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An Economic Model for Comprehensive Regional Forest Assessments

A Case Study - some issues and considerations

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Abstract

The regional forest agreement process, as outlined in the National Forest Policy Statement, offers a consultative process whereby Australian governments can reach agreement on the long-term management and use of forests in a particular region. This process will include comprehensive regional assessments to evaluate the environmental, heritage, social and economic impacts of alternate forest uses. These assessments will assist policy makers to answer questions relating to trade-offs between often competing forest uses, industry development options and changes to forest product markets.

ABARE is developing a regional linear programming model of production forestry, incorporating the variables and relationships of an operating forest system. This model - FORUM (Forest Resource Use Model) - can be used to simulate the complex interactions between regional forest resources, wood based forest industries and final product markets using spatially dissaggregated data. FORUM may be used to provide decision makers with information on the regional impacts of proposed resource use or industry development options, including spatial analysis of proposed resource use options on the commercial value of forests and the net returns to the wood based industries.

In order to demonstrate the use of FORUM, a stylised case study of the forest product industries of the Bathurst region of New South Wales was chosen. This region has been assessed previously by ABARE and provides a good example of a forest region where the data are readily available to assess the validity of the model. The analysis focuses on the economic implications of policy or proposed resource use changes, including a change in the wood resource base; industry structure and a shift in world

prices for forest products. This paper contains a discussion of the development of the modelling framework and outlines some alternative approaches to its further development.

Introduction

Australia has around 40 million hectares of native forests with less than three per cent of these being plantation forests. About 30 million hectares are publicly owned and managed on a sustainable basis by State governments for the Australian community. (ABARE 1995). Since the late 1960s there has been a rise in broad based community sentiment for nature conservation with the use and management of Australia's public native forests receiving particular attention.

Three aspects of Australia's native forests have drawn particular public attention; the impacts of wood production on old-growth forests, wilderness values and the issue of whether there are adequate and representative samples of all major forest ecosystems in conservation reserves. The conflict over the allocation of public forest resources between competing uses also includes concerns over the adequacy of the decision making process to determine the socially optimal level and pattern of forest use (Industry Commission 1993). As a result, forests have been the subject of intense examination by governments, community groups, forest managers and the scientific community. From this, the integration of economic and conservation goals within a decision making framework based on the principle of ecologically sustainable forest use has become a priority (Commonwealth of Australia 1991).

The development of forest policy

State and Territory governments are primarily responsible for forest management and land use decisions in Australia. The Commonwealth government is responsible for meeting various international and domestic obligations relating to forests and forest product trade. A range of policy requirements relating to the National Forest Policy Statement (NFPS 1992) and the Inter governmental Agreement on the Environment (IGAE) have added further to the development of Australian forest policy. These requirements are described in the Commonwealth Regional Forest Agreement position paper (Commonwealth of Australia 1995a).

Past criticism of the processes under which forest land use decisions are made has led to the joint Commonwealth and State governments' decision to develop Regional Forest Agreements. This process involves the Commonwealth and States entering into an assessment and agreement on the use of forests within a specified region. The primary basis for the negotiation of Regional Forest Agreements will be a comprehensive assessment of the environmental, heritage, economic and social values of a specific region.

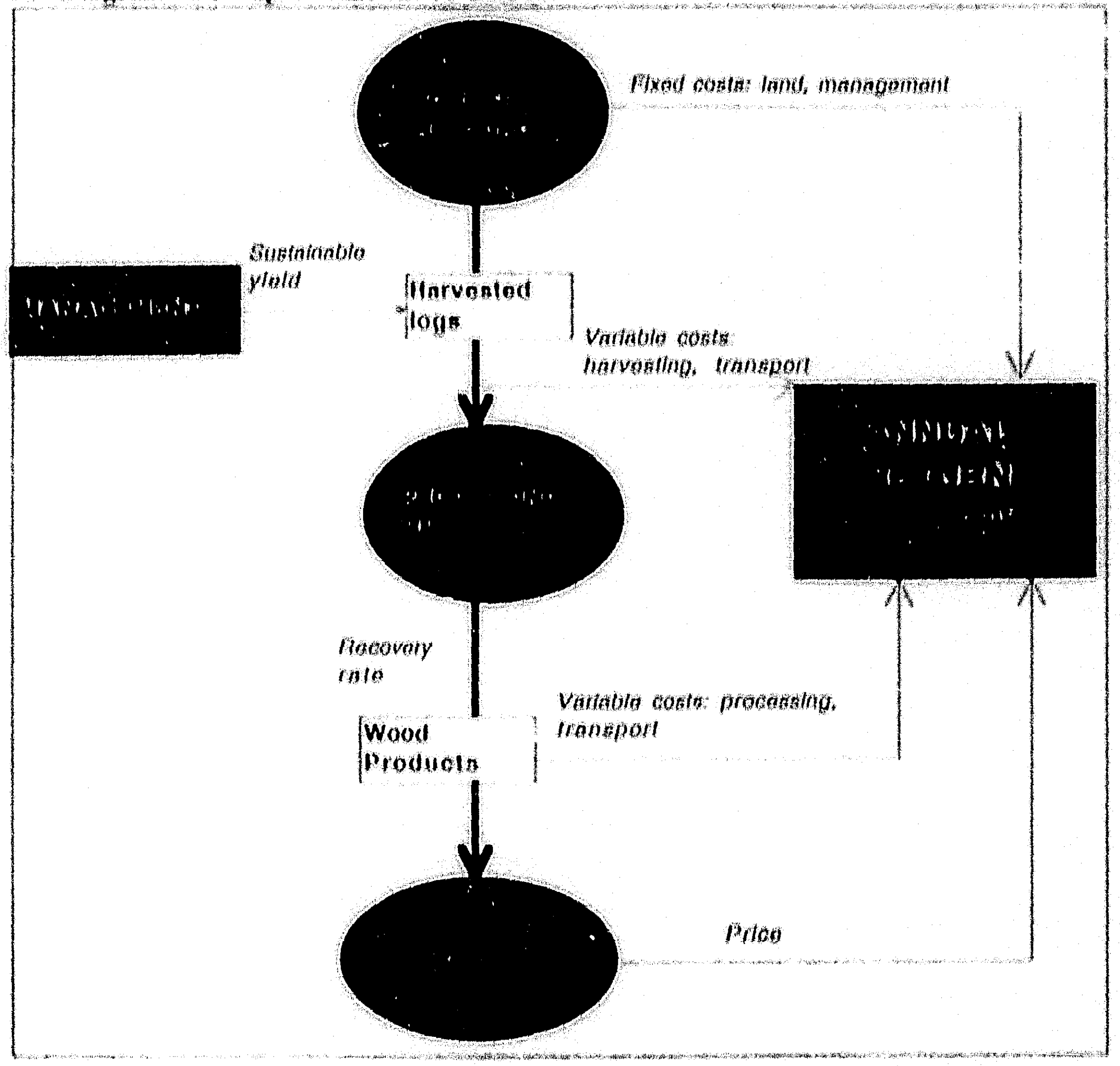
The Regional Forest Agreement process will generate a significant demand for information related to the long term economic interactions between forest resource use, forest industry structure and forest product markets. This information will be needed to answer policy questions relating to the economic costs and benefits of a range of possible forest use and industry development options for the forest region. ABARE has primary responsibility within the Commonwealth for collecting this information and undertaking necessary economic analysis (Commonwealth of Australia 1995b).

FORUM - A modelling framework

ABARE has been developing an economic model - FORUM (Forest Resource Use Model) - to simulate the resource use activities involved and the economic principles required for the analysis of forest use and industry development options. It is intended to assist in meeting the analytical requirements to answer policy questions that are likely to evolve out of the development of a Regional Forest Agreement. The modelling framework is designed to link the regional forests with wood based industries and associated forest product markets. The model is based on a partial benefit-cost framework and represents the economic and institutional features that determine management decisions within a given policy framework for the forest industry. It can be used to examine the potential impact of changes in management, prices or costs on both the profitability and structure of the forest industry. The model does not explicitly incorporate non market values, or any values associated with alternate land use options such as agriculture. However, the model can provide information on the valuation of forest land use for the wood based industries and hence the opportunity costs of alternative forest uses such as forest conservation and recreation (Neck, Stephens and Hansard 1995).

The structure of the model is shown in figure A. There are a number of distinct components – natural (the forest resource), institutional (management) and economic (revenue and cost structure of mills and markets). Together these components enable the model user to estimate the resource and economic outcomes for the forest industry under different management strategies. The model estimates a set of control variables that maximises the return to the forest subject to a set of constraints. In this study, the model was used to estimate the level of forest harvested, the level of output from each mill, and the quantity of each product sold at each market in order to maximise returns to growers given the prevailing resource availability and constraints imposed by the assumed industry structure and management.

A Diagrammatic representation of FORUM



The key methods used in the development of FORUM are discounted cash flow analysis, residual pricing and linear programming. Combining these methods allows a residual value for a forest to be established which reflects the maximum potential return to the forest owner subject to processing costs and product price regimes. For a given resource base, industry cost structure and market outlook, logs are allocated to processing sectors on the basis of the highest residual value until the constraints of processing capacity or the resource base yield are reached (Neck, Stephens and Hansard 1995). In this way, the flow of resources from alternative areas to processing industries can be identified over time. When the returns from these flows are calculated in each time period and discounted over time, a maximum net present value for the commercial use of the forest is obtained (in terms of using the forest to produce wood products). The commercial return to the forest owner will vary with the costs and prices associated with alternative resource and industry options examined.

The ability to spatially represent the allocation of wood resources is likely to be critical to economic analysis with the comprehensive regional assessment process. Spatial analysis will enable the determination of which regions face the greatest impacts of any changes to wood resources, market conditions or industry structure. FORUM is structured so that wood flows can be traced from forest to mill to market.

In this case study the objective was to maximise the annual land rent to the forest owner for the region. The annual value of land rent is fully defined in the appendix. It is a measure of revenue less all costs (including transport, mill processing, harvesting, and forest management costs). The model determines which wood flow path is most profitable on the basis of the land rent per unit of input. The per unit land rent is an estimate of the value of the wood on the stump (and is derived in the appendix) and represents the implicit price that would be received by the grower for the sale of the standing wood resource (Stephens et al, 1993). A different per unit land rent is obtained for alternative wood flows associated with each scenario. The model allocates logs to the wood flow path in each scenario that has the highest per unit land rent.

Although land rent to the forest owner is maximised in the model, it is not necessarily an indication of the profit to be made by any individual or group of individuals at any stage of the forest to mill to market process. Instead it represents the total potential rent created throughout the growing, processing and marketing chain. Profit is maximised at each stage of the chain and competition between participants ensures that only the underlying land rent in the system is obtained. The maximum amount investors could pay for available land for plantation development in perfectly competitive forest product markets is equivalent to the net present value of land rent. This is because all the revenue in excess of costs for harvesting, transporting, processing and marketing is assumed to accrue to the plantation investor (Stephens et al 1993). The study is based on a planning horizon of thirty five years, which corresponds with a plantation rotation over this period. The net present value of the resource is obtained by discounting the annual land rent over the plantation rotation of thirty five years.

Case study background

A key objective in undertaking this case study was to demonstrate the potential uses of FORUM for the comprehensive regional assessment process. The model identifies the economic impacts from proposed policy or resource use changes on a regional basis. The case study has also allowed an opportunity to validate the model using data from the Bathurst plantation region. The model results are validated against the results from this previous ABARE study of the Bathurst region of New South Wales (Stephens, Hansard and Dean 1993).

Resource

The Bathurst region is a typical example of the major softwood plantation development undertaken by State Governments during the 1960s and 1970s. The plantation resource in the region has largely been established by the New South Wales Government, although the area of privately owned plantations is increasing. Softwood plantations were first planted in 1920 and routine planting has continued annually. Annual plantings were increased in the 1960's and 1970's largely in response to Commonwealth government assistance under the *Softwood Forestry Agreement Acts*. The dominant plantation species is *P. radiata*, occupying 99 per cent of the total 60 900 hectares of publicly owned plantation area. Approximately 18 000 hectares of privately owned plantations also exist in the area, the majority of these managed by forestry investment companies. The average growth rates for existing forest management areas were based on the Bathurst Management Plan, and varied between 9 and 16 cubic metres per hectare per year (Forestry Commission of NSW 1987). The average yield calculated from this was assumed to be an uniform sustainable annual harvest for each forest area.

Industry

The Bathurst region presently supports a concentration of associated forest processing industries including a number of wood processing facilities geared to process softwood sawlogs and pulplogs. As the majority of the plantation resource is owned and managed by the State Forests of New South Wales, the forest processing industries have not been directly linked with the development of the plantation resource. Most of the logs are processed in the region by three mills, producing medium density fibreboard, particleboard and sawntimber. These mills utilise around 690 000 cubic metres of plantation sawlog and pulplog per year (Stephens et al 1993). Products from these mills are usually transported by road to Sydney to be sold in final markets or exported to other markets outside New South Wales.

For the purposes of this study, the potential use of the regions forests by new 'greenfields' mills is examined, which includes the processing of sawlogs into sawntimber and pulplogs into either particleboard, medium density fibreboard or newsprint. Estimated mill capacities and resource requirements for each of the 'greenfield' processing mills are presented in table 1. Processing options were based on new rather than existing mills as data were available for the new mills.

Table 1: Mill capacities for possible processing mills in the Bathurst region

Processing mill	Mill output (cubic metres/tonnes per year)	Mill resource requirement (cubic metres log per year)
	Final product	Pulplogs
Particleboard	90 000	139 500
Medium density fibreboard (MDF)	100 000	185 000
Newsprint	220 000	501 600
		Sawlogs
Sawntimber	260 000	637 000

Source Mill capacities are based on Forestry and Forest Products Industry Council (1990).

As in Stephens et al. 1993, these processing options are based on internationally competitive scale wood processing facilities for products that could be processed within the region. The cost of capital, operating and maintenance costs over the life of a mill is expressed as an average cost per unit of throughput at full capacity. Economies of scale are not considered, so that any increase in unit costs when mills are operating at less than full capacity is not considered. Further research to develop cost functions, dependent on the level of mill output, will be required, and is likely to be a major data input in the comprehensive regional assessment process.

International competitiveness

It is assumed that Australia's international competitiveness in the forestry sector is represented by the small country tradeable good model (Stephens, Hansard and Dean, 1993). In this model it is assumed that Australia is a country with no influence on import and export prices for forest products. If Australia is an efficient small trading country, then import and export parity prices for processed forest products will largely determine domestic prices, production, consumption and trade.

The adoption of the small country model also means that changes to the production of forest products within a region will not influence forest product prices in regional or international markets. All producers of forest products in a region are assumed to be price takers and all changes to market prices are a result of exogenous influences.

Model scenarios

Simulations

As discussed above, the evaluation of the Bathurst region using FORUM is based on cost and price data used in Stephe s et al. (1993). However, the FORUM model also includes spatially differentiated data on the forest resource, which is divided into forest management areas. Each forest management area has a distinctive set of yield and transport cost data, depending on site productivity and the geographic location of each management area with respect to processing mills. Growth data for forest management areas are based on the Bathurst management plan (Forestry Commission of New South Wales 1987), whereas Stephens et al. (1993) used the regional average. For transport costs from forest to mill, additional data on distance to mill were obtained from the Bathurst management plan and were used in the transport cost function estimated by Stephens et al. (1993). All data used are listed in the appendix.

An annual model of the forest region was constructed composing seventeen forest areas, three processing mills and a final product market. The three processing mills produce one product each, sawntimber, particleboard and medium density fibreboard (MDF) respectively. The product market was assumed to be located in Sydney. It was assumed that there was no temporal variation in resource availability or industry structure.

The study region represents a subsection of the forest resources covered under the Bathurst area management plan. The current supply of wood from the area studied is around 521 000 cubic metres of sawlogs and 253 000 cubic metres of pulplogs a year. This is significantly less than the potential total annual yield from the entire Bathurst management area of 900 000 cubic metres of sawlog and 439 000 cubic metres of pulplog (Stephens et al 1993). The total wood supply is less than that currently estimated for the region as a whole as the case study region only includes public plantation areas for which location and yield data were available. The studied region does not include private plantations which occupy approximately 18 000 ha. Also, the wood supply is based on resource data from 1987 (Forestry Commission of New South Wales 1987), and it is likely that planting rates for public plantations have since increased. As a consequence, the simulation results from this analysis may only demonstrate a part of the total return that may be gained from the resource of the entire Bathurst management area.

To illustrate the type of analysis that can be undertaken using FORUM, five scenarios were developed. The scenarios can be classified into three broad categories; changes in industry; the wood resource and market conditions. The assumptions of each scenario are described in table 2. Scenario A is the base case, which is most similar to the current forest processing situation in the region.

Changes in industry structure were examined in two scenarios. In scenario B, a newsprint mill located within the Bathurst region was added to examine the impact of alternative industry development on the allocation of wood to mills.

The distinction between an existing mill and a new mill is an important component of any economic analysis of industry structure within comprehensive regional assessments. The capital cost of new mills represents a significant component of total costs. However the capital cost of an existing mill will largely be sunk, with the salvage value of mill capital representing an opportunity cost. To examine the difference that capital costs create between the profitability of an existing mill and a new mill, the particleboard mill was assumed to be pre-existing rather than new in scenario C. The processing cost per unit was reduced to reflect a zero capital cost, indicating the mill has no salvage value. It was assumed that there were no higher costs with potentially less efficient processing methods of an older mill.

The impacts of a change in market conditions was examined in scenario D. The newsprint price was increased so that the impact of a change in market conditions on wood allocation and mill output could be examined.

The impact of a change in the wood resource was examined in scenario E. An additional forest management area was included within the region. The area was 18 000 ha (approximately the size of the private plantation resource) and was assumed to be located approximately 50km from the existing mills in the region. The yield of each log type from this area was assumed to be consistent with the average yield from the Bathurst region.

Table 2: Model scenarios

Simulation	Assumptions
ALL	Objective function is to maximise annual return (or value of land rent) All sawlogs harvested are processed into sawntimber. Sawmill residues are not considered All pulplogs harvested are processed into one or more of particleboard, MDF or newsprint A maximum forest supply of around 521 000 cubic metres of sawlogs and 253 000 cubic metres of pulplogs is in place - is binding in all simulations A maximum mill capacity constraint is in place (as per table 1) Each processing mill produces only one product type All output produced by mills is sold at either one of the two markets Transport costs from the forest is same for all mills except newsprint in Sydney
A	Base scenario: Three mills - sawntimber, particleboard and MDF
	Change in industry structure
B	Four mills - sawntimber, particleboard, MDF and newsprint
C	Four mills - sawntimber, particleboard, MDF and newsprint The particleboard mill is pre-existing - has a lower processing cost as capital costs are sunk
	Change in market conditions
D	Four mills - sawntimber, particleboard, MDF and newsprint A higher market price is used for newsprint
	Change in wood resource
E	Four mills - sawntimber, particleboard, MDF and newsprint A higher maximum forest supply of around 693 000 cubic metres of sawlogs and 337 000 cubic metres of pulplogs is in place - is binding for pulplogs only

In all the scenarios the objective was to maximise the annual value of land rent to the forest owner for the region. It was also assumed that all sawlogs harvested went to the production of sawn timber and all harvested pulplogs are allocated to the other mills.

Results

Given the assumed log supply in this case study, not all mills would be able to operate at maximum capacity, as shown in table 3. If the log supply limit was lifted the processing mills would be able to operate at greater capacity and therefore generate greater output. However, these volumes would not be sustainable without access to new additional forest resources.

Table 3: Estimated annual mill output under each scenario

Simulation	Mill output(m^3)			
	Sawntimber	Particleboard	MDF	Newsprint
A	212 588	44 069	100 000	na
B	212 588	44 069	100 000	0
C	212 588	90 000	61 475	0
D	212 588	0	0	111 140
E	260 000	90 000	100 000	5 560

Table 4: Estimated annual mill revenues under each scenario

Simulation	Mill revenue ($m)			
	Sawntimber	Particleboard	MDF	Newsprint
A	62.3	14.6	42.3	na
B	62.3	14.6	42.3	0
C	62.3	29.8	26.0	0
D	62.3	0	0	96.5
E	76.2	29.8	42.3	4.1

Estimated mill revenue (table 4) is calculated by multiplying the level of mill output by an estimate of mill door price per unit of output. The mill door price is estimated as the final market price for the product less the transport costs associated with getting the product to the market.

Table 5: Estimated value of land rent under each scenario

Simulation	Annual land rent ($m)	Net present value of land rent ($m)
A	32.4	378.6
B	32.4	378.6
C	36.9	430.2
D	37.5	437.0
E	38.7	451.0

The annual value of land rent (table 5) is fully defined in the appendix. It is a measure of revenue less all costs (including transport, mill processing, harvesting and forest management costs).

Discussion of results

The results of this case study were compared to those obtained by Stephens et al. 1993 (table 6). It can be seen from these results that in most cases the mills were operating at less than full capacity, largely due to the supply constraint mentioned earlier. In the base scenario the MDF mill was the most profitable pulplog based mill and reached its maximum capacity constraint, whilst the sawmill and particleboard mills operated at less than full capacity.

The effect of alternative industry structures was examined when the Bathurst based newsprint mill was added. Logs were allocated to the MDF mill followed by the particleboard mill, reflecting their relative profitability. This produced the same result as for the base scenario as in this scenario newsprint was the least profitable alternative for pulplogs and therefore no newsprint was produced. This result is consistent with the findings of Stephens et al. 1993, who noted that the option of supplying the domestic market with newsprint failed to produce a positive net present value.

Table 6: Case study outcomes

FORUM	Stephens et al. (1993)
MDF production generates greatest land rent	MDF production generated highest internal rate of return
Newsprint not produced under current price conditions	Newsprint failed to produce positive net present value - not internationally competitive under the most likely conditions

The impact of cost differences between existing mills and new mills was demonstrated when the particleboard mill was assumed to be pre-existing. The decrease in processing cost associated with the sunk capital cost of the existing mill meant that the particleboard mill became more profitable than the MDF mill. The newsprint mill was still the least profitable of the pulplog based mills. Hence, with no minimum mill throughput constraint, the particleboard mill operated at full capacity, the MDF mill at less than full capacity, and newsprint was not produced. The difference in wood allocation and mill profitability highlighted by the change to a pre-existing particleboard mill demonstrates the kind of issue that will be prevalent during the comprehensive regional assessment process. It will be important to analyse industry development options having due regard for the efficiency of existing mills.

The importance of market conditions was simulated by examining the impact of an increased newsprint price on log allocation and the value of land rent. The estimated annual land rent was increased when a higher newsprint price was introduced. Under this scenario logs were allocated to the most profitable production alternative, newsprint. Logs were no longer allocated to particleboard and MDF as they had a lower per unit land rent than newsprint. As the newsprint mill did not reach maximum capacity no logs were allocated to the other pulplog based mills.

The issue of resource availability was examined by the increase in the wood resource, and was most notable in its impact on mill output. With a higher log supply the sawntimber mill reached maximum capacity and not all sawlogs were harvested. Pulplogs were allocated to the most profitable mill, MDF, until it reached full capacity. Pulplogs were then allocated to the particleboard mill as the most profitable alternative. The log supply was large enough for both the MDF and particleboard mills to reach full capacity so that some pulplogs were also allocated to the newsprint mill.

Investment in the Australian forest product industries is subject to the usual commercial risks associated with large scale capital projects such as future costs, prices and interest rates, as well as the perceived risk or uncertainty associated with access to native forest resources. While the development of comprehensive regional assessments and regional forest agreements (RFAs) is likely to reduce the overall level of uncertainty regarding access to forest resources for wood production, there is likely to remain a degree of risk associated with any new investment decision.

In these circumstances, there are a number of approaches for dealing with risk in forest industry investment decisions or industry development proposals. These include the use of adjusted or higher discount rates to reflect the additional risk associated with the project; the use of sensitivity analysis to assess the robustness of a project subject to the estimated range of values for each uncertain parameter; and the use of stochastic investment analysis where the shape or distribution of uncertain values is known with some degree of confidence. The stochastic method of analysis has been used previously in the context of domestic forestry investment by Kirby, Sinden and Kaine (1993) and Stephens and Hansard (1994), where estimates of the range and likelihood of values for uncertain parameters are used to derive a range of results with their corresponding probability of occurrence.

ABARE is exploring all three approaches in the treatment of risk associated with forest industry investment proposals. Particular attention will need to be applied to the inclusion of sovereign risk aspects of forestry investments.

Direction for further research

FORUM is being developed to meet the demand for quantitative information in the context of comprehensive regional assessments of forest regions within Australia. The analysis in this paper was simplified and styled to be applicable to a case study region. Mills were assumed to produce single products and for average costs to equal marginal costs. The study was based on 'greenfields' mills with new scale and technology. It was also assumed that there was no temporal variation in resource availability or industry structure. Whilst these are significant simplifications of the circumstances to be encountered in undertaking comprehensive regional assessments, it has provided a basis to demonstrate the broad economic framework to be adopted.

The ability to determine whether a new or existing mill is more likely to operate under future options proposed as part of a comprehensive regional assessment will be an important feature of FORUM. There will be a period in the life of a mill where the operating and maintenance costs will be lower than the operating and capital costs of a new mill. Given that a new mill is likely to be more efficient and have lower per unit operating costs, there will be a point in time where maintenance costs for an existing mill will rise sufficiently for it to be more profitable to replace it with a new mill.

However, there is also an important distinction between the economic and financial profitability for mill owners. An existing mill owner may still be incurring some capital payments, and hence returns for financial viability may need to be higher than those required for economic viability - the latter being a competitive return to salvageable capital. If the existing mill owner owes money for capital, then the mill will need to more than cover operating costs for that owner to remain in front financially. The mill will continue to operate, either by the owner finding funds from other sources or by someone else buying the mill (at a lower price) and continuing the mill's operations. However, the financial and economic compatibility of industry development options, particularly their effects on existing owners, will be of particular concern in the comprehensive regional assessment process.

The model can simulate the use of forests by wood based industries and provide policy makers with insight into how these uses may be affected by various forest resource use options. Extensions to include full general equilibrium analytical capabilities are being explored. FORUM is a partial analysis of the forest sector from the supply of wood to final markets. It can be linked with general equilibrium models, such as MONASH (MONASH Impact Group 1994), to demonstrate broad economy effects of changes in forest resource availability, industry structure of market fluctuations.

At present FORUM is not intended to be a land use optimisation model which identifies all potential uses of forests and determines an optimal balance of those uses. Rather it offers a tool to evaluate the effects of alternate forest processing options for given forest resources under prescribed management regimes.

FORUM can be used to estimate the commercial returns that can be obtained from forestry operations in a particular forest area. Within the Regional Forest Agreement process, the commercial value that can be derived from a forestry operations in an area will also depend on other land use priorities, such as heritage and wilderness classifications. Hence the values calculated within FORUM will vary depending on how the forest areas are classified, and how the land is managed for alternative uses.

ABARE is continuing to assess a number of issues to increase the reliability of FORUM as an analytical tool in the Regional Forest Agreement process. These include approaches to emulate the behaviour of industry, and the relationships between industry cost structures, input, product mix and employment.

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Appendix

Mathematical specification of the model

The FORUM model is a linear programming model.

The specifications of FORUM used in the case study are given in this appendix. The coefficients used in the model are also presented. For simplification, variables are written in upper case and parameters are written in lower case. Subscripts are elements of the sets of forest areas, mills, markets, log types and final wood products. A summary of variable and parameter definitions is given in table 7.

Table 7: Variable and parameter definitions (Alphabetical order)

Sets	
$f \in F$	A regional forest in the set of all forest areas (a subset of I)
I	Locations - includes forest areas, mills and markets
K	A subset of I, all markets
$m \in M$	A mill in the set of all mills(a subset of I)
O	Inputs and outputs - includes log types and final product outputs
Parameters	
a_f	The size of forest area f ('000 ha)
$alpha_f$	The level of utilisation of the resource in forest area f (%)
hc_f	The cost of harvesting logs in forest area f (\$ / ha)
lc_f	The opportunity cost of land in forest area f (\$ / ha)
$lmax_{f,o}$	The maximum volume of log type o that can be harvested from forest area f ('000 m^3)
mc_f	The management cost of forest area f (\$ / ha)
$mmax_{m,o}$	The maximum capacity of mill m to produce product o ('000 m^3)
$mp_{m,o,k}$	The price received by mill m for sending product o to market k (\$ / m^3)
mr_m	The revenue received by mill m (\$)
$pc_{m,o,oo}$	The cost of processing log type oo into output type o at mill m (\$ / m^3)
$pr_{k,o}$	The price of product o at market k (\$ / m^3)
$rr_{m,o,oo}$	The conversion rate at which log type oo is processed into product type o at mill m
$tc_{i,o,ii}$	The cost of transporting product o from place i to place ii (\$ / m^3)
$ulr_{f,m,o,oo,k}$	The per unit land rent of log type oo in forest area f from producing product type o at mill m and selling it at market k (\$ / m^3)
Variables	
$FY_{f,o}$	The quantity of log type o harvested at forest area f (000 m^3)
$RENT$	The annual value, or land rent, of the forest resource
$MD_{k,o}$	The quantity of product o sold at market k ('000 m^3)
$MI_{m,oo}$	The quantity of log type oo used as input to mill m (000 m^3)
$MO_{m,o,oo}$	The quantity of log type oo processed into output type o at mill m (000 m^3)
$QT_{i,o,ii}$	The quantity of product o transported from place i to place ii (000 m^3)

The objective function in this case study was to maximise the total return to the forest sector as a whole. The annual level of land rent is defined by:

$$(1)\qquad RENT = \sum_{k\in K}\sum_{o\in O} pr_{k,o}MD_{k,o} - \sum_{i\in I}\sum_{o\in O}\sum_{ii\in II} tc_{i,o,ii}QT_{i,o,ii} - \sum_{m\in M}\sum_{o\in O}\sum_{oo\in OO} pc_{m,o,oo}MO_{m,o,oo} - \sum_{f\in F}\sum_{o\in O} hc_f FY_{f,o} - \sum_{f\in F} mc_f a_f - \sum_{f\in F} lc_f a_f$$

where $MD_{k,o}$ is the quantity of each product sold at each market or market demand, $pr_{k,o}$ is the final market price for each product, $QT_{i,o,ii}$ is the quantity of either log type or final product transported from forest to mill or mill to market, and $tc_{i,o,ii}$ is the associated cost of transporting this volume. $MO_{m,o,oo}$ is the quantity of each final product produced from each log type at each mill, and $pc_{m,o,oo}$ is the mill cost of processing those final products. $FY_{f,o}$ is the quantity of logs harvested from each forest area, hc_f is the harvesting cost in each area, mc_f and lc_f are management and land costs per hectare respectively and a_f is the total area of each forest.

A number of constraints are imposed on the model. The first two ensure that mill output equates with forest outputs. The level of mill output is determined by the quantity of log inputs and the recovery rate for each mill. This is the rate at which log inputs are converted into final products. Mill output is given by:

$$(2)\qquad MO_{m,o,oo} = MI_{m,oo}rr_{m,o,oo}$$

where $MI_{m,oo}$ is the quantity of log inputs at each mill, and $rr_{m,o,oo}$ is the recovery rate or conversion factor for each mill. Equation 3 ensures that the quantity of logs harvested is equal to the volume of log inputs at each mill.

$$(3)\qquad \sum_{f\in F} FY_{f,o} = \sum_{m\in M} MI_{m,o}$$

A further constraint ensures that the level of mill output is equal to the amount of product demanded at market and is given by equation 4.

$$(4)\qquad \sum_{k\in K} MD_{k,o} = \sum_{m\in M}\sum_{o\in O} MO_{m,o,o}$$

Constraints are imposed such that the mills operate within capacity constraints. The level of mill output must be no greater than the maximum capacity of the mill, $mmax_{m,o}$, as given in equation 5.

$$(5)\qquad mmax_{m,o} \geq \sum_{oo\in OO} MO_{m,o,oo}$$

There was also a constraint on the amount of logs that could be harvested from each forest area. The forest yield had to be no greater than the total volume of logs in each area, $lmax_{f,o}$, multiplied by the level of resource utilisation, α_f. This is assumed to be level of sustainable harvest each year in each land unit, and is given by equation 6.

(6) $$FY_{f,o} \leq \alpha_f l\max_{f,o}$$

A number of transport constraints were imposed to ensure that the volume of outputs transported was equal to the actual level of output from each sector. Equation 7 ensures that the volume of wood harvested is transported to a mill.

(7) $$YF_{f,o} = \sum_{m \in M} QT_{f,o,m}$$

The level of log inputs to each mill has to equal the quantity of wood transported from all forest areas, as given by equation 8.

(8) $$MI_{m,o} = \sum_{f \in F} QT_{f,o,m}$$

The quantity of final products produced by each mill must be equal to the quantity of product transported to all the markets, as shown in equation 9.

(9) $$\sum_{oo \in OO} MO_{m,o,oo} = \sum_{k \in K} QT_{m,o,k}$$

Finally, the quantity of product sold at each market must be equal to the quantity of products transported from all mills, as determined by equation 10.

(10) $$MD_{k,o} = \sum_{m \in M} QT_{m,o,k}$$

A number of parameters were determined exogenously to the model once the optimal solution had been determined. The domestic mill door price, $mp_{m,o,k}$, is the price received by the mill for each unit of mill output. It is calculated by subtracting the transport cost from mill to market from the final market price for that product, and is given in equation 11.

(11) $$mp_{m,o,k} = pr_{k,o} - tc_{m,o,k}$$

The level of mill revenue, mr_m, is then simply determined by multiplying the mill door price by the quantity of product output from the mill. The level of revenue for each mill is given by equation 12.

$$(12) \qquad mr_m = \sum_{k \in K} \sum_{o \in O} \sum_{oo \in OO} mp_{m,o,k} MO_{m,o,oo}$$

Finally, an estimate is made of the per unit land rent, $ulr_{f,m,o,oo,k}$. The per unit land rent is given in equation 13 is calculated by subtracting all costs from the mill door price. The recovery rate is used to convert the price from a per unit of output to a per unit of log input base.

$$(13) \qquad \begin{aligned} ulr_{f,m,o,oo,k} = {} & (mp_{m,o,k} - pc_{m,o,oo})RR_{m,o,oo} - tc_{f,o,m} \\ & - hc_f - mc_f - lc_f \end{aligned}$$

Data used in the model

All data used in cost figures is derived as a cost per cubic metre of log input. The only exceptions are for management and land costs which are derived on a per hectare basis. The latter costs are calculated as an annuity over the thirty-five year life of the plantation and are deducted as an annual cost on a net present value basis. A real discount rate of 8 per cent, as used in Stephens, Hansard and Dean 1993.

Table 8: Generic cost data

Parameter	
Harvest cost ($ / m^3)	22
Land cost ($ /ha). a	70
Management cost ($ / ha). b	277

a: Land cost is annuitised cost of land as in Stephens et al (1993) for a 35 year rotation.
b: Management cost includes the annuitised value of establishment, thinning, roading, pruning, clearfell and maintenance costs contained in Stephens et al (1993) for a 35 year rotation.

Table 9: Mill cost data

Mill	Transport cost to domestic market ($ / m^3)	Processing cost ($ / m^3)
Sawntimber	28	85
Particleboard	18	200 a
MDF	25	223
Newsprint (from Bathurst)	25	591
Newsprint (from Sydney)	0	591

a: Processing cost for existing particleboard mill is $132/m^3

Table 10: Mill physical data

Mill	Recovery rate (log to product)	Maximum capacity ('000 m^3)
Sawntimber	0.408	260
Particleboard	0.645	90
MDF	0.541	100
Newsprint	0.439	220

Table 11: Market price data. a

Product	Domestic price ($ / m^3)
Sawntimber	321
Particleboard	349
MDF	448
Newsprint	758
Newsprint (higher price)	893

Table 12: Forest land unit data

Forest management area	Area ('000 ha)	Max log yield ('000 m^3)- pulplog	Max log yield ('000 m^3)- sawlog	Transport cost to local mills. a ($ / m^3)
1	3.028	14.357	29.549	5.94
2	2.490	13.435	27.650	4.27
3	0.570	3.075	6.330	3.23
4	0.898	4.570	9.407	3.75
5	13.751	72.187	148.568	5.73
6	9.801	52.197	107.427	6.57
7	0.196	1.058	2.176	6.46
8	8.017	36.013	74.119	7.09
9	4.963	24.441	50.302	5.11
10	0.581	3.135	6.452	6.67
11	1.899	5.601	11.528	10.01
12	3.816	20.589	42.375	14.59
13	0.937	5.056	10.405	14.91
14	1.821	5.371	11.054	14.70
15	0.504	2.719	5.597	12.09
16	0.293	1.389	2.859	13.24
17	0.273	1.299	2.674	13.86
18	18.000	88.290	181.710	7.40

Source: Stephens et al (1993); Forestry Commission of New South Wales (1987).