag 1	—	—	−·23 (·76)	64·5	·19	—
(d) (a) and (b)	·57 (·12)	−·47 (·28)		94·6	2·68	−9·3
(e) (a) and (c)	·75 (·05)	—	−·07 (·19)	93·6	2·24	−·06

Note: Income is GNP at 1967 prices.

TABLE 64

TIME TREND EQUATIONS FOR PACKAGING PAPER AND PAPERBOARD

Equation	$\bar{R}^2$	*D-W* statistic	*n*	Implying maximisation:	
				in year	at consumption
Packaging paper Consumption per unit of GNP(y) kg/£ th. (annual data 1962–70)	%				kg./£th. (th. tonnes)
(1) $y = 29{\cdot}94 \div 2{\cdot}612x - {\cdot}0439x^2$ (·44) (·021)	94·0	1·06	19	1981 (1997)	68·8 (4430)
(2) $\ln y = 3{\cdot}402 + {\cdot}0735x - {\cdot}00184x^2$ (·011) (·00054)	91·7	·95	19	1971 (1978)	62·5 (2759)
Paperboard Total consumption(y) th. tonnes (3-year av. data 1955–69)					th. tonnes
(3) $y = 1133{\cdot}0 + 49{\cdot}20x - 1{\cdot}036x^2$ (5·0) (·31)	98·2	1·24	15	1978	1717
(4) $\ln y = 7{\cdot}041 + {\cdot}0383x - {\cdot}000953x^2$ (·0035) (·00021)	98·3	1·26	15	1974	1677

Notes:
(1) $x = 1,2,3 \ldots n$.
(2) Maximum *total* consumption of packaging paper (shown bracketed) assumes 2·5 per cent annual increase in GNP.

gradual fall in the timber input per ton of coal.

Annual figures for total pitwood consumption (but not the breakdown of Table 66) are available from 1940 onwards. They show a roughly constant annual demand of around 2·75 million true m³ until 1958, when a steady decline began. Annual consumption from 1951 onwards is shown in Figure 6.42 and it is evident that fitting a trend curve is helped by starting at 1957. A number of trend equations involving logarithms gave excellent fits to the data, but the

TABLE 65

CONSUMPTION FORECASTS FOR PACKAGING PAPER AND PAPERBOARD

Period no. (length in years)	Year or years	Fluting medium: 20% of total packaging paper (lognormal)	Fluting medium: 30% of paper board (quadratic)	Total packaging paper (i.e. incl. fluting): Lognormal on GNP (1963 prices)	Total packaging paper: Per unit of GNP Quadratic (1)	Total packaging paper: Per unit of GNP Semi-log quadratic (2)	Paperboard: Quadratic (3)	Paperboard: Semi-log quadratic (4)
		th. tonnes						
1 (5)	1971	478	501	2390	2632	2544	1670	1662
	1972	494	505	2470	2731	2602	1683	1670
	1973	511	508	2560	2831	2652	1694	1675
	1974	528	511	2640	2930	2693	1703	1677
	1975	544	513	2720	3027	2724	1709	1675
	(1971–75)	(2555)	(2538)	(12780)	(14151)	(13215)	(8459)	(8359)
2 (5)	1976	560	515	2800	3124	2746	1714	1671
	1977	574	515	2870	3220	2757	1717	1663
	1978	589	515	2940	3315	2759	1717	1652
	1979	604	515	3020	3407	2750	1716	1638
	1980	617	513	3090	3498	2731	1712	1621
	(1976–80)	(2944)	(2573)	(14702)	(16564)	(13743)	(8576)	(8245)
3 (5)	1981–85	3276	2530	16380	18769	13041	8434	7757
4 (10)	1986–90	3530	2410	17660	20582	11295	8033	6958
	1991–95	3718	2211	18580	21782	8926	7373	5953
5 (10)	1996–2005	7754	3519	38770	43141	10674	11730	8634
6 (10)	2006–15	7928	1795	39640	32530	3939	5983	4786
7 (15)	2016–30	11988	110	59940	5023	1149	365	2726

Notes:
1 Bracketed figures at heads of columns are equation numbers from Table 64.
2 Fluting medium estimates are the two used in the model; from the method of calculation they are not the only ones obtainable from the data shown here.
3 The RHS values for "other packaging paper" are total packaging paper *less* whatever estimate is being used for fluting.
4 The saturation level for the lognormal curve is 4 million tonnes annually.

TABLE 66

TRENDS IN THE UNITED KINGDOM COAL INDUSTRY 1949–69

	Coal output m. tonnes	Mechanised output %	Pitwood consumption, th. true m³: Roundwood	%	Sawn softwood	%	Sawn hardwood	%	Total	%	Per unit of coal output, true m³ p. th. tonnes
1949	219	3·2	1892	67	639	22	305	11	2836	100	12·9
1954	228	8·3	1588	62	552	21	443	17	2583	100	11·3
1959	209	31·3	1034	47	569	26	582	27	2185	100	10·5
1964	197	68·4	693	41	399	24	602	35	1694	100	8·6
1969	150*	91·8	332	31	280	27	441	42	1053	100	7·0*
% change 1949–69	−27		−82·5		−56		+44·5		−63		

* this year included a miners' strike.
Sources:
1 Output figures from *Annual Abstract of Statistics*.
2 Consumption figures from National Coal Board (adapted from unpublished data).

simplest was also the most plausible, agreeing well with the National Coal Board's own forecast of consumption in 1975. The equation is:

$$\ln y = 7{\cdot}952 - {\cdot}07294x \qquad \bar{R}^2\ 98{\cdot}2\%$$
$$({\cdot}0027)$$

where y = annual pitwood consumption in thousand true m³

x = time, 1957 = 1, 1970 = 14

The consumption levels predicted by this equation are shown in Figure 6.43, up to the year 2000.

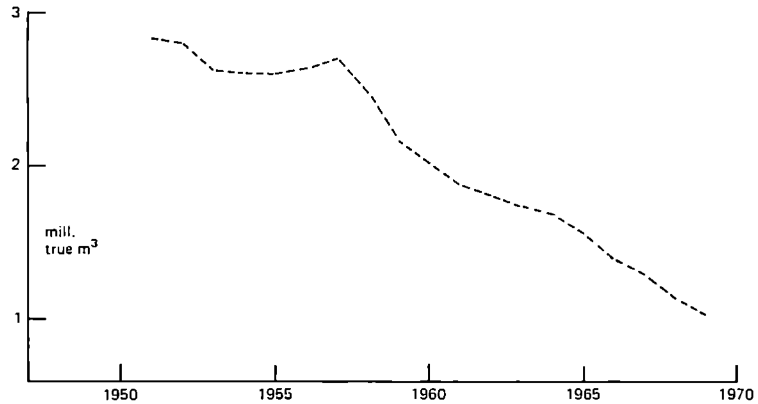


Figure 6.42 Consumption of pitwood

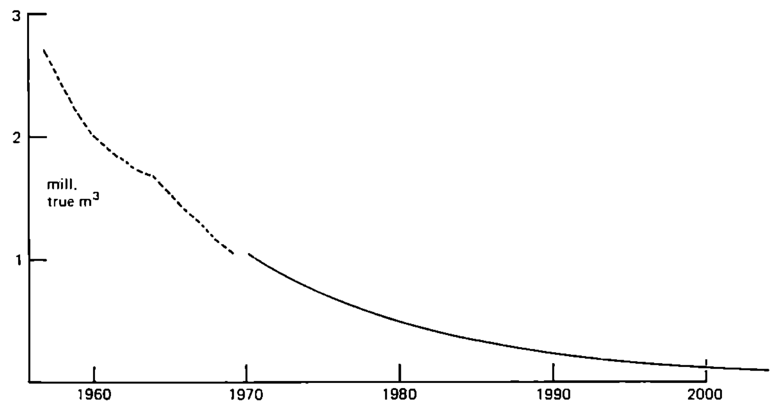


Figure 6.43 Consumption forecast for pitwood

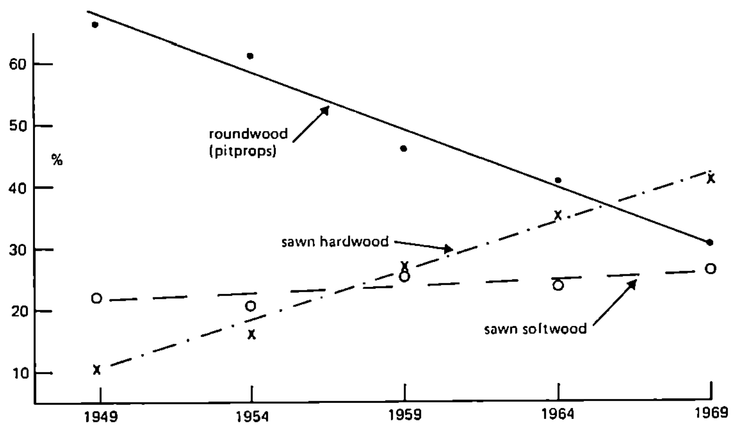


Figure 6.44 Percentage composition of pitwood consumption

Composition of Total Consumption

As one of the final products in the model is pitprops, as distinct from pitwood, it is necessary to break down the diminishing total to arrive at the roundwood figure, and to allocate the remainder to the coniferous and broadleaved sawnwood categories. To do this the trends in percentage composition shown in Figure 6.44 were extrapolated by linear equations, and recalculated to 100 per cent when the percentage for pitprops became negative, in 1987.

The equations are:

Pitprops	$y = 69{\cdot}6 - 1{\cdot}82x$	$x = 1 = 1949$
Sawn softwood	$y = 21{\cdot}8 + {\cdot}204x$	
Sawn hardwood	$y = 8{\cdot}58 + 1{\cdot}62x$	

The consumption estimates obtained by applying these trends to the trend for total consumption are listed in Table 67 annually for the next ten years and in period totals thereafter.

TABLE 67

CONSUMPTION FORECASTS FOR PITWOOD, BY CATEGORY

Period no. in model (length in years)	Year or years	Consumption th. true m³			
		Pitprops	Sawn softwood	Sawn hardwood	Total
1 (5)	1971	264	435	252	951
	1972	229	419	236	884
	1973	198	403	221	822
	1974	170	387	207	764
	1975	146	371	194	711
	(1971–75)	(1008)	(2015)	(1110)	(4133)
2 (5)	1976	123	356	182	661
	1977	103	341	170	614
	1978	86	326	159	571
	1979	70	311	149	531
	1980	56	297	140	493
	(1976–80)	(439)	(1631)	(800)	(2870)
3 (5)	1981–5	123	1294	576	1993
4 (10)	1986–90	—	980	402	1382
	1991–95	—	696	265	961
5 (10)	1996–2005	—	837	293	1130
6 (10)	2006–15	—	414	131	545
7 (15)	2016–30	—	263	75	338

Chapter 7

RESULTS

The model provides for two rates of discount, two levels of wood production costs, and two sets of demand values. This gives a total of eight possible sets of results, apart from parametric analysis of various kinds. It is impracticable to present all these results in their entirety, and to reduce them to manageable proportions attention is concentrated on the 5 per cent discount rate and the higher level of forestry costs. The aim of including a 10 per cent discount rate and (hypothetical) lower costs is to see if they make substantial differences to the solution, and this aspect is discussed where relevant.

Two general features common to the solutions can be mentioned here. Firstly, new planting never occurs (unless forced into the solution), even where the demand constraints specify large wood requirements in periods 6 and 7. The shadow prices (reduced costs) of planting activities are always high, rarely less than -£100 per hectare. Correspondingly the shadow prices (dual activities) of the constraints involving plantable land are always zero. Secondly, the solutions are very insensitive to changes in the objective function values for imports of final products. These values were set initially at 1 per cent of the discounted sale price used in the calculation of net revenues, as described in Chapter 4. This stability in the results means that it is adequate to consider only solutions incorporating the initial values.

The presentation of the results is based on two solutions, for convenience labelled 1 and 2, which differ in the demand values specified in the RHS. Broadly speaking, solution 1 incorporates large demand values and solution 2 small values. The figures used are selected from among the results described in Chapter 6, as indicated in Appendix E. The values are listed in Appendix F as total consumption per period, and they are graphed in Figures 7.11 and 7.12 for each product separately. The approximate total roundwood equivalent of each set of values is shown in histogram form in Figure 7.13, where (as in the other histogram diagrams) the vertical scales refer to totals per five years.

The program output shows the range on either side of each RHS value within which the solution would remain unchanged (taking each individual RHS value in turn) and thus gives an indication of the sensitivity of the solution to these changes. The use of two sets of RHS demand values is a limited form of parametric analysis, and further parametric variation of these RHS values was also carried out.

Several aspects of a solution are of interest. Firstly there are the wood-producing activities in the solution, which represent an aggregate management plan for United Kingdom forests as a whole. Secondly there are the wood volume outputs from these activities, according to species and time period. Thirdly there is the utilisation of the wood by various wood-processing activities, and fourthly the implications of the results in terms of the balance between domestic and imported supplies. These points are discussed in turn.

Wood-producing Activities

The results for the two solutions in terms of forest area are summarised in the bar charts, Figures 7.1 and 7.6. It is clear from a comparison of the two figures that the results are fairly similar. The main difference is in the first and second age classes, where much less of the forest area is used in solution 2 than in 1. Even with solution 1, however, the youngest stands of larch, pine and broadleaved trees are left unused (i.e. age class 1). Naturally the shadow prices for these resources (areas) are zero. For the other age classes, shadow prices vary from £38 per hectare for broadleaved age class 2, to £2332 per hectare for spruce age class 2. These figures are for solution 1; in solution 2 the values are generally lower. In a national context, however, such figures are not particularly meaningful since there is no way of obtaining more of the resource.

In general the activities in the solutions are those specifying little or no thinning, with rotations of varying length. For example, in solution 1 most of the spruce of age class 1 has a rotation of 57·5 years but for age class 2 it is only 35 years. Changing the objective function values through (assumed) lower silvicultural and extraction costs, and a discount rate of 10 per cent, produces some modifications in the results. A lower level of silvicultural costs leaves the solutions fairly unchanged, but any changes which do occur are in the direction of more thinnings and shorter rotations. The higher discount rate generally results in a) a larger area of existing forest unused, especially in the younger age classes of larch and broadleaved, and b) shorter rotations. In the case of solution 2 (low demand values) the effect of the discount rate outweighs that of the cost change, so that the two solutions (high and low costs) incorporating 10 per cent resemble each other more than they resemble the solutions using 5 per cent. Conversely, with solution 1 (high demand values) the solution with low costs and a 10 per cent discount resembles the 5 per cent solutions more than the other solutions using 10 per cent.

In terms of forest management one implication of these results is that some areas of forest should be abandoned, in the sense that they should not be maintained. This is particularly true for the youngest age class of larch, pine and broadleaved species. However, this conclusion is dependent on the demand values assumed for wood products, and on the maximum permissible proportions of larch and broadleaved wood in the furnish of some products; these points are discussed below. A second implication is that thinning should in general not be practised. For the near future, a further implication is that about 100 thousand hectares of both broadleaved and coniferous forest should be felled in the next ten years.

Wood Volume Outputs

The total wood volumes corresponding to the aggregate forest management plans for solutions 1 and 2, are shown diagrammatically in Figures 7.2(a) and 7.7(a), where the areas of the histograms represent wood volumes. These diagrams assume that predicted tree growth will in fact occur. The domestic wood output implied by the solutions rises to nearly 10 million cubic metres of (unbarked) roundwood annually by 1980–85, falling more or less steeply thereafter, depending on the demands assumed. The breakdown of output by species is fairly similar up to about 1990, but from then on the patterns diverge. For solution 1, the large amounts of spruce and other conifer wood in periods 6 and 7 come from spruce age class 1 and pine age class 2, respectively. In solution 2 these plantations are mainly unused. To some extent these results are determined by the demand values used in the RHS. For example, although solution 2 specifies substantial demands for sawnwood in periods 6 and 7, the spruce plantations currently of age class 1 cannot meet this economically unless they can also dispose of the substantial volumes of small roundwood (SP1) produced simultaneously. This smaller wood could be used in the activities for integrated production of tissue, involving chemical pulp production, but because this appears unprofitable the plantations are left unused.

Parametric increase of some of the demand values results in progressively greater use of plantations, as would be expected, but even with approximate doubling of the demands of solution 1, the youngest age classes of larch and broadleaved species remain unused. However, if some of the limitations on their use were relaxed slightly, at least some of these areas could also be usable. For example, larch and broadleaved are restricted to a maximum of ten per cent of the furnish for particle board, but these proportions might be increased somewhat.

Utilisation

In Figures 7.2(b) to (e) and 7.7(b) to (e), the usage of individual species is shown in histogram form. Again these results are partly determined by the assumptions built into the model, such as the minimum of 80 per cent spruce wood for newsprint, with no larch allowed. The diagrams refer to roundwood only, so that for example particle board is under-represented because it can be made from residues. It is clear from these diagrams that the main outlets for domestic wood are sawnwood, newsprint and particle board.

Final Products

The results for wood-processing activities are given in Appendix F, which lists the respective contributions of domestic production and imports, in the two solutions. This aspect is summarised in percentage terms in Table 68. Additional information on the source of supplies of coniferous sawnwood, particle board and newsprint is given diagrammatically, in Figures 7.3 to 7.5 for solution 1, and Figures 7.8 to 7.10 for solution 2.

In Table 68 the figures refer to percentages imported, and the results for the two solutions appear quite similar, much more so than if absolute values are considered. The general conclusions from the figures are:

Sawnwood	a gradual declining share for imports of coniferous sawnwood, but an increasing share for broadleaved sawnwood;
Wood Sheets	a temporary decrease in the imported share for plywood and fibreboard, but the complete elimination of particle board imports;
Newsprint	a fluctuating balance, with self-sufficiency in periods 3 and 5;
Printings and Writings	no imports, but domestic production is almost all non-integrated, using imported pulp;
Tissue	a gradual phasing out of the current (non-integrated) domestic production;
Packaging Paper : and Board	domestic fluting medium production to be phased out but other packaging paper, and paperboard, to be predominantly or entirely domestically produced, mainly in non-integrated plants;
Pitprops	the results for the two solutions are very different but the amounts involved are small.

TABLE 68

PROPORTION OF FINAL PRODUCTS IMPORTED, IN SOLUTIONS 1 AND 2

Product	Per cent imported													
	Solution 1							Solution 2						
	Period: 1	2	3	4	5	6	7	Period: 1	2	3	4	5	6	7
Coniferous sawnwood	93	89	85	90	83	76	0	94	87	81	83	72	80	79
Broadleaved ,,	47	12	52	89	90	80	68	46	30	56	88	94	91	80
Plywood	91	87	86	90	95	100	100	93	84	78	80	80	100	100
Particle board	0	0	0	0	0	0	0	10	0	0	0	0	0	0
Fibreboard	61	27	29	100	100	100	100	67	25	0	57	100	100	100
Newsprint	60	41	0	19	0	100	—	60	41	0	18	0	100	—
Uncoated p. & w.	0	0	0	0	0	0	0	0	0	0	0	—	—	—
Coated printings	0	0	0	0	0	0	0	0	0	0	0	—	—	—
Tissue	22	54	73	100	100	100	100	27	51	68	100	100	100	100
Fluting	34	62	83	100	100	100	100	34	56	78	100	100	100	100
Other paper	12	0	0	0	0	0	0	10	0	0	0	0	0	0
Paperboard	5	7	0	6	0	0	0	5	6	27	15	0	—	—
Pitprops	35	0	0	—	—	—	—	42	100	0	—	—	—	—
Wastepaper grade 1	0	0	0	—	—	—	—	0	0	0	—	—	—	—
Wastepaper grade 2	12	7	4	0	0	0	0	14	10	8	0	0	0	0

Notes:
1 In the table "—" means "not applicable" because zero demand is postulated.
2 Many "domestically-produced" products are based on imported wood pulp, e.g. paintings and writings.

These figures treat non-integrated production in Britain as "domestic" but since the wood pulp required is imported, the figures are in a sense misleading. An approximate indication of the overall contribution of British forests can be given by converting all products to roundwood equivalent. Assuming that waste paper is not a domestic product (most of it coming from imported pulp or paper) the results for the two solutions are shown in Table 69; the estimated quantities of domestic wood are included in Figure 7.13 for solution 1 only. The values for solution 2 are very similar up to and including period 4, after which they fall away as does the total consumption.

TABLE 69

PERCENTAGE CONTRIBUTION OF UNITED KINGDOM FORESTS TO TOTAL FORECASTED WOOD CONSUMPTION

Period	1	2	3	4	5	6	7
Solution 1	13	19	21	14	14	12	16
Solution 2	12	20	26	23	28	18	22

The results for the two solutions will now be examined in more detail.

Wood-using Activity Levels in Solution 1 (high demand values)

The results are summarised in Appendix F, where the columns for total consumption of each product represent the demand values incorporated in the RHS; absence of values is indicated by -. The comments which follow include some details which are not shown in the Appendix.

Looking first at *wood pulp* production (excluding newsprint and fluting medium) the small amount of mechanical pulp produced is used in paperboard manufacture, while the much larger output of broadleaved pulp goes to fibreboard production. Most of the raw material for the pulp is residues such as sawmill offcuts. As Apppendix F shows, a little new capacity is installed in the first period, but production does not extend beyond period 3 although manufacturing capacity is available. Chemical pulp production also is confined to the first three periods, but in this case any subsequent production would require new capacity to be installed.

Sawnwood

For coniferous sawnwood Figure 7.3(a) shows diagrammatically the gradually increasing domestic share of a diminishing total, while 7.3(b) shows the usage of different species within the domestic supply. Broadleaved sawnwood shows a temporary increase in domestic supplies in period 2, as some of the older plantations are felled. For sawmilling. new capacity is installed fairly regularly.

Wood Sheets

Domestic plywood production is limited by log supply, but contributes modestly towards total supplies. Installation of new capacity does not go beyond period 4 because of absence of suitable logs from period 6 onwards. The situation for particle board is shown in Figure 7.4, where the histogram reflects the lognormal curve used in demand prediction. Because the raw material is made up of many species and residues, the diagram is restricted to three types of raw material. Residues such as sawnwood offcuts contribute from 93 per cent (period 2) to 33 per cent (period 6) of the total, measured in terms of board. New capacity is installed in most periods. By contrast most of the forecast demand for fibreboard is met from imports, and only hardwood pulp contributes some production in the first three periods.

Newsprint

Newsprint supplies are shown in the histogram of Figure 7.5, which indicates that non-integrated production does not continue beyond period 1, being replaced in period 2 by increased integrated production. Newsprint from de-inked waste paper is confined to existing capacity, which is specified in the model to last only up to and including period 3. The species composition for integrated production largely follows from the constraint that spruce must be at least 80 per cent of the roundwood, but in period 3 "Other Conifer" is less than its maximum 20 per cent. The only new capacity installed is for integrated production, in period 2, and this lasts until period 5 after which demand is negligible.

Printings and Writings

Integrated production of uncoated paper is continued up to period 3, the physical life assumed for the Fort William mill. Apart from the first three periods, all projected demand for uncoated paper and for coated printings, is met from non-integrated production using imported pulp. This result is a reversal of the recent trend towards increased imports of printing and writing paper, and may stem in part from the aggregation of various grades of paper under the heading of printings and writings. For example, most of the growth in imports has taken place in the cheaper grades such as mechanical printings.

Tissue

Production from imported pulp is continued for the life of the existing plant, but thereafter domestic production is replaced by imports.

Packaging Paper

Fluting medium is currently produced in integrated mills, from semi-chemical pulp and from waste paper. However, the cost of extending capacity as existing plant wears out, is apparently too high and therefore from period 4 onwards all requirements of fluting medium are met from imports. Conversely with other packaging paper (including special paper), forecast demand is met from non-integrated production in the United Kingdom with new capacity installed in most periods.

Paperboard

The domestic production shown in Appendix F consists of both the production activities described in Chapter 3, but the semi-integrated production alternative (using domestic roundwood, plus some imported pulp in the furnish) does not survive beyond period 3, whereas that with a high proportion of waste paper provides most of total supplies. Correspondingly, new capacity is installed in most periods.

Pitprops

Most of this relatively small, and declining, demand is met from domestic wood, specifically small larchwood, which has fewer alternative uses than the other conifer species.

Waste Paper Usage

Grade 1 waste paper is defined as suitable for newsprint manufacture by de-inking, and therefore it is present (i.e. transferred from the supply row to the use row) for the first three periods. However, the amounts shown are well in excess of requirements for this purpose, because some is transferred to augment the supply of grade 2 paper, for which small quantities of imports are also required. Apart from this all waste paper used comes from domestic sources, and in fact there are substantial quantities unused, in the later time periods.

Residues (not shown in the Appendix).

The importance of residues in particle board manufacture has already been mentioned, and this and other products account for almost all the sawmill offcuts and plylog cores implied by the solution. However, large quantities of sawdust remain unused, at least for the options specified here, and waste paper also comes into surplus in the later time periods.

Other Points

Imports of pulpwood are allowed, defined as small sprucewood, and small quantities are imported in periods 1 to 3, and 7. Also the option for converting non-integrated newsprint capacity to uncoated printings, is taken up in period 1, leaving no capacity for later periods.

Sensitivity of the Demand Values

Broadly speaking, the solution is not affected by large changes in the demand values for sawnwood, plywood, fibreboard and tissue, for all or most periods. Conversely, the solution is highly sensitive to changes in the values for particle board, and sensitive in varying degrees to changes in the other products.

Wood-using Activity Levels in Solution 2 (low demand values)

The results are summarised in Appendix F, in the same way as for Solution 1, and Figures 7.8 to 7.10 deal with sawnwood, particle board and newsprint, as the products of most interest for utilisation of domestic wood. All these are products where economies of scale in production are not as marked as in the case of most other wood products.

The activity levels shown in Appendix F are in most cases affected by the generally lower demand values postulated in this solution, and naturally most of the impact is in the later time periods. However, in terms of action over the next ten years the solutions are very similar.

For coniferous sawnwood, up to period 6 much of the impact of difference in demands is taken by imports, but thereafter the results are very different, with no domestic sprucewood being used, compared with about 25 million cu. m. For this reason most of age class 1 spruce is not used, in solution 2. The demand values for broadleaved sawnwood are reasonably similar in both cases and therefore the activity levels are also fairly similar.

For plywood, the demand values are very different but the impact is taken by imports, so that domestic output is little affected. The species mix for particle board varies considerably in detail, although the proportionate split between small roundwood and residues is fairly similar, as can be seen by comparing Figures 7.4 and 7.9. Taking all time periods together, residues account for about one half of the total production, in both cases. With fibreboard, a good deal of the difference in demand values is reflected in the values for imports. The results for fibreboard affect the production figures for broadleaved mechanical pulp, and solution 2 has some output in period 4, whereas in solution 1 there is none after period 3. Coniferous mechanical pulp production is identical in both solutions, and chemical pulp is extremely similar; this goes to integrated production of uncoated printings and writings.

For newsprint the demand forecasts are the same in both solutions and correspondingly the activity levels are almost identical. On the other hand demand values for the two categories of printings and writings are much lower in solution 2, and the difference is taken up by a reduction in non-integrated production, with the small integrated domestic output (in periods 1 to 3) unchanged. Similarly, domestic output of fluting medium remains the same, but imports act as the balancing factor. Other packaging paper comes almost entirely from non-integrated domestic production in both cases, and output directly reflects the much lower demand values assumed.

With paper board the "integrated" production alternative using domestic mechanical pulp, remains the same, but the system using more waste paper in the furnish shows reduced output to meet the new demand values, and rather higher import levels. Tissue production in the United Kingdom remains the same as in solution 1, with the adjustment coming from imports. For pitprops, supply in period 2 comes from imports instead of domestic larchwood.

Waste paper usage is similar in the early periods but thereafter falls away. However, in spite of the smaller usage, unused waste paper is also much reduced, because of the smaller overall consumption of paper. The same is true to a lesser extent of unused sawdust residues. In spite of the lesser demands on wood supplies, pulpwood imports are rather higher in solution 2.

Where non-negative demand values are present, their sensitivity is generally similar to that in solution 1. However, plywood becomes very sensitive in the downward direction. Fibreboard demand is also considerably more sensitive in this respect.

The types of new capacity installed in solution 2 are similar to those in solution 1, but the amounts are related to the demand values and therefore are generally smaller. For example, new particle board capacity is installed in the same periods (1, 3, 4, 5 and 6) in both cases but in solution 2 it is only 211 thousand cu. m. compared with 3150 thousand in solution 1.

Shadow Prices of New Capacity

The products and methods of production indicated by the solutions as appropriate for the United Kingdom differ in some respects from recent investments in wood processing plant. In particular the results do not include new capacity for the following production processes:

integrated chemical pulp, and printings and writings
integrated fluting medium
newsprint from de-inked waste paper
non-integrated tissue

The initial investment costs estimated for these activities must be regarded as approximate (see Chapter 4) but the shadow prices for the relevant constraint rows are well below the cost estimates used, and it seems unlikely that more accurate estimates could affect the result. The shadow prices

TABLE 70

SHADOW PRICES FOR SOME PRODUCTION CAPACITIES

Process	Period	Estimated cost of capacity expansion	Shadow price of capacity constraint row in:	
			Solution 1	Solution 2
		discounted £ per tonne		
Integrated chemical pulp	1 2 3	101·8 79·8 62·4	not limiting 2·3 not limiting	not limiting " " " "
Integrated un-coated printings and writings	1 2 3	177 138·8 108·6	13·7 ·7 12·7	16·2 ·7 10·7
Fluting medium	1 2 3	88·5 69·4 54·3	6·6 6·9 2·8	8·7 7·5 4·0
Newsprint from de-inking	1 2 3	212·4 166·6 130·3	16·1 12·6 9·0	16·1 12·6 8·9
Non-integrated tissue	1 2 3	106·2 83·3 65·2	9·2 7·2 5·6	9·2 7·2 5·6

for the four production processes mentioned above, are listed in Table 70, for the first three time periods. They can be interpreted as the amounts it would be worth paying to expand capacity by one unit.

Effect of a Ten per cent Discount Rate

The solutions obtained using a discount rate of 10 per cent instead of 5, show some fairly similar changes, by comparison with solutions 1 and 2. With both sets of demand values, the impact of the higher discount rate is to increase domestic sawnwood production in the first two periods, at the expense of later periods. The same is true of domestic plywood. Because fewer sawmill residues are available in the later periods, sprucewood forms more of the furnish for particle board, and this is reflected in substantial imports of pulpwood (i.e. small sprucewood). With the small demand values (the same as those used in solution 2) the higher interest rate even results in large imports of particle board, especially in period 5. However, the shadow prices for many of the domestic producing activities are very small and the change is not as fundamental as might appear.These changes towards earlier use of resources are only to be expected with a higher interest rate, which discounts the future to a greater extent.

The hypothetical lower costs in the forestry (wood-producing) activities, obtained by assuming lower overhead cost, result in changes of detail in the results but the overall pattern is very similar.

Forcing-in New Planting

To examine the effect of introducing new planting into the results, a program run was included where a total of 300 thousand hectares of new plantations was forced into the solution. The requirement was for 150 thousand hectares each of Sitka spruce and other conifer (Lodgepole pine or Douglas fir), on unroaded land, within the first three time periods. Apart from the equality signs for the two rows representing unroaded plantable land, for spruce and other conifer, the data were identical with those for solution 1, which is therefore the best comparison.

For convenience all the planting activities were included in the matrix simultaneously, although for the present purpose only the higher yield class options (of the two yield classes per species) are relevant. These are Sitka spruce YC14, Lodgepole pine YC8 and Douglas fir YC16. In the event planting was confined to periods 2 and 3 as follows:

Period 2: 647 hectares of spruce } Fell in period 6,
69554 hectares of fir } no thinning
Period 3: 149353 hectares of spruce } Fell in period 7,
80446 hectares of fir } no thinning

Naturally a main effect of these activities is to increase the potential domestic wood supply in periods 6 and 7 by comparison with solution 1, but the result shown by the program is that most of the existing spruce plantations of age class 1 are not used. Also more larch of age class 2 is not used. The changes in manufacturing activity levels are mainly trivial, but the composition of the raw material for particle board is markedly affected, especially in periods 4, 5, and 6. Coniferous mechanical pulp production reappears in periods 6 and 7, after being absent in periods 4 and 5, and is used for paperboard production (period 6) and fibreboard (period 7). These increases in domestic production therefore reduce imports. Another point is that imports of small sprucewood in period 7, are eliminated.

The net effect of these changes is to reduce the value of the objective function by £69 million (discounted), about 2·3 per cent of the initial value (in solution 1). The total direct cost of introducing the four planting activities listed earlier, is about £151 million, so that by re-arranging activities the program has reduced the loss to about 45 per cent of the apparent cost.

Conclusions

The linear programming model used in this study is a useful method of analysing the wood products sector of the economy and its development over time. Further work could include the formulation of the model on a regional basis, incorporation of greater detail in some processing sectors, such as printing and writing paper, and variation of the general price level of wood products over time.

Some of the results obtained, summarised above, are consistent with what is actually happening in the wood products sector. For example, sawnwood, particle board and newsprint are all produced in the United Kingdom in integrated plants. Conversely, the solutions indicate that products such as printing and writing paper, packaging paper, and paperboard should be mainly or wholly produced in the United Kingdom from imported pulp, a result which is against the current trend towards higher imports of the finished products. In view of this discrepancy it would be instructive to extend the model using a larger number of categories of paper and board.

The results obtained also differ from the current situation in that they do not recommend either new planting, or the choice of fluting medium and uncoated printing paper as suitable products for integrated production from United Kingdom roundwood. However, current planting is carried out either by government directive or (in the private sector) largely because of tax concessions; it can only be profitable in a commercial sense if future wood prices increase relative to other prices, and since this is not specified in the model, planting does not enter a solution unless forced in. In the case of printing paper, the recently erected mill in Scotland received substantial government capital grants as part of regional economic policy. Similarly the fluting medium mill in Monmouthshire received some assistance with capital expenditure. These may have been the most promising products at the time decisions were being taken, but the results from the model suggest that investment in new integrated wood processing plants should be directed towards particle board, sawnwood and (in the shorter run) newsprint. These conclusions are not affected by regional policy except in so far as some products may generate more employment than others.

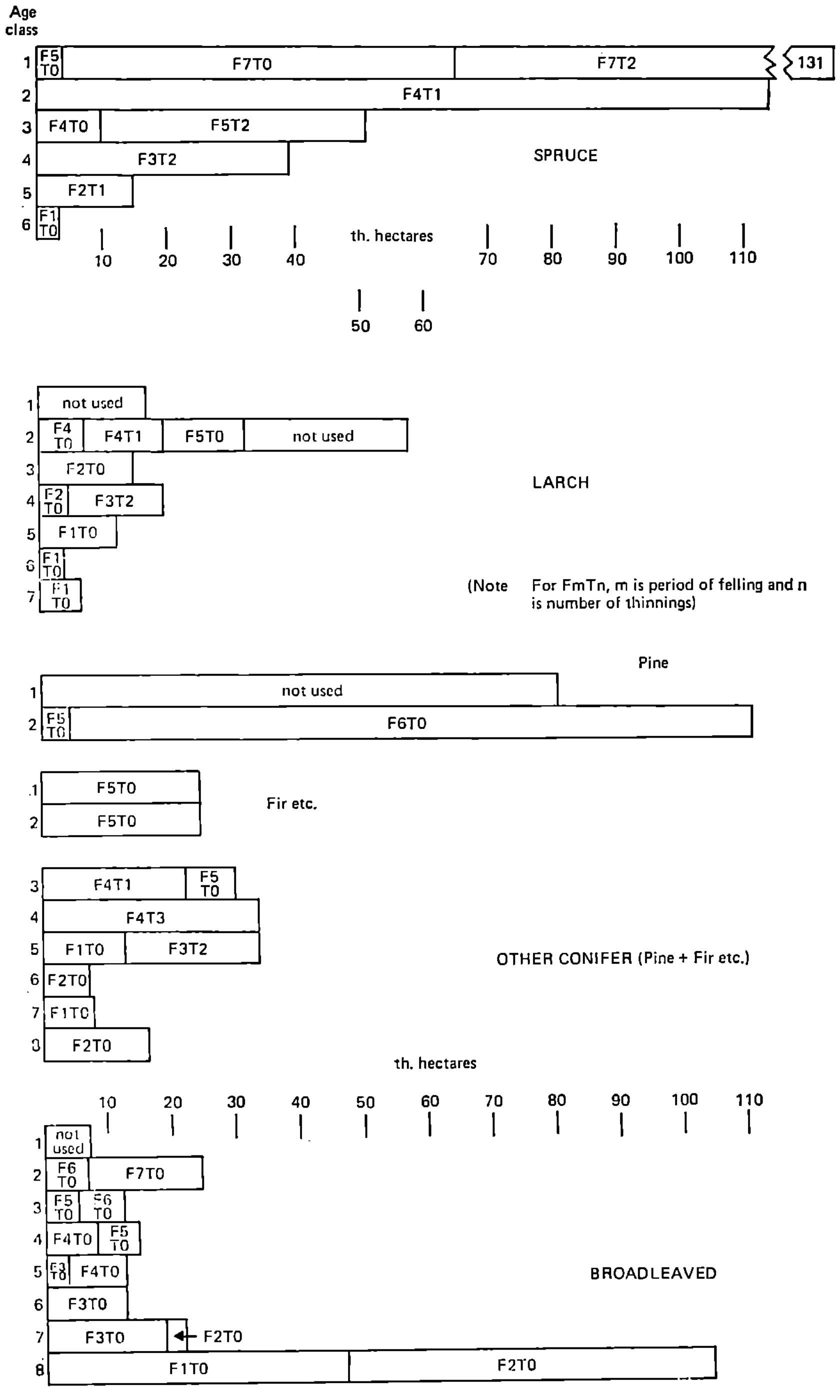


Figure 7.1 Overall Management Plan from Solution 1

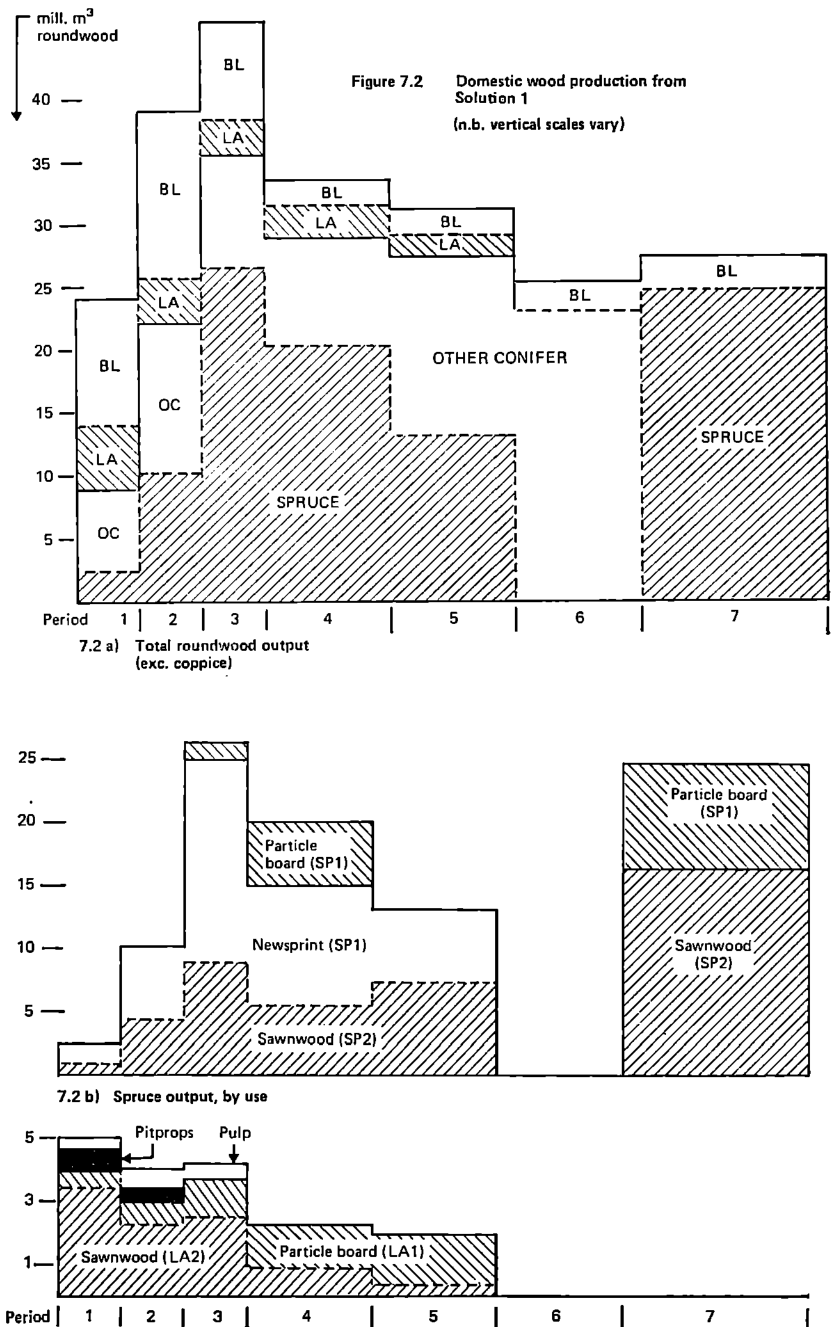


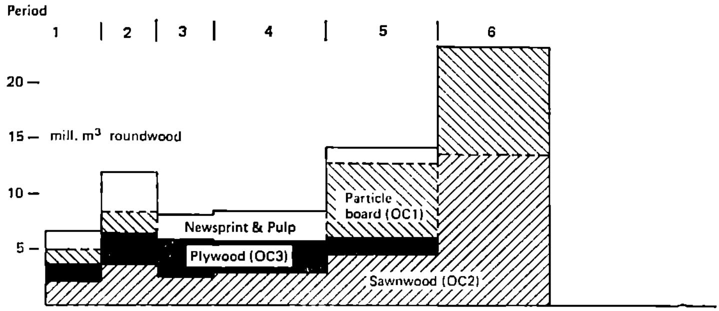
Figure 7.2 Domestic wood production from Solution 1

(n.b. vertical scales vary)

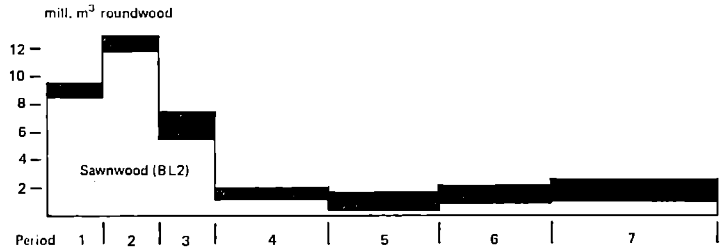
7.2 a) Total roundwood output (exc. coppice)

7.2 b) Spruce output, by use

7.2 c) Larch output, by use

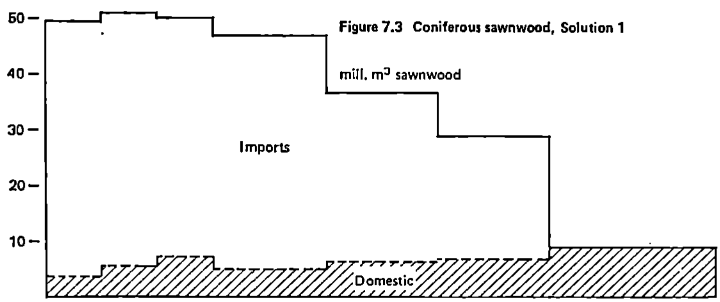


7.2 d) Other Conifer output, by use

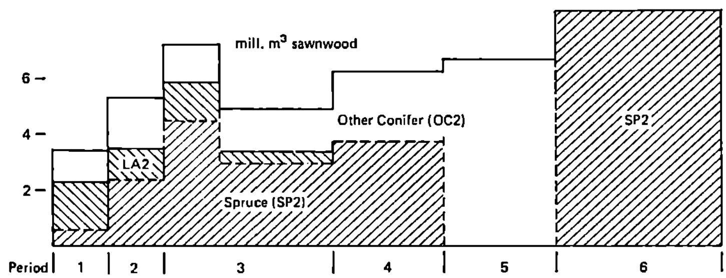


7.2 e) Broadleaved output, by use

Figure 7.3 Coniferous sawnwood, Solution 1



7.3 a) Domestic/Import breakdown



7.3 b) Breakdown of domestic production by species

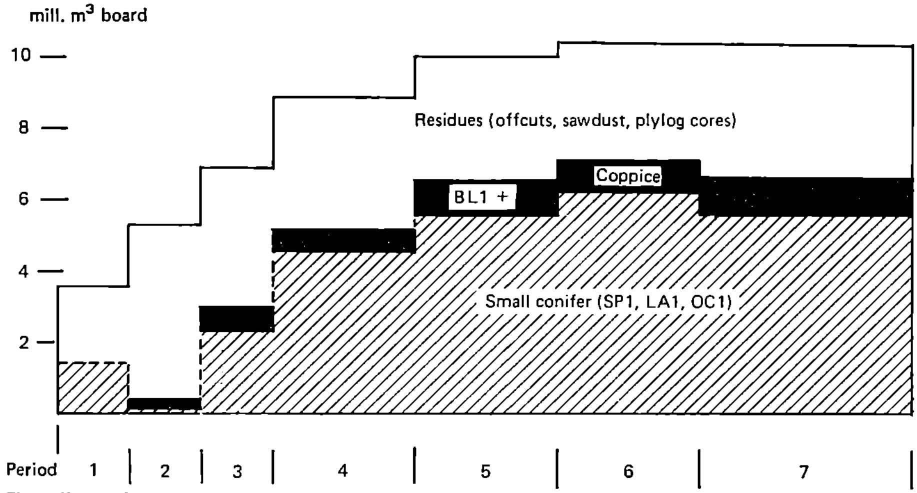


Figure 7.4 Particle board supplies by type of raw material (imports nil) (Solution 1)

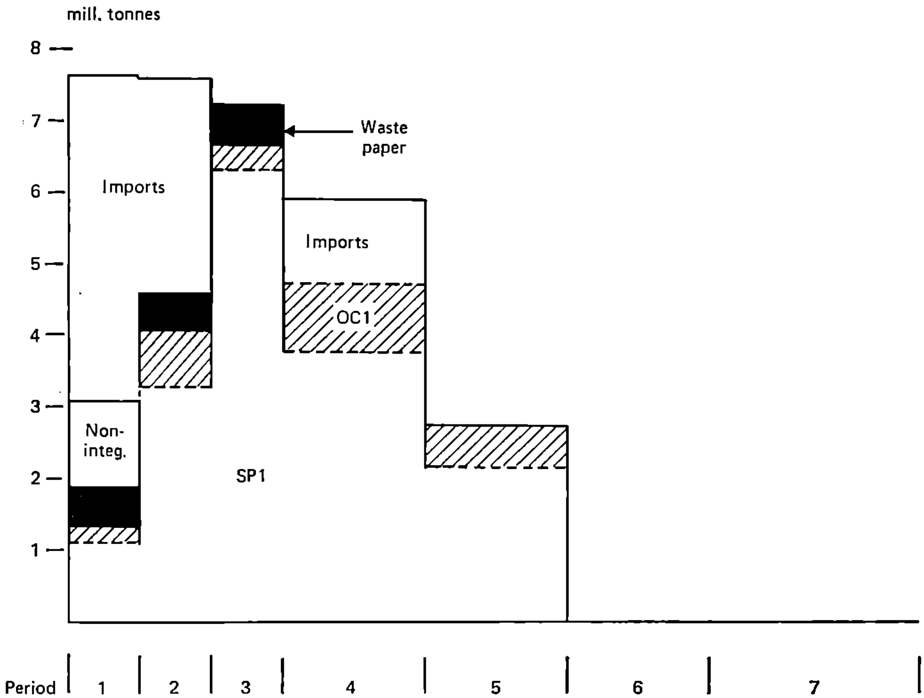


Figure 7.5 Newsprint supplies by source and raw material (Solution 1)

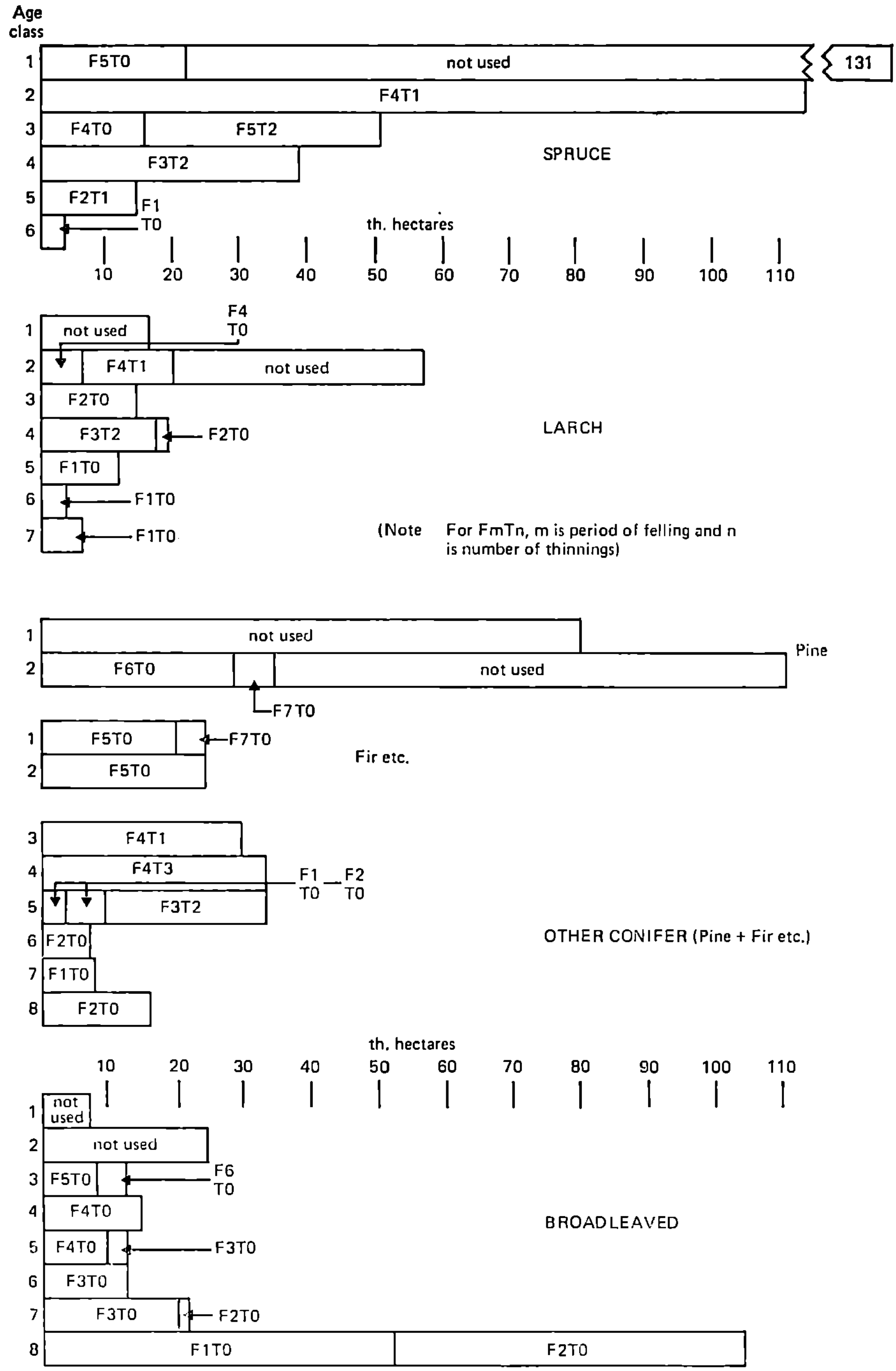
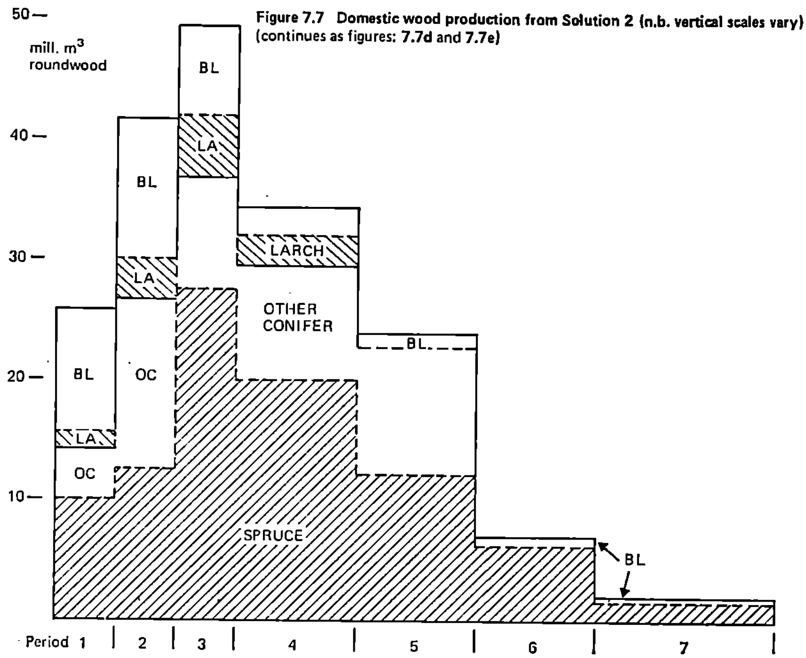
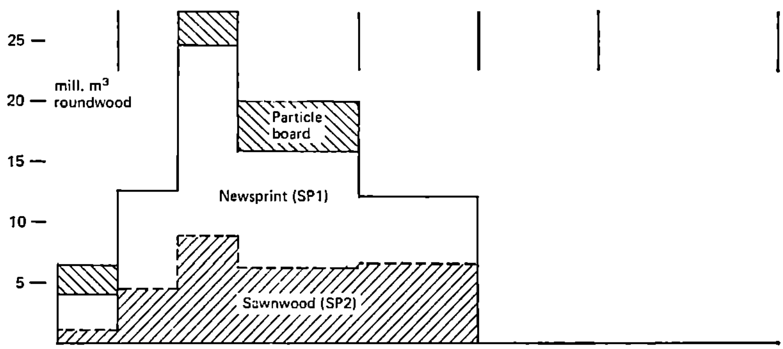


Figure 7.6 Overall Management Plan from Solution 2

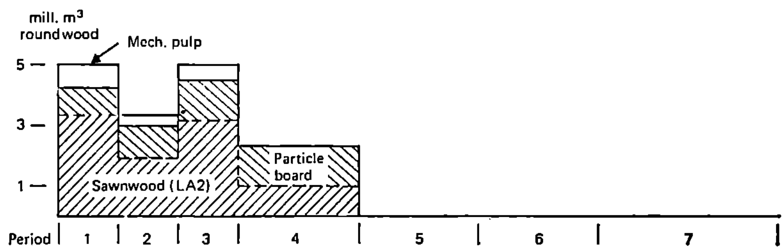
Figure 7.7 Domestic wood production from Solution 2 (n.b. vertical scales vary) (continues as figures: **7.7d** and **7.7e**)



7.7 a) Total roundwood output by species (exc. coppice)



7.7 b) Spruce output, by use



7.7 c) Larch output, by use

Figure 7.7 continued. Domestic wood production from Solution 2 (n.b. vertical scales vary)

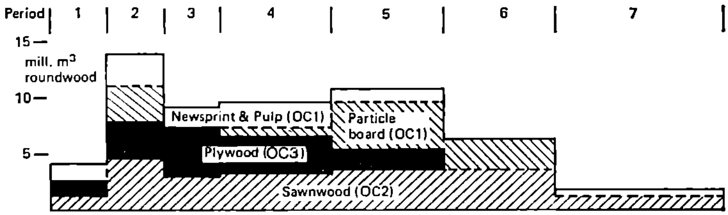
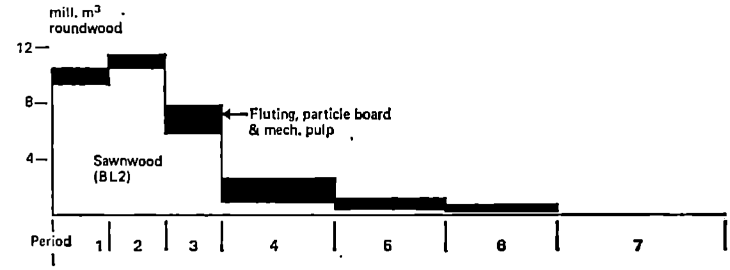
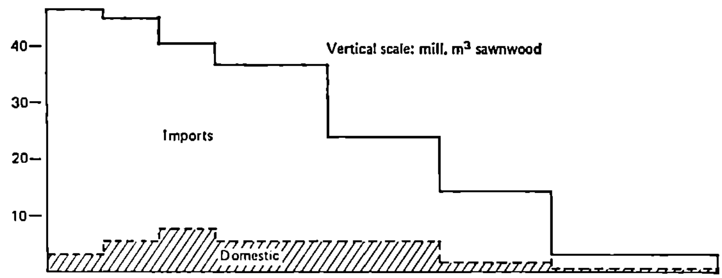


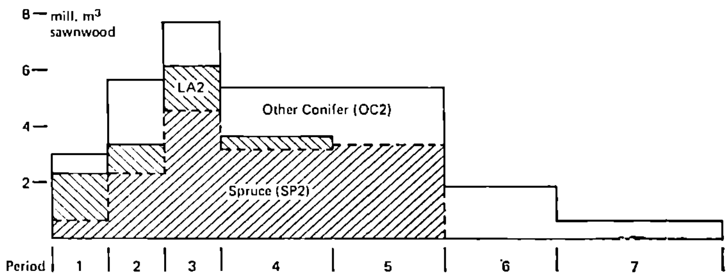
Figure 7.7 d) Other Conifer output, by use



7.7 e) Broadleaved output, by use



7.8 a) Domestic/Import breakdown



7.8 b) Breakdown of domestic production by species

Figure 7.8 Coniferous sawnwood, Solution 2

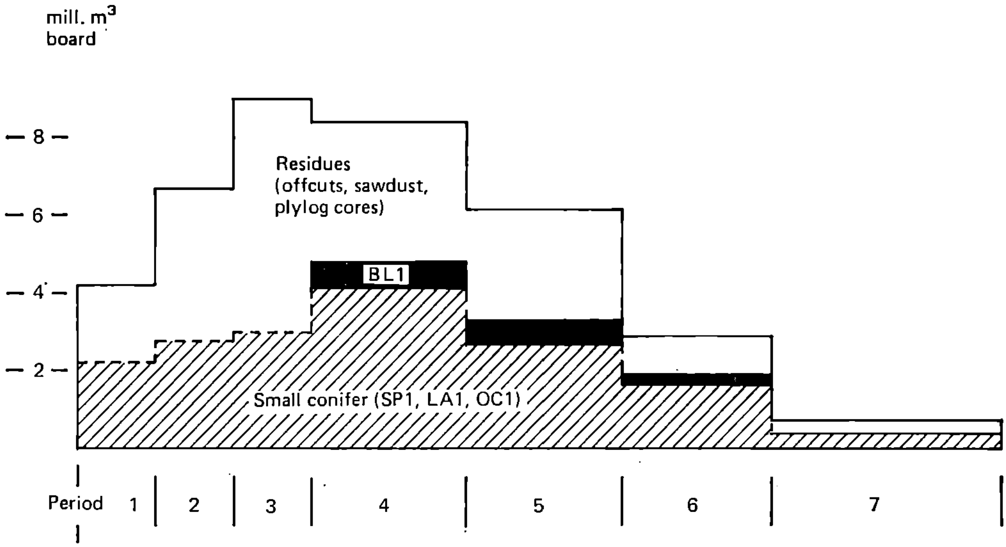


Figure 7.9 Particle board supplies by raw material type (imports nil) (Solution 2)

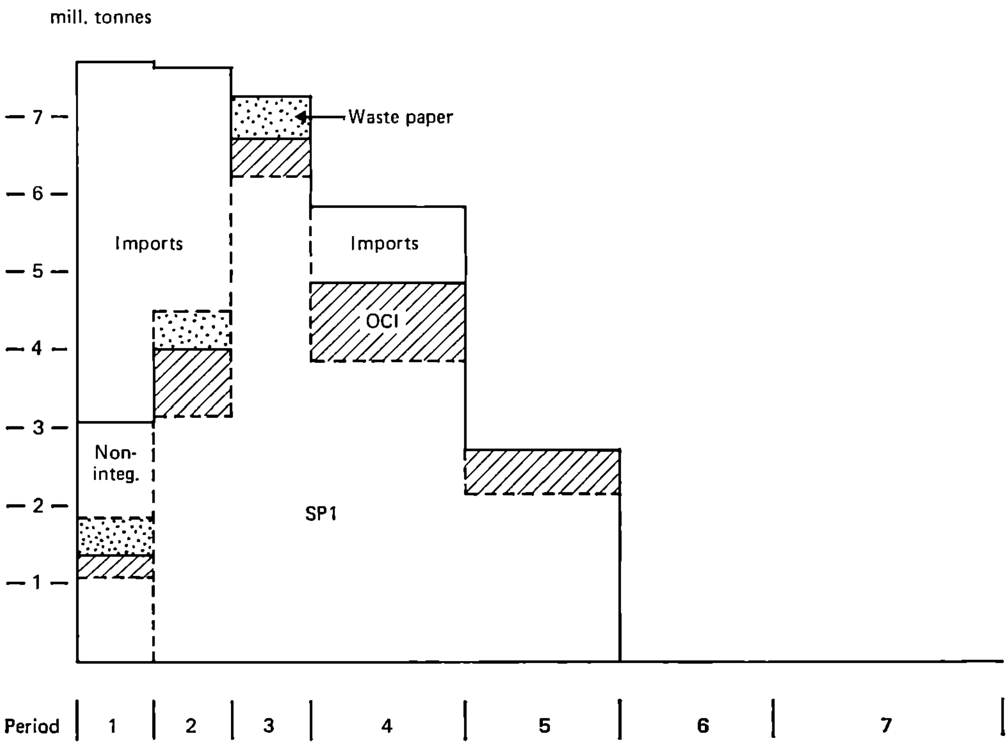


Figure 7.10 Newsprint supplies by source and raw material (Solution 2)

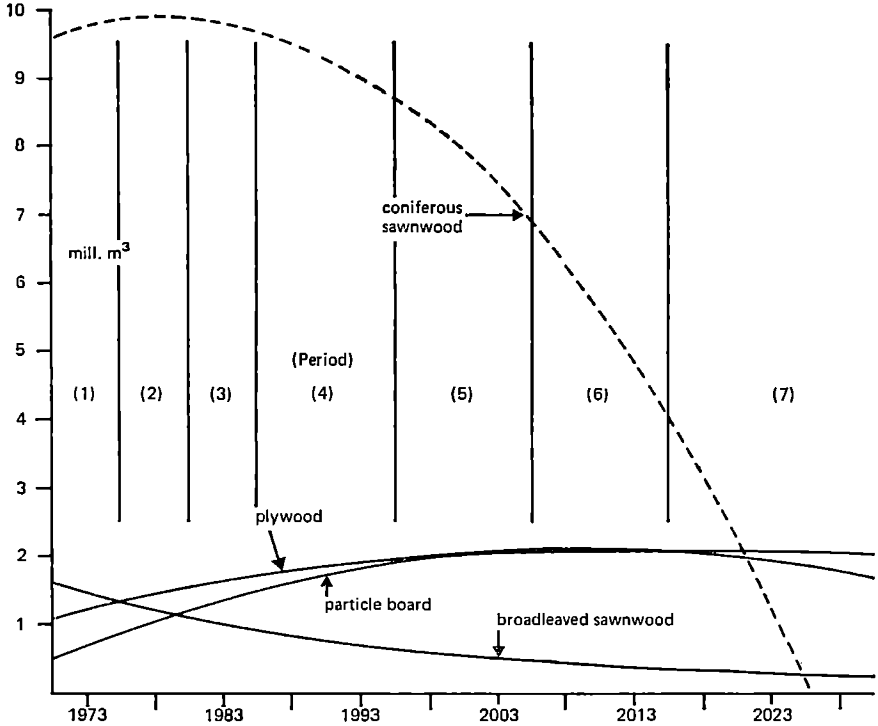


Figure 7.11a Demand forecasts used in Solution 1: Products measured by volume

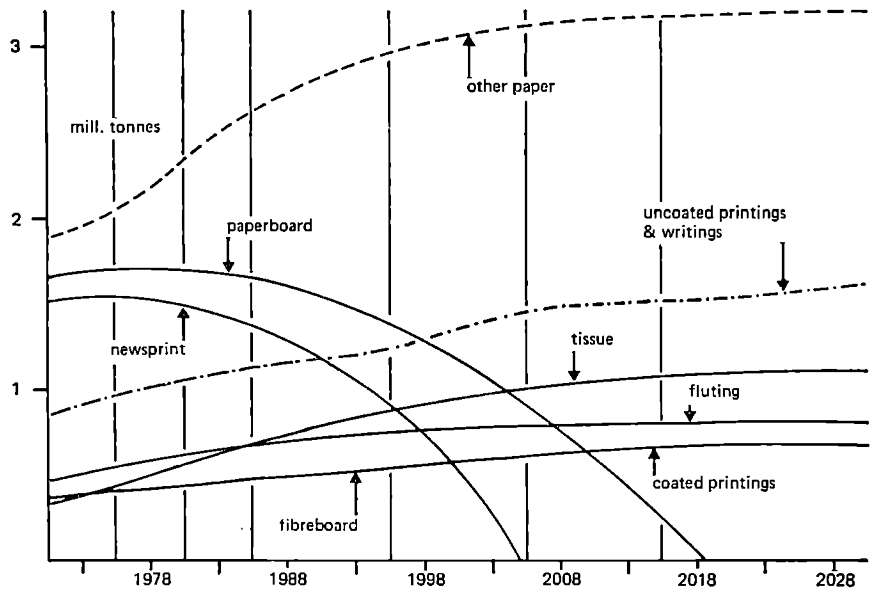


Figure 7.11b Demand forecasts used in Solution 1: Products measured by weight

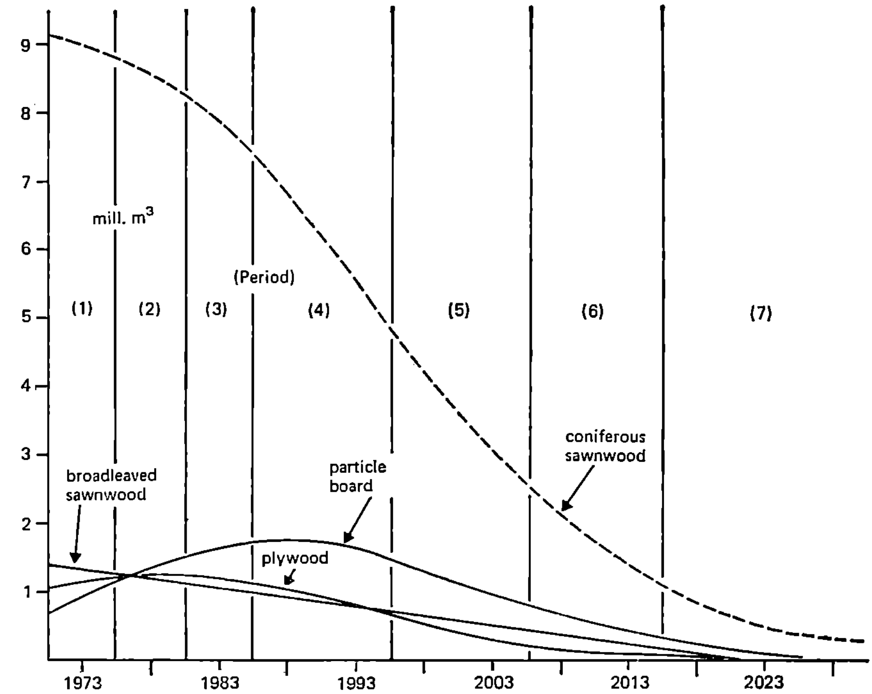


Figure 7.12 a Demand forecasts used in Solution 2: Products measured by volume

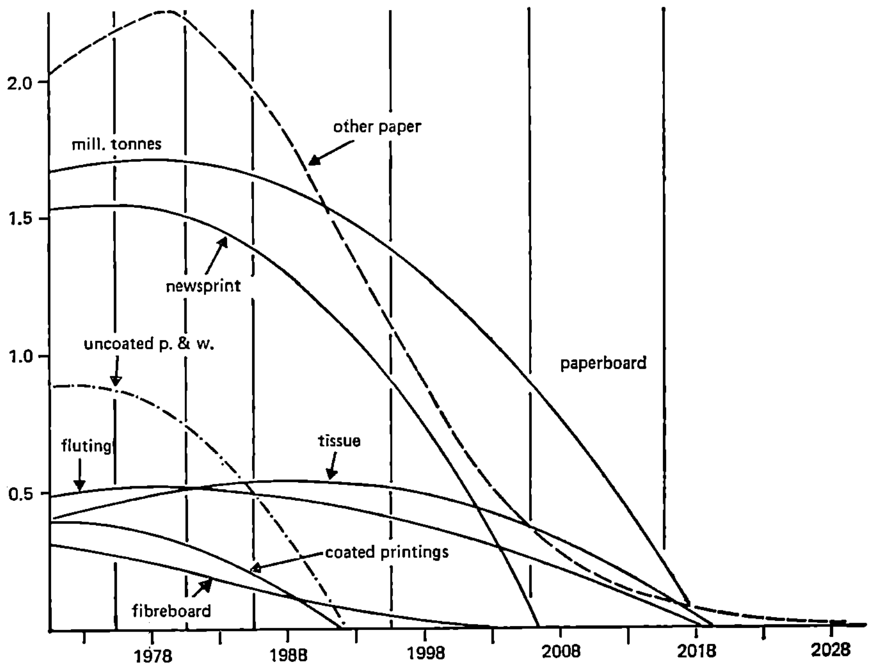


Figure 7.12 b Demand forecasts used in Solution 2: Products measured by weight

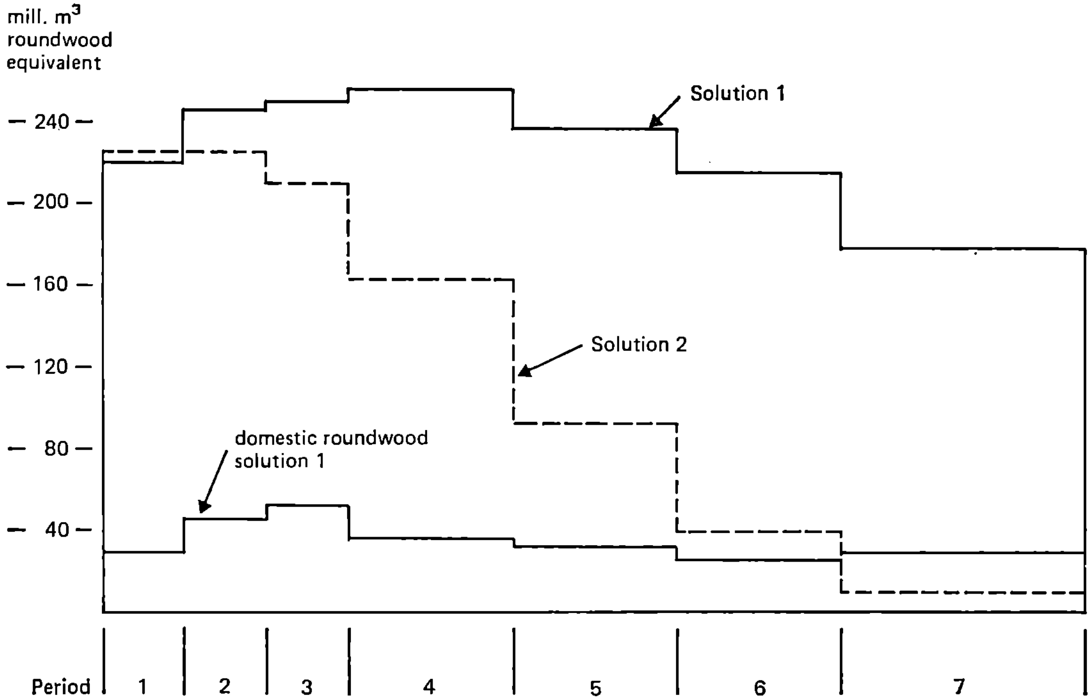


Figure 7.13 Total roundwood usage implied by the two solutions

BIBLIOGRAPHY

Akers, L. E. (1970). (Airscrew-Weyroc Ltd., Weybridge.) Personal communication.

Ashton Paper Mill (1970). Brochure prepared for visitors to the mill at Sudbrook, near Chepstow, Monmouthshire.

Baguley, M. (1970). Personal communication.

Bain, A. D. (1964). The Growth of Television Ownership in the United Kingdom Since the War, *University of Cambridge Department of Applied Economics: Monograph no. 12*, Cambridge.

Balman, F. E. and Lorrain-Smith, R. (1969). *Economic Survey of Private Forestry, England and Wales: Income and Expenditure*, no. 3, Economics Section, Forestry Department, Oxford University.

Baxter, R. E. and Rees, R. (1968). Analysis of the Industrial Demand for Electricity, *Econ. Journal*, vol. LXXVIII, no. 310 June 1968, pp. 277–298.

Begley, C. D. (1955). Growth and Yield of Sweet Chestnut coppice, Forestry Commission *Forest Record no. 30.*

BPBMA (1965). British Paper and Board Manufacturers Association, *Paper Making*, London.

BPBMA (1968). *Reference Tables* (annual), London.

Budden, C. E. (1971). (Wiggins Teape Ltd.) Personal communication.

Callow, C. (1969). "Wastepaper is imported as prices soar", *The Times* 23/12/69, p. 16.

Cantiani, M. (1963). (Yield and volume studies on the chestnut coppice of Monte Cimini.) *Ital. for. mont.*, 18 (4), pp. 162–168.

Carruthers, J. F. S. (1969). The manufacture of constructional grade plywood for home-grown softwoods. *Home Grown Timber Research Committee Paper no. 205.*

Christie, J. M. (1971). Personal communication.

Collet, M. E. W. (1970). External costs arising from the effects of forests upon streamflow in Britain, *Forestry*, vol. XLIII, no. 2, pp. 181–193.

Curry, H. G. (1970). (St. Anne's Board Mill Co. Ltd. Bristol.) Personal communication.

Dawkins, H. C. (1969). The future of industrial cellulose: unlimited or end in sight?, *Forestry* Supplement, pp. 89–92.

De-fibrator AB (1963). (De-fibrator Aktiebolaget.) *The Influence of Mill Capacity upon Investment and Manufacturing Cost—Insulation Board and Hardboard*, Stockholm.

ECE/FAO (1969). *European Timber Trends and Prospects, 1950–1980, An Interim Review*, vol. 1 (Supplement 7 to vol. XXI of the *Timber Bulletin for Europe*), Geneva.

Edwardson, T. E. (1970). Personal communication.

E.I.U. (1966). (Economist Intelligence Unit.) *The National Newspaper Industry. A Survey*, London.

Eklund, R. (1969). (Jaakko Poyry & Co.) *A Preliminary Appraisal of Alternative Programs for Forest Industries Development in Great Britain.*

Eklund, R. and Kirjasniemi, M. (1969). An approach to economic planning of forest industry integrates, *Paper Trade Jour.* Nov. 1969.

FAO (1954). Food and Agriculture Organisation, United Nations *World Pulp and Paper Resources and Prospects*, New York.

FAO (1960). *World Demand for Paper to 1975*, Rome.

FAO (1966). *Plywood and Other Wood-based Panels*, Rome.

FAO (1969). *The State of Food and Agriculture 1969*, Rome.

FAO (1969a). *Yearbook of Forest Products 1969*, Rome.

FAO (1971). *The State of Food and Agriculture 1971*, Rome.

Forestry Commission (1966). *Forest Management Tables*, F.C. Booklet No. 16, H.M.S.O.

Forestry Commission (1970). Metric Volume Ready Reckoner, *Forestry Commission Booklet No. 26*, H.M.S.O.

Francis, N. T. (1971). (Birmingham Waste Co. Ltd.) Personal communication.

Fussell, H. E. (1970). (St Anne's Board Mill Co. Ltd. Bristol.) Personal communication.

Grayson, A. J. (1969). Imports and consumption of wood products in the United Kingdom 1950–1967, with forecasts to 1980. Forestry Commission, *Forest Record No. 70*, H.M.S.O.

Hair, D. (1963). Economic importance of timber in the United States, *Forest Products Journal*, 13, 9.

Hamilton, G. J. (1969). Personal communication.

Harrison, P. J. and Pearce, S. F. (1971). (ICI Ltd.) *The Use of Trend Curves as an Aid to Market Forecasting*, Paper presented at the 6th Annual Conference of EVAF, the European Association for Industrial Marketing Research, May 1971.

Hart, C. E. (1966). *Timber Prices & Forestry Costings*, Hart, Coleford, Gloucs.

Henderson, P. D. (1968). Investment Criteria for Public Enterprises, in *Public Enterprise* (ed. R. Turvey), Penguin, London.

Higham, R. R. A. (1968). *A Handbook of Papermaking*, 2nd ed., London.

Hudson, R. W. (1970). (FPRL) *The Use of Mixed Hardwoods for Chipboard*, internal memorandum (Princes Risborough Laboratory).

Jackson, B. G. (1971). Linear programming model of the U.K. forest products sector, in *Forestry Commission Bulletin no. 44*, Operational Research and the Managerial Economics of Forestry, London. (ed. P. A. Wardle), H.M.S.O.

James, N. D. G. (1966). *The Forester's Companion*, 2nd ed., Blackwell, Oxford.

Johnsen *et. al.* (1969). (Johnsen, Jorgensen & Wettre Ltd.) *A Digest of U.K. Wood Pulp Imports and Price Reviews 1959–1968*, issue no. 5, March 1969.

Keeves, A. (1966). Some evidence of loss of productivity with successive rotations of *Pinus radiata* in the south-east of South Australia *Aust. For.*, vol. 30, no. 1.

Kimberly-Clark (1970). (Kimberly-Clark Ltd.) Personal communication. (R. J. Waller.)

Locke, G. M. (1970a). Private Woodlands, in *Forestry Commission Census of Woodlands 1965–1967*, H.M.S.O. London, 1970, pages 38–57, etc.

Locke, G. M. (1970b). Personal communication.

McKillop, W. L. M. (1967). Supply and Demand for Forest Products—an Econometric Study. *Hilgardia*, vol. 38, no. 1, March 1967.

Neville, C. W. (1970). (Forest Products Research Laboratory—now Princes Risborough Laboratory.) Personal communication.

OECD (1968). (I.M.D. Little and J. Mirlees, Organisation for Economic Co-operation and Development.) *Manual of Industrial Project Analysis in Developing Countries*, vol. II, Paris.

OECD (1970). (Arne Sundelin). *Paper & Board Consumption Patterns & Development Trends in the OECD Countries 1950–1967*, Paris, 1970.

Ollman, H. (1971). Der Holzverbrauch der Bundesrepublik Deutschland, Prognose der Entwicklung bis 1980, *Mitteilungen der Bundesforschungsanstalt für Forst- undHolzwirtschaft, Reinbek bei Hamburg, Nr. 84, Hamburg.*

Packman, D. F. & Orsler, R. J. (1964). Sulphite Pulping of British-grown Softwoods Pt. 1, Two-stage Cooking of Sitka Spruce, *Holzforschung*, 18 Band, Heft 6, pp. 179–183.

Packman, D. F. (1961). Pulping of British-grown softwoods, Pt. 5—Disc refining of chips from various species, *Paper Technology*, vol. 8, no. 4, pp. 339–340.

Packman, D. F. (1968). Pulping in Britain, *Quarterly Journal of Forestry*, vol. LXII, no. 1, Jan. 1968, pp. 137–144.

Pearce, D. W. (1971). *Cost-Benefit Analysis*, Macmillan, London.

Phillip *et al.* (1969). (Phillip, M. S., Grant, G. C., Cummings, D. G., and Lloyd, D. A.) *Economic Survey of Private Forestry, Scotland: Income and Expenditure for years 1960/61 to 1966/67*, Forestry Department, Aberdeen University.

Riihinen, P. (1962). Sales of Newsprint in Finland 1949–1959, *Models for Short-term Forecasting, Acta Forestalia Fennica 74*, Helsinki.

Riihinen, P. (1971). Forecasting (short-term) Demand, *Folia Forestalia 101*, Helsinki.

Robinson, W. (1971) (Bowater Paper Corp. Ltd.) Personal communication.

Savage, D. W. (1970). (Ashton Paper Mill Ltd.) Personal communication.

Simpson, A. W. (1971). (Northern Ireland Ministry of Agriculture.) Personal communication.

Treasury, H. M. (1972). *Forestry in Great Britain, An Interdepartmental Cost/Benefit Study*, H.M.S.O London.

University College of Wales, Aberstwyth, 1967, *Farm Management Survey, Comparative Tables, Livestock Rearing Farms—Poor land 1966/67* (especially Tables 4 and 6).

Vellani, S. Personal communication.

Wardle, P. A. (1971). (ed.:) Operational Research and the Managerial Economics of Forestry, *Forestry Commission Bulletin*, No. 44, H.M.S.O.

Warman, H. R. (1971). Future Problems in petroleum exploration, *Petroleum Review*, March 1971, pp. 96–101.

Webb, M. G. (1966). Rate of discount and inflation with particular reference to the electricity supply industry, *Oxford Economic Papers (New Series)*, vol. 18, no. 3, Nov. 1966.

Willis, W. E. (1968). *Timber from Forest to Consumer*, London.

Appendix A

NOTES ON ESTIMATING AREA AND YIELD CLASSES OF HIGH FOREST IN THE UNITED KINGDOM AT 1st JANUARY, 1971

For the purpose of the model three sets of estimates of areas and yield classes are combined, viz. for the Forestry Commission (Great Britain only), private estates in Great Britain (including local authority holdings etc.), and forests in Northern Ireland. These totals are shown in Table 8, and the notes in this Appendix indicate how the published data have been amended and amplified.

1. Forestry Commission (Great Britain)

Gross areas and yield classes for high forest are shown in English measure in *Analysis of Forestry Commission Growing stock as at 30.9.1967*, from the Planning and Economics Branch of the Forestry Commission. Since then some felling and new planting has taken place, and some of the figures referred to have been amended. The procedure used is as follows.

Felling

From Forestry Commission Annual Reports, the area felled from October 1967 to March 1970 (2·5 years) is 10,650 hectares, equivalent to about 4250 hectares per year. Therefore the area felled from April to December 1970 is estimated as 4250 × ·75 = 3200 hectares, and the total from October 1967 becomes 13,850 hectares (about 34 thousand acres). Allowing for rides etc. this is equivalent to about 11,770 hectares (about 29,000 acres) of actual plantations. It is assumed that these 11,770 hectares come from the 57 thousand hectares in age classes 5 and over, so the area in each species/age class combination at 30 September 1967, is reduced by 11,770/57,000, or 20 per cent.

New planting

This affects the areas in age-class 1, which at 30th Sept. 1967 were as follows (published figures less 15 per cent):

	spruces	*larches*	*pines*	*fir, etc.*	*broadleaved*
Th. hectares	67·0	8·8	46·1	14·1	3·1

According to the Forestry Commission Annual Reports, planting from October 1967 to March 1970 was 49·7 th. hectares of conifers and ·595 th. hectares of broadleaved species. These figures are shown below in more detail and adjusted by 15 per cent :

	Adjusted areas planted (th. ha.)	
	conifer	*broadleaved*
Oct. 1967–Mar. 1969	23·2	·37
Apr. 1969–Mar. 1970	19·0	·13
estimate Mar.–Dec. 1970	14·2	·10
	56·4	·60

The conifer area can be allocated to grouped species on the basis of number of plants used:

	Percent of plants	*Area planted th. ha.*	*Total area age class 1 th. ha.*
Spruces	57	32·2	99·2
Larches	5	2·8	11·6
Pines	30	16·9	63·0
Firs etc.	8	4·5	18·6
	100	56·4	192·4
Broadleaved		·60	3·7

The total areas shown are the sum of the areas at 30th September 1967, and the areas planted since.

2. Private Forestry (Great Britain)

Gross areas and estimated yield classes applicable to 1965 were supplied by the Forestry Commission Census Branch. There are no complete records of felling in these woodlands but the Census Branch estimate the annual area as about 7 thousand hectares, roughly 30 per cent conifers and 70 per cent broadleaved. For five years (1965–70) the totals should therefore be about 10 thousand hectares of conifers and 25 thousand hectares of broadleaved. These figures applied to the 1965 total areas of age classes 5–8, represent about 12·5 per cent of conifers and 15 per cent of broadleaved, and the 1965 areas in each species/age class combinations are reduced by the appropriate percentage.

New Planting

In 1965 private forest areas in age class 1 (plantings from 1961 onwards) were estimated as follows (census figures less 15 per cent):

	spruces	*larches*	*pines*	*firs etc.*	*broadleaved*
th. hectares	26·0	10·7	23·7	8·6	5·1

Since 1965 the Forestry Commission estimate new areas planted as follows (adjusted by 15 per cent):

	th. ha.
Oct. 1965–Sept. 1966	11·0
Oct. 1966–Sept. 1967	12·6
Oct. 1967–Mar. 1969	14·6
Apr. 1969–Mar. 1970	16·4
estimate Apr. 1970–Dec.	12·3
	66·9

The species breakdown is based on the averages recorded by the Oxford and Aberdeen Universities' surveys of private forestry. For 1965–67 these were as included overleaf.

	Per cent of planted area	*Estimated areas*	*Total area age class 1*
Spruces	37	24·7	50·7
Larches	8	5·4	16·1
Pines	37	24·8	48·5
Firs etc.	11	7·3	15·9
(Conifers)	(93)	(62·2)	(131·2)
Broadleaved	7	4·7	9·8
	100	66·9	141·0

3. Northern Ireland

The areas involved are relatively small, but as recent inventory estimates are available, the figures are included. The total area of plantations owned by the government is about 33 thousand hectares (mainly Sitka spruce), of which 26 thousand hectares have been planted since 1950. Private woodlands are mainly plantings before 1910, plus about 3 thousand hectares since 1945.

Appendix B

SUMMARY OF ACTIVITIES FOR EXISTING PLANTATIONS

Appendix B

TABLE B.1
SUMMARY OF ACTIVITIES FOR EXISTING PLANTATIONS

Age class	Species												Total no. of activities
	Spruce		Larch		Pine		Fir		Broadleaved		Coppice		
	Fell	Thin	Fell	Thin	Fell	Thin	Fell	Thin	Fell	Thin	Cut	Re-cut	
	Figures refer to time periods												
1	5 5 6 6 6 7 7 7	— 4 — 4 4 5 — 4 5 4 5 6	5 5 6 6 7 7 7	— 4 — 4 4 5 — 4 5 4 5 6	6 6 7 7 7	— 5 — 5 5 6	5 6 6 7 7 7	— — 4 5 — 4 4 5 6	6 6 7 7	— 5 — 5 6	3 3	— 5 7	32
2	4 4 5 5 5 6 6 6 7 7 7 7	— 3 — 3 3 4 — 3 3 4 5 — 3 3 4 3 4 5	4 4 5 5 5 6 6 6	— 3 — 3 3 4 — 3 3 4 5	5 5 6 6 6 7 7 7	— 3 — 3 3 4 5 — 3 4 3 4 5 6	4 5 5 6 6 6 7 7 7	— — 2 3 4 — 2 3 2 3 4 5 — 2 3 2 3 4 5 6	5 5 6 6 7 7 7	— 4 — 4 5 — 4 4 5 6	1 1 2 2	— 4 6 — 5 7	48
					'Other Conifer'								
					Fell	Thin							
3	2 2 3 3 4 4 4 5 5 5 5 6 6 6 6	— 1 — 1 2 — 2 1 2 3 — 2 2 3 1 2 3 — 2 2 3 1 2 3 4 5	2 2 3 3 4 4 5 5 5 6 6 6	— 1 — 1 2 — 1 2 3 — 2 3 1 2 3 4 — 2 3 1 2 3 4 5	4 4 4 5 5 5 6 6 6 7 7 7	— 2 1 2 3 — 2 3 1 2 3 4 — 2 3 1 2 3 4 5 — 2 3 4 1 2 3 4 5 6			4 4 5 5 6 6 6 7 7 7	— 3 — 3 4 — 3 3 4 5 — 3 4 3 4 5 6			49

32	19	15	9	247

TABLE B.2
SUMMARY OF ACTIVITIES FOR NEW PLANTATIONS

Plant in period	Species												Total no. of activities
	Sitka spruce		Lodgepole pine		Douglas fir		Oak YC 4		Beech YC 6		Coppice		
	Fell	Thin	Fell	Thin	Fell	Thin	Fell	Thin	Fell	Thin	Cut	Re-cut	
	Figures refer to time periods												
1	*YC 12*		*YC 8*		*YC 14*								31
	6	—	6	—	6	—	7	6	7	6	4	6	
	6	5	6	5	6	4 5					4	6 7	
	7	—	7	—	7	—							
	7	5	7	5	7	4 5 6							
	7	5 6	7	5 6									
	YC 14		*YC 12*		*YC 16*								
	6	—	6	—	5	—							
	6	6	6	4 5	6	—							
	7	—	7	—	6	4 5							
	7	5 6	7	4 5 6	7	—							
					7	4 5 6							
2	*YC 12*		*YC 8*		*YC 14*								24
	6	—	7	—	6	—	7	—	7	6	4	6	
	7	—	7	6	6	5							
	7	5 6			7	—							
					7	5 6							
	YC 14		*YC 12*		*YC 16*								
	6	—	6	—	6	—							
	6	5	7	—	6	5							
	7	—	7	5 6	7	—							
	7	5			7	5 6							
	7	5 6											
3	*YC 12*		*YC 8*		*YC 14*								12
	7	—	7	—	7	—							
	7	6	7	6	7	5 6							
	YC 14		*YC 12*		*YC 16*								
	7	—	7	—	7	—							
	7	6	7	5 6	7	5 6							
Total no. of activities	21		18		21		2		2		3		67

Notes:
1. YC is metric yield class.
2. For conifer species the activities shown above are duplicated, to allow for roaded and unroaded land.

Appendix C

CALCULATION OF FORESTRY OPERATIONAL COSTS

(current prices except where stated)

Year	(1) Total overhead costs	(2) Total direct costs	(3) O/H per unit of direct cost (1)/(2)	(4) Establishment costs: Direct	(5) Establishment costs: Direct + O/H share (4) × (1 + (3))	(6) Maintenance costs: Direct	(7) Maintenance costs: Direct + O/H share (6) × (1 + (3))
	£ th.	£ th.		£ th.	£ th.	£ th.	£ th.
1958	4005	4844	·827	3167	5785	325	594
1959	4102	5385	·762	3717	6548	384	676
1960	4488	5533	·811	3863	6996	383	694
1961	5369	6582	·816	4873	8848	432	784
1962	5245	5683	·923	3957	7609	451	867
1963	5749	5732	1·003	3947	7906	461	923
1964	5947	6054	·982	4004	7937	596	1181
1965	6305	6199	1·017	3918	7903	553	1115
average			·893				

Year	Direct costs of harvesting: Thinning	Direct costs of harvesting: Felling	Direct costs of harvesting: Other	Thinnings as per cent of harvested volume	"Other" harvesting costs allocated to: Thinning $(10) \times \frac{(11)}{100}$	"Other" harvesting costs allocated to: Felling (10) − (12)
	£ th.	£ th.	£ th.	%	£ th.	£ th.
	(8)	(9)	(10)	(11)	(12)	(13)
1958	245	46	859	78·5	674	185
1959	243	45	731	73·8	539	192
1960	203	53	797	72·1	575	222
1961	209	63	723	69·0	499	224
1962	199	54	740	69·7	516	224
1963	188	54	753	69·4	523	230
1964	229	61	855	71·7	613	242
1965	280	83	995	69·2	689	306

Year	Road construction costs: Total expenditure on new roads and bridges £ th. (20)	Road construction costs: Length completed km. (21)	Road construction costs: Cost per km. (1967 prices) (20)/price index / (21) £ per km. (22)	Road maintenance costs: Total cost £ th. (23)	Road maintenance costs: Length maintained km. (24)	Road maintenance costs: Cost per km. (1967 prices) (23)/price Index / (24) £ per km. (25)
1957	1407	644	2791			
1958	1641	668	3072	369	8533	54·1
1959	1752	723	3004	465	9196	62·7
1960	1681	647	3180	424	10093	51·5
1961	1902	810	2801	512	10724	56·9
1962	1802	658	3165	542	11669	53·8
1963	1864	697	3040	659	12173	61·5
1964	2423	770	3492	613	13049	51·9
1965	2576	828	3313	748	13901	57·3
1966	3018	1124	2756			
1967	2810	781	3600			
average			3110			56·2

Year	(26) Protection costs: Direct £ th.	(27) Protection costs: Direct + O/H Share (26) × (1 + (3)) £ th.	(28) Area of plantations less than 10 years old th. ha.	(29) Protection cost per hectare*: Current prices (27)/(28) £ p. ha.	(30) Protection cost per hectare*: 1967 prices (27) / price index £ p. ha.
1958	439	802	241	3·33	4·16
1959	488	860	246	3·50	4·34
1960	511	925	248	3·73	4·57
1961	523	950	252	3·77	4·49
1962	536	1031	251	4·11	4·75
1963	539	1080	247	4·37	4·97
1964	558	1106	240	4·61	5·11
1965	552	1113	234	4·77	5·08
average					4·68

* See note

Year	All costs of harvesting inc. overheads: Thinning [(8) + (12)] × (1 + (3)) £ th.	All costs of harvesting inc. overheads: Felling [(9) + (13)] × (1 + (3)) £ th.	Costs per unit at 1967 prices: Establishment (5)/price index / area planted £ p. ha	Costs per unit at 1967 prices: Maintenance (7)/price index / area maintained £ p. ha	Costs per unit at 1967 prices: Thinning (14)/price index / vol. thinned £ p. m³	Costs per unit at 1967 prices: Felling (15)/price index / vol. felled £ p. m³
1958	1679	421	341	2·13	6·61	6·04
1959	1379	418	364	2·23	7·34	6·26
1960	1408	499	343	2·11	6·56	6·01
1961	1286	521	(409)	2·19	5·83	5·26
1962	1375	535	351	2·24	6·58	5·89
1963	1424	569	399	2·25	7·00	6·35
1964	1669	600	401	2·69	6·44	5·86
1965	1953	785	387	2·32	6·29	5·68
average			370	2·27	6·58	5·92

Note:
For age class 1 of existing plantations, assuming an even distribution of planting years within the age class, in period 1 the average 10 hectares will be composed of 1 hectare just planted, 1 hectare one year old, and so on. Most protection expenditure is incurred in the first five years, but the average can be estimated as:

$$\sum \frac{4{\cdot}68n}{10} = £11{\cdot}7$$
$$(n = 9,7,5,3,1)$$

Appendix D

AVERAGE IMPORT PRICES

TABLE D.1

AVERAGE COST-INSURANCE-FREIGHT (c.i.f.) IMPORT PRICES FOR INTERMEDIATE PRODUCTS

Year	Mechanical pulp		Chemical pulp		Waste paper		Pulpwood	
	Prices							
	Current	1967	Current	1967	Current	1967	Current	1967
	£ per tonne						£ p true m³	
1950	19·4	33·9	39·1	68·3	—	—	5·0	8·8
1951	36·9	57·5	90·9	141·5	25·5	39·7	8·4	13·2
1952	38·3	56·3	83·3	122·4	22·3	32·8	10·0	14·6
1953	27·3	40·0	49·0	71·8	24·6	36·1	8·0	11·7
1954	27·4	39·7	47·7	69·0	22·8	33·0	7·9	11·4
1955	28·8	40·1	50·8	70·8	15·5	21·5	8·6	11·9
1956	32·6	43·0	52·7	69·6	17·8	23·5	9·0	11·9
1957	32·1	41·1	52·7	67·3	12·8	16·3	9·2	11·8
1958	29·5	36·9	49·7	62·1	15·6	19·4	7·7	9·7
1959	28·5	35·3	46·7	57·8	22·8	28·3	7·1	8·8
1960	28·2	34·6	47·5	58·1	24·5	30·0	7·2	8·8
1961	28·0	33·3	48·8	58·2	20·1	23·9	7·6	9·0
1962	28·0	32·4	45·3	52·4	14·3	16·5	7·7	9·0
1963	27·7	31·5	46·0	52·3	16·7	19·0	7·4	8·4
1964	27·5	30·4	49·7	55·1	17·1	19·0	7·8	8·6
1965	29·1	31·0	51·5	54·8	19·5	20·7	7·8	8·3
1966	29·2	29·9	49·0	50·2	16·5	17·0	7·6	7·8
1967	29·4	29·4	48·9	48·9	23·9	23·9	7·7	7·7
1968	34·2	32·6	54·0	51·4	17·3	16·5	8·0	7·6
1969	34·9	31·7	58·2	52·9	16·6	15·1	9·0	8·1

Sources:
1 Figures at current prices, from United Kingdom Annual Statement of Trade and (1954–on) from BPBMA *Reference Tables 1970*, adjusted to metric measures.
2 Price index from NIESR (see Table 34).
Note:
The import price of waste paper is not used explicitly as the basis for the net revenues for importing waste paper.

Table D.2
Average c.i.f. Import Prices for Sawnwood and Pitprops

Year	Coniferous sawnwood (sawn softwood)		Broadleaved sawnwood (sawn hardwood)		Pitprops	
	Prices, £ per true m³					
	Current	1967	Current	1967	Current	1967
1948	11·9	22·1	21·1	39·1	5·7	10·6
1949	11·3	20·4	20·6	37·1	5·1	9·2
1950	11·7	70·5	19·5	34·1	4·7	8·2
1951	18·7	29·1	26·2	40·8	8·3	13·0
1952	18·7	27·4	29·5	43·3	10·1	14·8
1953	16·4	24·0	26·2	38·3	7·0	10·3
1954	16·4	23·7	27·0	39·1	6·2	9·0
1955	17·8	24·8	28·1	39·1	7·5	10·5
1956	18·1	23·9	29·2	38·5	8·0	10·6
1957	17·7	22·6	28·8	36·8	7·9	10·1
1958	16·1	20·1	27·9	34·9	7·0	8·8
1959	14·9	18·4	27·1	33·6	6·3	7·8
1960	16·3	19·9	29·2	35·7	5·9	7·3
1961	16·9	20·2	31·0	37·0	6·5	7·7
1962	16·1	18·6	29·2	33·7	6·4	7·4
1963	16·4	18·6	29·9	33·9	6·4	7·2
1964	17·8	19·7	30·5	33·8	6·5	7·3
1965	19·0	20·2	31·0	33·0	7·4	7·9
1966	19·0	19·5	31·7	32·5	7·8	8·0
1967	18·3	18·3	32·0	32·0	7·5	7·5
1968	20·2	19·1	34·9	32·9	8·1	7·6
1969	22·1	19·9	37·1	33·4	9·4	5·9

Sources:
1 Figures at current prices, from TTFUK *Yearbook of Timber Statistics 1970*
2 Price index from NIESR (see Table 34).
Note:
Broadleaved sawnwood includes some logs for sawing in United Kingdom.

Table D.3
Average c.i.f. Import Prices for Wood Sheets

Year	Plywood (Canadian)		Particle board (exc. Flaxboard)		Fibreboard	
	Prices					
	Current	1967	Current	1967	Current	1967
	£ p. m³				£ p. tonne	
1950					43·5	76·1
1951					52·0	80·9
1952					48·5	71·3
1953					41·7	61·2
1954					39·2	56·7
1955					41·4	57·7
1956					40·7	53·7
1957					40·7	52·0
1958	n.a.	n.a.	n.a.	n.a.	40·3	50·4
1959	43·2	53·5	27·6	34·2	38·3	47·4
1960	42·5	52·1	26·5	32·4	38·5	47·1
1961	43·8	52·2	30·0	35·8	36·3	43·3
1962	43·2	50·0	28·4	32·8	34·9	40·3
1963	43·7	49·7	26·5	30·2	35·3	40·1
1964	43·7	48·4	24·3	26·9	37·6	41·7
1965	44·2	47·0	22·5	23·9	40·2	42·7
1966	45·7	46·9	23·9	24·5	40·9	41·9
1967	45·8	45·8	25·0	25·0	39·6	39·6
1968	49·6	46·8	27·2	25·7	42·6	40·2
1969	53·4	48·1	30·1	27·1	42·6	38·3

Sources:
1 Plywood price from UK *Annual Statement of Trade.*
2 Particle board price from TTFUK *Yearbook of Timber Statistics 1970.*
3 Fibreboard price from UK *Annual Statement of Trade*, and (1954–on) from BPBMA *Reference Tables 1970.*
Note:
Particle board and Canadian plywood imports were not separately recorded before 1959.

TABLE D.4

AVERAGE C.I.F. IMPORT PRICES FOR NEWSPRINT, PRINTINGS AND WRITINGS, AND TISSUE

Year	Newsprint		Printings and writings		Tissue (unconverted)	
	Prices, £ p. tonne					
	Current	1967	Current	1967	Current	1967
1948	32·6	60·4				
1949	34·9	62·8				
1950	34·3	59·9				
1951	52·7	82·0			very small quantities pre-1954	
1952	55·3	81·3				
1953	51·4	75·3				
1954	51·7	74·8				
1955	52·0	72·4			105·0	146·2
1956	54·0	71·3	very small quantities pre-1960		105·1	138·9
1957	55·2	70·5			104·9	134·0
1958	55·9	69·9			107·1	134·0
1959	54·8	67·8			116·2	144·0
1960	54·6	66·9	90·0	110·1	111·8	136·8
1961	53·5	63·8	95·3	113·6	111·4	132·8
1962	54·2	62·7	86·2	99·7	112·2	129·7
1963	53·8	61·2	85·6	97·3	107·6	122·3
1964	53·0	58·7	86·0	95·4	109·4	121·3
1965	51·9	55·2	82·5	87·7	108·4	115·3
1966	52·6	54·0	75·2	77·1	107·8	110·6
1967	54·1	54·1	78·6	78·6	109·9	109·9
1968	62·0	59·0	84·7	80·6	121·5	115·7
1969	62·3	56·7	88·2	80·3	122·2	111·2

Sources:

1 Tissues and (pre-1954) newsprint current prices from UK *Annual Statement of Trade*.

2 Printings and writings, and (1954–on) newsprint current prices from BPBMA *Reference Tables 1970*.

Notes:

1 "very small quantities" means less than ten thousand tonnes.

2 Printings and writings imports are mainly the cheaper grades and the prices are not representative of the category as a whole.

TABLE D.5

AVERAGE C.I.F. IMPORT PRICES FOR PACKAGING PAPER AND PAPERBOARD

Year	Semi-chemical fluting medium		Other packaging and special paper		Paperboard	
	Prices, £ per tonne					
	Current	1967	Current	1967	Current	1967
1950					31·2	54·5
1951					74·9	116·6
1952					64·5	94·9
1953					n.a.	
1954					44·0	63·7
1955					47·5	66·1
1956					48·8	64·4
1957					48·1	61·5
1958	n.a.		n.a.		48·3	60·4
1959	43·3	53·6	71·5	88·6	47·3	58·6
1960	45·5	55·6	72·9	89·2	49·4	60·5
1961	44·4	53·0	72·6	86·5	49·8	59·4
1962	42·8	49·5	72·9	84·3	52·8	61·1
1963	42·4	48·2	72·7	82·6	54·8	62·2
1964	43·9	48·6	75·5	83·7	56·3	62·4
1965	44·2	47·0	75·1	79·9	58·1	61·8
1966	44·2	45·3	74·9	76·8	59·3	60·8
1967	45·7	45·7	73·4	73·4	59·5	59·5
1968	n.a.		n.a.		64·4	61·3
1969	45·4	40·9	86·9	79·1	67·1	61·1

Sources:

1 Fluting medium and other packaging paper current prices from BPBMA Monthly Bulletin (February issue), various years.

2 Paperboard current prices from BPBMA *Reference Tables* 1970.

Note:

Semi-chemical fluting imports were not separately recorded before 1959; therefore the "other packaging paper" price also cannot be estimated.

Appendix E

BASIS FOR DEMAND VALUES USED IN SOLUTIONS 1 AND 2*

Product	Solution 1	Solution 2
Coniferous sawnwood	Quadratic trend curve + share of pitwood	Semi-log quadratic trend curve + share of pitwood
Broadleaved sawnwood	Semi-log linear trend of consumption per unit of construction output, + share of pitwood	Linear trend curve + share of pitwood
Plywood	Quadratic trend curve	Market share (linear trend) of total wood sheets (quadratic trend curve)
Particle board	Lognormal on construction output	Market share (linear trend)
Fibreboard	Double-log quadratic trend curve	Market share (semi-log trend)
Newsprint	Quadratic trend curve	Quadratic trend curve
Uncoated printings and writings	70 per cent of lognormal on GNP at 1963 prices, for total printings and writings	70 per cent of quadratic trend curve for total printings and writings
Coated printings	30 per cent of lognormal	30 per cent of quadratic
Tissue	Lognormal on GNP at 1967 prices	Quadratic trend curve
Fluting medium	20 per cent of total packaging paper	30 per cent of paperboard
Other packaging paper	Lognormal on GNP at 1963 prices, *less* 20 per cent for fluting	Semi-log quadratic trend of consumption per unit of GNP at 1967 prices
Paperboard	Quadratic trend curve	As for Solution 1
Pitprops	Market share (linear trend) of total pitwood (semi-log trend curve)	As for Solution 1

* All forecasts involving GNP assume a growth rate of 2·5 per cent, and all forecasts involving construction industry output assume it is 12·5 per cent of GNP.

Appendix F

LEVELS OF WOOD-PROCESSING ACTIVITIES IN THE SOLUTIONS

Product	Period (years)	Solution 1				Solution 2			
		Consumption			New capacity	Consumption			New capacity
		Domestic	Imported	Total		Domestic	Imported	Total	
Coniferous	1 (5)	3,454	45,780	49,234	1,757	2,991	44,132	47,123	1,720
sawnwood	2 (5)	5,387	44,719	50,106	0	5,719	39,330	45,049	0
	3 (5)	7,249	42,624	49,873	0	7,745	33,133	40,878	326
th. cu. m.	4 (10)	9,800	84,741	94,541	1,271	10,848	52,970	63,818	879
	5 (10)	12,582	60,784	73,366	85	10,718	27,675	38,393	303
	6 (10)	13,529	43,737	57,266	2,704	3,717	15,018	18,735	195
	7 (15)	25,687	0	25,687	0	1,845	7,130	8,975	0
Broadleaved	1	3,862	3.471	7,334		4,234	3,665	7,899	
sawnwood	2	5,347	804	6,151		4,831	2,058	6,889	
	3	2,510	2,667	5,177	included	2,645	3,317	5,962	included
th. cu. m.	4	949	7,076	8,025	above	1,105	8,229	9,334	above
	5	558	5,175	5,733		398	5,755	6,153	
	6	846	3,306	4.152		290	2,894	3,184	
	7	1,358	2,873	4,231		109	452	561	
Plywood	1	550	5,717	6,267	166	399	5,599	5,998	106
	2	919	6,355	7,274	0	1,001	5.350	6,351	153
	3	1,132	6,999	8,131	103	1,388	4,706	6,044	0
th. cu. m.	4	1,788	16,454	18,242	69	1,864	7,346	9,210	91
	5	944	18,946	19,890	0	906	3,718	4,624	0
	6	0	20,350	20,350	0	0	1,579	1,579	0
	7	0	28,787	28,787	0	0	409	409	0
Particle board	1	3,644	21	3,665	917	4,239	449	4,688	1,156
	2	5,290	0	5,290	0	6,679	0	6,679	0
	3	6,900	0	6,900	745	8,155	0	8,155	1,044
th. cu. m.	4	17,595	0	17,595	1,570	16,938	0	16,938	723
	5	20,185	0	20,185	524	12,192	0	12,192	471
	6	20,990	0	20,990	3,150	5,767	0	5,767	211
	7	31,500	0	31,500	0	2,108	0	2,108	0
Fibreboard	1	647	1,052	1,699	233	487	971	1,458	169
	2	1,229	511	1,740	0	909	295	1,204	0
	3	1,217	547	1,764	0	896	0	896	0
th. tonnes	4	0	3,552	3,552	0	422	548	970	0
	5	0	3,545	3,545	0	0	306	306	0
	6	0	3,510	3,510	0	0	169	169	0
	7	0	5,172	5,172	0	0	11	11	0
Newsprint	1	3,050	4.645	7,695	0	3,050	4,645	7,695	0
	2	4,550	3,116	7,666	1,260*	4,513	3,153	7,666	1,245
	3	7,255	0	7,255	2	7,255	0	7,255	31
th. tonnes	4	9,471	2,272	11,743	0	9,653	2,090	11,743	0
	5	5,500	0	5,500	0	5,500	0	5,500	0
	6	0	89	89	0	0	89	89	0
	7	—	—	—	—	—	—	—	—

* Integrated.

Product th. tonnes	Period (years)	Solution 1				Solution 2			
		Consumption			New capacity	Consumption			New capacity
		Domestic	Imported	Total		Domestic	Imported	Total	
Uncoated printings and writings	1 (5)	4,571	Nil	4,571	183*	4,434	Nil	4,434	1298*
	2 (5)	5,103		5,103	370	4,112		4,112	8
	3 (5)	5,597		5,597	357	3,198		3,198	91
	4 (10)	12,516		12,516	1,143	1,818		1,818	0
	5 (10)	13,920		13,920	320	—		—	—
	6 (10)	14,886		14,886	2,337	—		—	—
	7 (15)	23,373		23,373	0	—		—	—
Coated printings and writings	1	1,959	Nil	1,959	154*	1,900	Nil	1,900	130*
	2	2,187		2,187	153	1,762		1,762	26
	3	2,398		2,398	137	1,371		1,371	26
	4	5,364		5,364	494	779		779	0
	5	5,965		5,965	137	—		—	—
	6	6,379		6,379	1,002	—		—	—
	7	10,017		10,017	0	—		—	—
Tissue	1	1,530	436	1,966	Nil	1,530	577	2,107	Nil
	2	1,190	1,376	2,566		1,190	1,257	2,447	
	3	850	2,332	3,182		850	1,801	2,651	
	4	0	8,035	8,035		0	5,372	5,372	
	5	0	9,685	9,685		0	4,558	4,558	
	6	0	10,545	10,545		0	2,658	2,658	
	7	0	16,365	16,365		0	288	288	
Fluting medium	1	1,687	869	2,556	Nil	1,688	850	2,538	Nil
	2	1,125	1,819	2,944		1,125	1,448	2,573	
	3	563	2,714	3,277		563	1,967	2,530	
	4	0	7,248	7,248		0	4,621	4,621	
	5	0	7,754	7,754		0	3,519	3,519	
	6	0	7,928	7,928		0	1,795	1,795	
	7	0	11,988	11,988		0	110	110	
Other packaging paper	1	8,948	1,276	10,224	1,743*	8,482	972	9,454	1,557*
	2	11,776	0	11,776	0	10,844	0	10,844	0
	3	13,104	0	13,104	1,264	11,169	0	11,169	1,201
	4	28,992	0	28,992	2,399	18,997	0	18,997	619
	5	31,016	0	31,016	774	10,867	0	10,867	334
	6	31,712	0	31,712	4,795	4.332	0	4,332	198
	7	47,952	0	47,952	0	1,983	0	1,983	0
Paperboard	1	8,013	446	8,459	735†	7,796	429	8,225	649
	2	7,977	599	8,576	—	7,543	455	7,998	0
	3	8,434	0	8,434	933	5,407	1,967	7,374	682
	4	14,417	988	15,405	650	9,607	1,676	11,283	232
	5	11,730	0	11,730	580	4,028	0	4,028	0
	6	5,983	0	5,983	37	—	—	—	—
	7	365	0	365	0	—	—	—	—

* Non-integrated.
† "High waste paper" process.

Appendix F—*continued*

Product	Period (years)	Solution 1				Solution 2			
		Consumption			New capacity	Consumption			New capacity
		Domestic	Imported	Total		Domestic	Imported	Total	
Pitprops	1 (5)	624	384	1,008		582	426	1,008	
	2 (5)	439	0	439	Not applic.	0	439	439	Not applic.
	3 (5)	123	0	123		123	0	123	
th.cu.m.	4 (10)	—	—	—		—	—	—	
	5 (10)	—	—	—		—	—	—	
	6 (10)	—	—	—		—	—	—	
	7 (15)	—	—	—		—	—	—	
Intermediate products									
Waste paper used (Grade 1)	1	1,349	Nil	1,349		1,334	Nil	1,334	
	2	1,405		1,405	Not applic.	1,296		1,296	Not applic.
	3	1,414		1,414		1,150		1,150	
th. tonnes	4	0		0		0		0	
	5	0		0		0		0	
	6	0		0		0		0	
	7	0		0		0		0	
Waste paper used (Grade 2)	1	8,711	1,225	9,936		8,926	1,325	9,621	
	2	9,559	755	10,314	Not applic.	8,760	1,003	9,763	Not applic.
	3	10,189	404	10,593		8,580	784	9,364	
th. tonnes	4	21,248	0			14,046	0	14,046	
	5	19,888	0	19,888		6,905	0	6,905	
	6	15,706	0	15,706		1,516	0	1,516	
	7	17,064	0	17,064		694	0	694	
		CF	*BL*			*CF*	*BL*		
Mechanical pulp* (integrated)	1	182	700	882	244	182	511	693	177
	2	182	1,291	1,473	0	182	954	1,136	0
	3	182	1,278	1,460	0	182	940	1,122	0
th. tonnes	4	0	0	0	0	0	442	442	0
	5	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	0
Chemical pulp† (integrated)	1	230		230	Nil	230		230	Nil
	2	400	Not applic.	400		379	Not applic.	379	
	3	230		230		230		230	
th. tonnes	4	0		0		0		0	
	5	0		0		0		0	
	6	0		0		0		0	
	7	0		0		0		0	

* Excluding that used in newsprint.
† Excluding that used in fluting medium.

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