THE EVOLVING ECONOMICS OF LONG-TERM FOREST PLANNING

by

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DECLARATION

Except where otherwise indicated, this thesis is my own work. The Monte Carlo analyses in Chapter 6 were done in close collaboration with Mick Common.

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ABSTRACT

Public forest management has become increasingly complex and controversial in many parts of the world. This study deals with the application of the economic principles of allocative efficiency on the practical problem of long-term forest planning. The relevant economic theory is examined. How public forest agencies actually plan is reviewed, revealing very little use of analytical, quantitative tools that include consideration of intertemporal efficiency. An application of the US Forest Service's FORPLAN (FORest PLANning) model to an Australian forest illustrates the utility of the quantitative approach to planning. FORPLAN can, in principle, include consideration of un-priced forest goods and/or services. It is shown that perfect information on either biological economic values is not necessary to help inform public debate on forest management. For example, the management of old growth forest in Australia is particularly controversial because of its importance to some wildlife species and perceived wood values. Conservation groups want those forests left unharvested while the wood processing sector wants to maintain access to them. Empirical analysis shows that the old growth forest, in the region studied, is actually less valuable for its wood resources than the surrounding younger forest. These results are not always immediately obvious without some form of quantitative analysis.

A major difficulty in forest planning arises in accounting for many of the inherent uncertainties. The implications of various types of uncertainty on policy development can be investigated using Monte Carlo techniques. Two examples are presented. One refers to the development of stumpage price expectations for planning and the other to the application of hedonic pricing for willingness to pay (WTP) for forest preservation estimates. An application of Monte Carlo simulation techniques in the context of a hedonic travel

cost approach to obtain WTP for forest preservation estimates showed incorrect answers are highly likely, even in situations of good data availability.

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CHAPTER 1

INTRODUCTION

1.0 Introduction

The management of public forests is a complex and controversial business. There are a number of reasons for the complexity. Firstly, the biological systems which comprise forests are capable of producing, directly and indirectly, a wide range of goods and services of interest to humans. The outputs, or potential outputs, include wood, water, wildlife, a myriad of non-commercial flora and, various sorts of recreational opportunities. Generally, the biological systems are poorly understood even in developed countries. Secondly, valuing all the potential outputs is profoundly difficult. Few forest resources are traded in markets such that acceptable social valuations, from an economic perspective, are easily obtainable. A third complicating factor is the intertemporal nature of forest management. Forests can produce a flow of goods and services through time. Thus, any forest management plan has numerous explicit or implicit assumptions about current and future physical and social values. Zivnuska (1961) made a similar characterisation of the difficulties of forest management almost 30 years ago:

> A basic problem to be faced is the very low level of knowledge of the physical relationships and values and costs involved in the various uses which can be made of forests and wildlands.

Controversy in forest management arises out of the incompatibilities, or perceived incompatibilities between different forest uses. In Australia, forestry issues often dominate the news media's environmental agenda. The Resource Assessment Commission (RAC), an independent statutory authority recently established by the Commonwealth Government (*Resource Assessment Commission Act* 1989) to investigate natural resource management issues, has been instructed to make forestry its first topic of inquiry. According to the Act (Schedule 1, #2):

> Resource use decisions should seek to optimise the net benefits to the community from the nation's resources, having regard to efficiency of resource use, environmental considerations, ecological integrity and sustainability, ecosystem integrity and sustainability, the sustainability of any development, and an equitable distribution of the return on resources.

The RAC inquiry into forestry will attempt to identify and evaluate options for the use of Australia's forest and timber resources (RAC, 1990).

This thesis deals with the problem of public sector forest management planning when there is concern for multiple-uses and intertemporal economic efficiency. In the light of the establishment of the RAC, the relevance of this thesis is clear. The following section gives a brief historical perspective on multiple-use forest management and describes the goals of the thesis. Section 1.2 describes the organisation of the thesis.

1.1 Background and General Goal of the Thesis

Before proceeding, a definition of multiple-use should be provided. The definition given by the Victorian government (Australia) in its Timber Industry Strategy is sufficient to illustrate the potential ambiguities involved:

> ... (multiple-use is) determining the best combination of products or uses, in a way that best serves the interests of the community. The best combination of uses will depend on the interrelationships between uses, all of which should be considered when multiple-use decisions are being made. (Victoria, 1986)

What are the "interests of the community"? How does one determine the "best combination of uses"? What should be done when the "interrelationships between uses" are poorly understood and highly uncertain? How are conflicts of interest between different sections of the community to be resolved?

As a workable concept in forestry, multiple-use has remained controversial. An editorial in the *Journal of Forestry* in 1943 identifies the problem facing foresters that is applicable today. Foresters, given the remit of multiple-use, need to consider and coordinate

> ...timber management, wildlife management, range management, watershed management and recreation management that will result in the optimum production of different values.

That some uses and values compete and others complement each other has been well-recognised. Clawson (1975) provides a useful qualitative summary of various forest use compatibilities. Such an approach can help to identify and clarify, at a broad level, various land-use options.

Foresters have tended to advocate zoning solutions to multiple-use problems whereby lands are allocated for a particular purpose (Webster and Hacker, 1986; Strang, 1983; Stout, 1983, Pearson, 1944) and in practice this seems to be what has occurred (eg. parks, reserves, protected water catchments). This approach promotes specialisation in land use, albeit in a potentially arbitrary fashion, rather than attempting to manage forests for varying levels of compatible outputs. Overlay mapping techniques and the relatively recent development of sophisticated geographic information systems can be used to assist in zoning problems. However, without consideration of costs and benefits, zoning outcomes may result in inefficient land allocations.

Early economic forays into the problem of multiple-use suggested the development of iso-cost and iso-revenue curves (Gregory, 1955) and product transformation curves (Muhlenberg, 1964; Pearse, 1969) to examine the trade-offs between competing forest outputs. Convery (1977) discusses the economics of multiple-use more formally from the perspective of a multi-product, multi-factor firm under conditions of perfect and imperfect competition. Besides the information problems mentioned at the outset, this sort of economic approach could result in arbitrary cost allocations because of the joint supply nature of many forest outputs (Hof *et al.*, 1985; Bowes and Krutilla, 1979). Since cost allocations influence efficiency, management strategies may end up being arbitrarily biased. Chapter 2 of this thesis reviews the economics of forestry in detail.

Many of the difficulties of public forest management suggest the desirability of making land management objectives explicit. Making objectives explicit should reveal many of the hidden preferences of individual resource managers and thereby perhaps force more justification of their decisions. The perspective taken in this thesis is that the tools of economics can provide an internally consistent and systematic means to investigate, though not necessarily solve, multiple-use planning problems even when there is only limited information available. Such an approach could help clarify objectives by explicitly identifying some of the trade-offs involved in alternative management strategies.

The general goal of this thesis is therefore to examine the application of the principles of economic analysis to the problem of long-run public forest management planning. It should be noted that this is not a thesis solely about economics. It is a thesis about the practical application of economic logic to multiple-use forestry. Like the nature of the management problem itself the thesis has multiple objectives that entwine the general goal stated above. These are as follows:

- to identify and review the economic principles of relevance to public forest planning;
- to place the economics literature in perspective by examining the stated goals and current planning practices of numerous public forest agencies;
- to demonstrate the utility of a quantitative economic approach to forest planning via a case study of multiple-use planning in a native forest in Victoria, Australia. This sort of case study analysis has not previously been performed in Australia;
- to examine the literature on the demand for forest products with a view to identifying its relevance to long-run forest planning;
- to identify some implications of uncertainty for forest planning and economic analysis using Monte Carlo techniques.

1.2 Organisation of Thesis

The thesis is divided into this introductory chapter, five major chapters, and a final concluding chapter. Chapter 2 reviews theoretical developments in the economics of forestry. Economics here is taken to mean the problem of determining and realising intertemporally efficient resource allocations. The chapter includes a discussion of why intertemporal efficiency is a useful objective for public forestry and an articulation of how economists attempt to value non-priced goods. The goal of the chapter is to identify the relevant economic principles in a consistent fashion, since it is the framework for the subsequent analysis.

Chapter 3 attempts to determine what public foresters actually do in practice. This is achieved by examining the relevant legislation, bureaucratic guidelines and, planning methods of a number of public forest agencies in North America and Australia. The chapter also identifies the major impediments, perceived and actual, to the use of the economic principles identified in Chapter 2. The goal here is to substantiate the view that various tools of economics are relevant to the needs of public forest planners. The practical application of economic logic is considered in the case study.

Chapter 4 identifies and describes the data and problem formulation for the case study. Forest policy developments in Victoria, Australia, appear to make the State a prime candidate for the study of the use of advanced planning techniques including the use of economic analysis. A recent multiple-use planning project initiated by the State's forestry authority attempted to use the United States Forest Service FORPLAN (FORest PLANning) model to assist in the project. The case study stems from the project but is not itself a part of it. However, the case study uses FORPLAN as the major analytical tool so Chapter 4 includes a description of FORPLAN.

Chapter 5 describes the results of the case study analysis using the FORPLAN model. Due to the wide range of uncertainties involved, sensitivity analysis can play an important role in forest planning. The management implications of many uncertainties, including timber yields, costs and, future stumpage prices are considered in the chapter. The results demonstrate how a quantitative approach, including economic considerations, can be used to clarify some of the trade-offs between wood and non-wood values even in a situation of limited data.

As mentioned earlier a major problem in multiple-use planning is the derivation of an intertemporal stream of prices or values for forest resources. The forest economics literature has tended to ignore this problem. In an important analysis comparing potential wood values to inferred non-wood values on public forests in the U.S., Berck (1979) makes the point that uncertainty in demand is one of the most worrisome points in forest planning:

> Will wood alcohol be a major fuel source in 2000, thus increasing demand in an unforeseen fashion, or will - much to the contrary - fusion power be free, radically decreasing the price of aluminium and the demand for timber?

Chapter 6 is divided into three major sections. The first section examines the literature on the demand for forest products. The results indicate the limited applicability of that literature's suggestions to intertemporal multiple-use planning. To help elicit a clearer picture of the intertemporal valuation problem a Monte Carlo approach to developing stumpage price expectations is presented in the second part of the chapter. Results of the simulation are used in the case study FORPLAN model to examine some implications of price uncertainty on planning. Despite the specific applicability of the numerical results to the case study, the approach itself and the implications of the results are a more general contribution to forest economics. The third section of Chapter 6 is primarily devoted to the presentation of a Monte Carlo version of a simple hedonic travel cost model. The model is used to clarify the uncertainties involved in estimating willingness to pay for forest preservation. The results suggest hedonic pricing techniques should be applied cautiously in actual planning exercises. The likelihood of getting "wrong" answers from such applications for policy development appears high. Monte Carlo techniques allow analysts to actually control the quantitative dimensions of uncertainty. Policy implications can therefore be derived which are relevant to real world situations. It also means that attention does not have to be restricted to situations where definite analytic results in statistical inference are available, or can be derived.

Chapter 7 summarises the thesis and presents the conclusions about the use of economic logic and quantitative analysis in forest planning.

CHAPTER 2

THE EVOLVING ECONOMICS OF FORESTRY

2.0 Introduction

This thesis is concerned with the extent to which public sector forest management agencies can use economic principles and analysis as an operational guide for multiple-use planning. In this chapter the economic theory applicable to multiple-use planning by public sector forest management agencies is reviewed. The objective here is not the development of new theoretical insights, nor is it a totally comprehensive review of forestry economics. Rather, the intention is to provide an account of what economic theory has to say about public sector forest management principles and how the theory can be operationalised to improve forest planning.

Section 2.1 reviews important cost-benefit rules for public sector forest management. Section 2.2 discusses the economic valuation of forest outputs and managerial inputs. Section 2.3 examines the economics of forestry from a single stand perspective. Section 2.4 examines the economics of multiple-use forestry where stand interdependencies may exist. Interdependencies exist when the benefits of goods and services from one stand are affected by the condition of other stands within a forest. This is an important perspective for many non-wood values in forests. Section 2.5 explains the standard linear programming approach to multiple-use forest planning.

2.1 An Overview of Efficiency and Cost-benefit Analysis

Natural resource planning ultimately involves decisions about investment, extraction and asset management. Economic theory shows that given certain conditions market clearing equilibria represent efficient allocations (Bohm, 1973). The important conditions include the absence of external effects and public goods, a "sufficient" degree of information about prices and, competition existing among many producers who are profit maximisers and consumers are utility maximisers (all individual agents will therefore act as price takers). Efficient outcomes are called pareto optimal by economists: they imply that no individual can be better off without another individual being worse off. It is a standard result that different pareto optimal conditions can arise from different income distributions. Economists typically leave the issue of income distribution to politics. Note that the perception of efficiency as being in the public interest requires adherence to an individualist ethic - that is individuals are their own best judge of what is good for them. Social values are judged only by the preferences of individuals. Also, by its very nature, economic theory is anthropocentric.

In a world where time exists, consumers and producers are faced with current decisions which will affect their future well-being. Producers will utilise current resources or borrow money at the market rate of interest to produce goods through time such that their rate of return on marginal investments equals the market rate of interest. Similarly, consumers have the choice of saving or borrowing at the market rate of interest. If market rates of interest are determined the way equilibrium commodity prices are, that is, investment demand equals supply (savings), then pareto optimality will exist through time (Bohm, 1973). It follows then, that as long as producers are profit maximisers and consumers are utility maximisers, in a perfect market economy intertemporal efficiency will result. All assets will be earning an equal rate of return. No reallocation of the total economy's investments could increase that return. When rates of return do differ between assets, market incentives will result in a reallocation of investments which will eventually equalise returns. So, given certain assumptions forestry enterprises maximising the value of their assets will serve a particular notion of the public interest - intertemporal efficiency.

It should be made explicit that the assumptions of a perfectly operating market economy are not necessarily descriptive of the real world. However, it does not follow that the criterion of intertemporal efficiency is of no relevance to the world we live in. It provides an ideal against which to consider actual outcomes in real world economies and to inform policy. In the real world, economies do not always operate according to economic theory. For example, if "sufficient" information and fully competitive markets do not exist, prices will not reflect proper social valuations. In some instances market failure may be due to institutional structures set up by governments that affect individual behaviour. Also external effects, both positive and negative, are associated with many economic activities. Public goods, in the sense that each unit cannot be consumed by only one consumer, are prevalent in most societies (eg. national defence, the existence of wilderness). Prices for these sorts of services cannot be determined by usual market mechanisms (Bohm, 1973).

To this point some results of capital theory have been briefly summarised. Chapters 6 and 7 of Common (1988) cover the main ideas and applications to natural resources in an introductory non-mathematical way. More rigorous treatments of capital theory in general are given by

Burmeister (1980) and Henderson and Quandt (1971). Bohm (1973) presents an excellent, concise treatment of efficiency in perfect and imperfect market conditions and a useful review of the principles of cost-benefit analysis. The relevance of much of natural resource economics theory cannot be appreciated without an understanding of the notion of efficiency.

Cost-benefit (CB) analysis provides a basis for decision making that has its roots in investment theory. Foresters from public agencies do not appear to have widely accepted and utilised cost benefit analysis as a decision making paradigm for forestry problems involving intertemporal consequences. One reason for this is probably a lack of appreciation of the notion of economic efficiency with respect to multiple-use forest management. A concern is that cost-benefit analysis ignores forest values that are not priced. However, un-priced values can, in principle, be included in CB analysis. A major problem lies in somehow quantifying measures for the less tangible forest outputs or services.

Basically, CB analysis provides an internally consistent framework to compare economic states in an economy. Note that none of the states need necessarily be economic optima due to market failures (Lesourne, 1975). The most general criterion for profitable, thence socially worthwhile investments, is that the discounted or present value of all revenues less all costs occurring through time be greater than or equal to zero. CB analysis should account for not only the direct effect of projects to the economy, but also external effects and if desired the implications on public goods. There are a number of texts which comprehensively review the principles and procedures of CB analysis (Sugden and Williams, 1978; Sassone and Schaffer, 1978; Dasgupta and Pearce, 1972; Mishan, 1977; Pearce and Nash, 1981).

The salient features of CB analysis are summarised below:

1. quantification - the identification and measurement of the costs and benefits in physical terms;
2. valuation - attaching social values to the physical effects of a project or projects;
3. discounting[1] - determining the relevant discount rate (rate of return) for the economy when evaluating time flows of cost and benefits;
4. constraints - determining the relevant social constraints for consideration in the analysis;
5. uncertainty - determining how to incorporate future physical and economic uncertainties into the analysis;
6. criterion - identification of the appropriate criteria for the evaluation (eg net present value, internal rate of return, benefit-cost ratio).

The type of cost-benefit analysis of interest here is the evaluation of various forest management strategies inclusive of wood and a range of non-wood values. There are few cost-benefit analyses in the published literature examining the multiple-use problem. In a survey article Bowes and Krutilla (1985) cite just one, and comment that "this is hardly surprising given the difficulties of valuing amenity services" (p.540). Most non-wood (amenity) outputs are not allocated by means of markets so prices for them do not exist. It is also the case in Australia that

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1. Much controversy exists in the economics profession on the determination of the appropriate discount rate to use when evaluating the costs and benefits of public projects (Lind *et al.*, 1982). Rather than enter this debate, sensitivity analysis on the effects of different discount rates are considered when examining the long-term costs and benefits of multiple-use forestry in the case study.

stumpage (standing trees) is allocated and priced bureaucratically so that we cannot be sure stumpage prices (fees paid by wood processors for standing timber) reflect proper social valuations by standard economic criteria.

The rest of this chapter examines economic theory of direct relevance to multiple-use forestry more thoroughly.

2.2 The Valuation of Forest Outputs and Forest Management

2.2.1 Categorising the Benefits of Forests

In economic theory something has value if it generates utility for a person either directly or indirectly. Economists do not examine how a person's value system has been derived. The main issue is whether utility is generated by some service or perceived service. With respect to natural resources a number of values have been conceptually defined and summarised by Randall and Peterson (1984). The categories generally include use value, option value, and existence value.

Use values are derived from some form of physical use of a resource for personal benefit. Use benefits could arise from a tangible priced good (eg. wood from a forest) or an unpriced good or service (eg. air).

Option values are linked to use values in the sense that management of a resource may need to be modified to account for possible future use. In other words, current value structures may include the desire to ensure the option of future use and/or future availability of a good or service. This category of value is particularly important in situations where extinction of a species or irreversible changes to a unique natural system may occur. Krutilla and Fisher (1975) provide other examples of this type of value in a forestry context.

Existence values are generally tied more to philosophical notions of altruism and the intrinsic worth of species or natural systems. There is an increasing literature on empirically derived existence values, their definitions and their use in benefit-cost analysis (Brookshire *et al.*, 1983; Walsh *et al.*, 1984; Peterson and Sorg, 1987). Brookshire *et al.* (1987) suggest that existence values are tied closely to "personally-held ethics" and as such, often represent moral commitments which cannot be tied to notions of efficiency. According to them, inclusions of existence values in benefit-cost analysis, which by definition uses efficiency as the decision criterion, could therefore cause problems. However, it can be argued that moral commitments are an integral part of individual utility functions and are therefore directly related to efficiency. Perhaps some existence values may rank lexicographically ahead of marketed priced goods. However, even in this case CB analysis can still be a justifiable tool to determine the opportunity cost of policy options, like removing a forest from timber production. Resource managers are often faced with such all-or-nothing choices.

Randall and Peterson (1984) summarised the major categories of wildland benefits. Figure 2.1 is a reproduction of the major characteristics of their chart. It identifies various linkages between natural resources and consumer benefits. Other than wood and minerals, and in some rare instances range forage and water, most resources that are associated with forested land are not priced through economic markets. Economists, in trying to quantify the value of non-marketed commodities and/or services, have developed techniques for estimating the economic value of un-priced goods or services. Before reviewing those techniques, the value of wood from forested lands will be discussed.

Figure 2.1: Major categories of wildland benefits

Wildlands resources	Beneficial product or services	Direct or derived	Human Demands User Demand Location	Typically priced in the market	Option and existence value significant?
Wood	Lumber, paper	derived	off-site	Yes	No
Mineral deposits	Minerals	derived	off-site	Yes	No
Range forage	Livestock products	derived	off-site	Yes	No
Water	Water for downstream use	direct, derived	off-site	No	Maybe
	Flood protection	direct, derived	on-site, off-site	No	Maybe
Wildlife populations	Recreation	direct	on-site & vicinity	No	Maybe
Habitat				No	Yes
	Ecological continuity	direct, derived	on-site, off-site	No	Maybe
Landforms				No	Maybe
Atmospheric visibility	Scenery	direct	on-site & vicinity	No	Maybe
Biological processes	waste assimilation	direct derived	on-site off-site	No	Maybe

Source: Randall and Peterson, (1984)

2.2.2 The Value of Wood Resources

Ultimately stumpage values result from both supply and demand forces. The demand for stumpage is derived from the demand for consumer products it helps to produce (eg. timber, pulp and paper products). Final product demands are influenced by the price of the product and its substitutes, income levels and consumer tastes and attitudes. The value of stumpage to a particular processor tends to be influenced by a number of factors including: tree diameter, logging method employed, terrain, sometimes weather conditions, average volume per hectare harvested, haul distance and forest regeneration method or other forest management restrictions in so far as they affect harvesting costs (Jackson and McQuillan, 1979). Citing earlier work, Jackson and McQuillan (1979) suggest that stumpage value increases at a decreasing rate as a function of tree size. Per unit volume felling, bucking, skidding and loading costs decrease with increasing diameter while value at the mill increases due to lower per unit handling costs and higher (potential) end product value.

In the private sector, stumpage price is an important short-run factor affecting a landowner's decision to harvest. If the stumpage price is greater than their own reservation price and the short-run costs, ie. administration, appraisal and perhaps road-building costs, then owners can harvest and make a short-run profit (Hyde, 1984). The reservation price may be related to non-wood objectives entering the landowner's utility function. Non-wood values aside, whether forests are managed on a renewable basis for wood production depends on stumpage price expectations through time exceeding the costs of growing the crop.

Public sector forest managers do not generally operate with market driven motivations. Most public forest agencies are given the mandate to account for wood and non-wood values in their management practices. Wood production is typically based on the concept of an annual harvest equal to the maximum sustained physical yield (MSY) of the forest. In foresters' jargon timber harvesting occurs at the culmination of mean annual increment of wood volume growth. This modus operandi appears to be based on eighteenth century European traditions that may have been a reasonable response to biological and economic conditions of the time (Hyde, 1981). A later section shows that the MSY model of forest management requires particular assumptions for it to be the optimal economic management regime for either wood or non-wood values. Only by accident will it account for the un-priced forest values that public agencies rightly attempt to manage for.

The derivation of stumpage value requires an understanding of the notion of economic rent as it applies to forest land. While many definitions of economic rent have been suggested, a simple interpretation is that it is the payment to the owner of a unit of a factor of production in excess of the opportunity cost of that unit. Opportunity cost is the return to that unit in its highest value alternative use. The value of stumpage to a firm can be directly linked to locational or spatial aspects of economic rents. Understanding the spatial aspects of the production of goods has its historical roots in the classic work of Johann Heinrich von Thunen (1783-1850):

> a town surrounded by a homogenous plain, trading city goods for the rural fruits of labor and land; ... the inner rings nearest the town specialising on the goods dearer to transport, while the farther out low rent-generating acres are growing the goods cheaper to transport. (Samuelson, 1983).[2]

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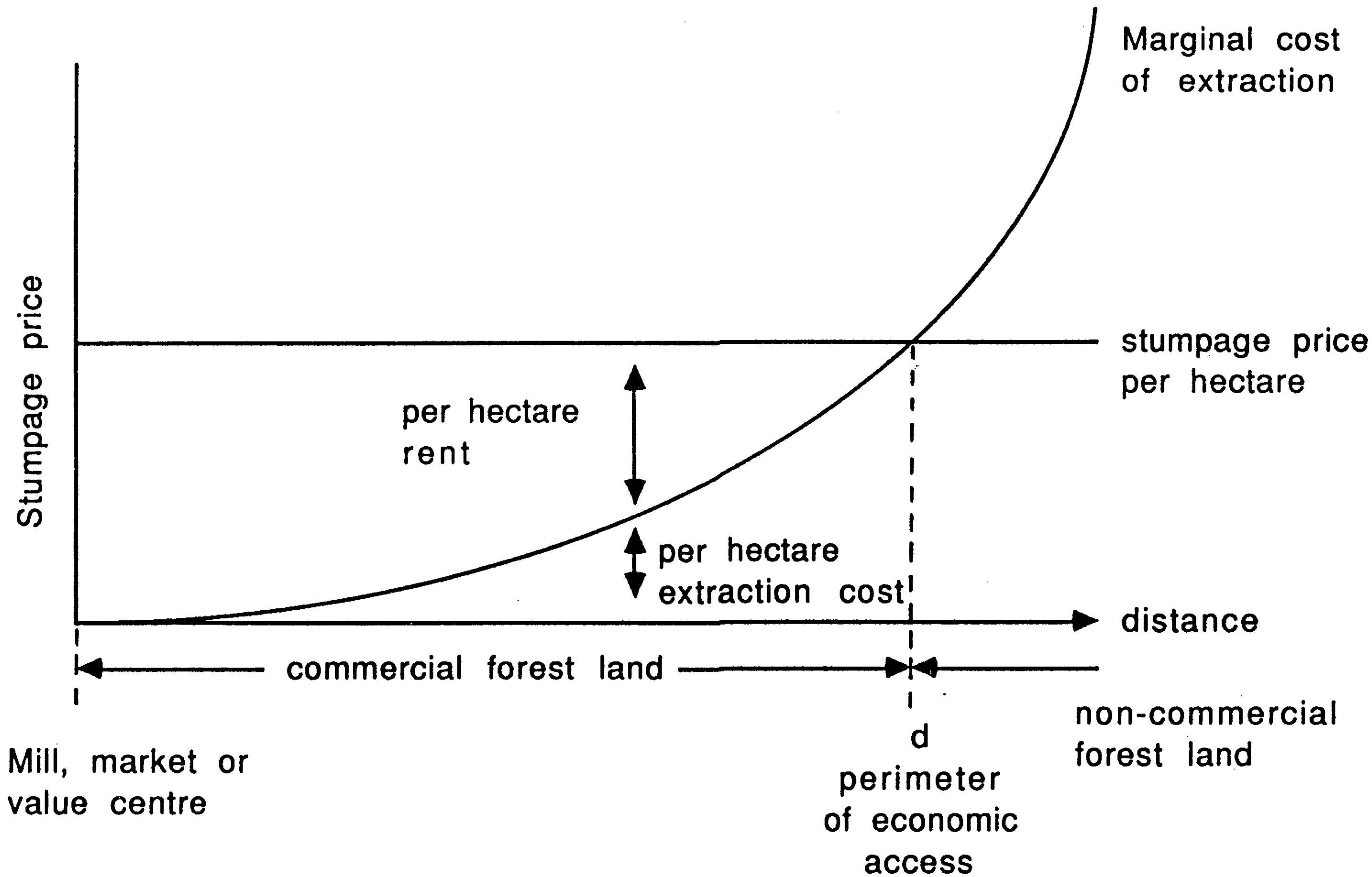
2. Samuelson (1983) also credits von Thunen with creating the economic notions of marginalism, managerial economics and elaborating one of the first general equilibrium models.

With respect to wood processing, Figure 2.2 illustrates how extraction costs and land rent vary as distance from harvesting site to a mill or market centre increases. For a given uniform land base and price, as distance from a mill increases per hectare rent declines and per hectare extraction costs increase due to transportation charges. The distance, d, is the mill's perimeter of economically profitable extraction (Hyde, 1980). When stumpage price increases, the area of commercial forest land and total rent increases.

One of the most important issues in Australia and other countries with large tracts of publically owned forest land is the determination of an appropriate stumpage price. Where there are many competing landowners price is determined in the marketplace and each owner and buyer is a price taker. Stumpage prices will therefore reflect proper social valuations and land owner's management practices will be driven by competitive market forces. In these situations government policy with respect to the taxation of forest land can influence management (Pearse, 1976). Yield taxes are generally thought to lengthen rotations while property taxes tend to shorten rotations (Gamponia and Mendelsohn, 1987). Koskela (1989a, 1989b) considers the effects of forest taxation under price uncertainty and perfect and imperfect capital markets. Under conditions of uncertainty effects are less clear. For example, changing taxes can introduce wealth effects that, depending on an individual's response to risk, will have either positive or negative effects on timber supply. Hence *a priori* effect on timber supply due to, for example, yield taxes are ambiguous (Koskela, 1989a). Max and Lehman (1988) set up a dynamic intertemporal behavioural model of timber supply, where owners had multiple objectives, to examine the outcome of various tax policies. They showed multiple objective management to be much more complicated than the conventional profit maximising framework.

Figure 2.2 Economic Rent and Forest Location



Source: Hyde, 1980

It should be noted that fiscal neutrality is often considered to be a desirable outcome of resource taxes, that is, if pre-tax resource allocation is believed to be efficient. In the case of forestry where non-wood un-priced outputs are thought to be important, existing outcomes are unlikely to be efficient. It appears impossible to establish simple general propositions on the direction of departures from the efficiency standard in forestry (Common and McKenney, 1990). Hence, general statements about acceptable directions for distortion due to taxation, or even other forms of regulation, cannot be made. This area requires further theoretical and empirical investigation.

When public land is the only or major wood supplier then stumpage price determination becomes more problematic. Public forest agencies in many countries, including Australia, tend to set stumpage prices bureaucratically. Residual pricing is a common approach for pricing wood in such circumstances (Byron and Douglas, 1981; Leslie, 1985). A residual value for stumpage can be calculated by subtracting producer costs, including an allowance for normal profit, from the price received for the final product. This should theoretically determine the rent. Stumpage fees on public land often attempt to capture this rent. Strictly speaking this approach implies nothing about the appropriateness of the residual value as the stumpage price. The residual approach implicitly accepts the existing industry structure as efficient (Byron and Douglas, 1981). Nor does the residual value approach provide information about the opportunity costs of the land. Essentially policy-makers are informed about what the stumpage price should be to maintain the current structure of the processing sector, not about what the price should be in the first instance. Byron and Douglas (1981) describe other approaches to pricing stumpage and actual policies in Australia.

In perfectly competitive situations and in the absence of external effects, public forest agencies in small open economies, like Australia, should use market prices when estimating the long-run expected value of forest management decisions. This is primarily due to small open economies being price-takers. General equilibrium implications of management decisions can be evaluated using, in this instance, world market prices as shadow prices (opportunity costs). Individual forests should therefore grow and sell as much stumpage as possible using the "world price" as a guide for profitability, after consideration of transportation charges. The mathematical derivation of this assertion is rigorously presented in a general equilibrium context in Johansson and Lofgren (1985, Chapter 11). It is sometimes felt that using stumpage prices when evaluating the costs and benefits of forest management decisions ignores the value of the final product to the economy. However, if the assumption that competitive markets exist in the processing sector is accepted, then net economic welfare changes due to forest management activities are reflected through stumpage values (Carlton, 1979; Jacobsen, 1979).

The Johansson and Lofgren assertion implies that wood growers should use some notion of world stumpage prices when evaluating extraction and investment choices. It should be noted here that even if this approach (using world stumpage prices) were possible, it may be limited if there are enough distortions in world markets due to various public forest policies. Repetto and Gillis (1988) provides evidence for the widespread occurrence of such policies. So, despite the fact that wood and wood products are tradable priced commodities, the determination of the appropriate or correct value to use in cost-benefit analysis is difficult.

2.2.3 Techniques for Estimating the Economic Value of Un-priced Goods and Services

The work of Hicks (1943) has provided economists with four measures of welfare change that have proven useful in determining the value of un-priced environmental services. These are: compensating variation, compensating surplus, equivalent variation and equivalent surplus. Seller *et al.* (1985) provide a useful summary of their definition:

> The compensating measures are the amount of compensation paid or received, which would keep the consumer at the initial welfare level after the change had taken place.

and

> The equivalent measures are the amount of compensation, paid or received, which would bring the consumer to the subsequent welfare level if the change did not take place.

Depending on the circumstance, willingnesses to pay (WTP) or willingnesses to accept compensation (WTA) could be used to estimate either equivalent or compensating measures of welfare (Knetsch, 1990). There are several methodologies which have been used to provide numerical estimates of these theoretical constructs. The contingent valuation, travel cost and hedonic travel cost methods are three common approaches and are described below.

Contingent Valuation Surveys

The contingent valuation method (CVM) uses a survey approach to elicit consumer's WTP or WTA for un-priced goods and services. The approach is based on the assumption that individuals are capable of answering questions to reveal their preferences for public goods or services (Mitchell and Carson, 1989). It is called "contingent" because the WTP and/or WTA questions are couched in some hypothetical market setting. Cummings *et* *al.* (1986a) in assessing contingent valuation techniques suggest respondents who are asked WTP or WTA questions should be familiar with the resource to be valued and results will be more reliable (accurate) as uncertainty decreases.

The literature on contingent valuation techniques has become extensive. Contingent valuation has been used to determine values for a wide range of environmental services, for example, air quality improvements in Los Angeles (Brookshire *et al.*, 1982), acid rain reduction (Johansson and Kristrom, 1988), agricultural pollution control (Hanley, 1988), boating recreation in Texas, water quality improvements (Desvouges *et al.*, 1987), hunting of wildlife (Brookshire *et al.*, 1983), forest recreation in the UK (Hanley and Common, 1987), and wilderness preservation in Colorado (Walsh *et al.*, 1984). Mitchell and Carson (1989) provide an annotated bibliography of the studies that have used CVM. Cummings *et al.* (1986a) and McConnell (1985) summarise the approach generally and in relation to outdoor recreation respectively. The following summarises some of the major features of the methodology (Cummings *et al.*, 1986b):

1. design a questionnaire which has the following 3 key features:
   a) a clear explanation of the survey and its purpose,
   b) a description of the goods or services to be valued,
   c) the WTA or WTP question with a description of the payment vehicle (eg. direct fees, increase in taxes);

2. other optional features of the survey include:
   a) interactive value questions dependent on the original response,

b) requests for demographic and attitudinal data.

Questionnaires can be directly presented, mailed or administered through a telephone survey. Generally, the mean value of the WTP or WTA value is calculated and then aggregated to estimate the value for the entire population in question (Hanley, 1988). Additionally, depending on the exact nature of the questionnaire, the values can be regressed on variables identified in the survey to obtain a WTP function (Hanley 1988):

$$WTP_{qs} = f(D_s, E_q)$$

where:

WTP_{qs} = the willingness to pay of the s^{th} individual for service/resource E_q

D_s = a vector of demographic variables for the s^{th} individual

E_q = quantity of the q^{th} resource or service flow in question.

Cummings *et al.* (1986b) summarise the major assumptions, strengths and weaknesses of the CVM. Two important assumptions which could be considered as weaknesses include:

1. subjects can determine their preferences for the good(s) in question relative to other goods and services;
2. subjects will not respond strategically or in a way which does not reflect their true preferences and also that responses reflect intended behaviour as opposed to attitudes.

Some other weaknesses include:

1. the possibility of biases and undue influences caused by the questionnaire design or interviewer (Boyle *et al.*, 1985);
2. for some environmental services, particularly non-use values, determining the relevant population to survey can be difficult (Hanley, 1988);
3. since information and uncertainty issues are inherent in the provision of many environmental services, respondents may not fully understand the implication of changing environmental services. Increased information and decreased uncertainty may change relative preferences through time.

Well designed surveys can reduce some of the weaknesses mentioned above. Also, contingent valuation methods appear to give results comparable to other methods of estimating the monetary value of unpriced goods (Duffield, 1984; Seller *et al.*, 1985; Hanley, 1988). Note that while two approaches may provide the same answer this does not necessarily imply both are identifying true welfare values. Mitchell and Carson (1989) in a recent examination of the contingent valuation methodology conclude:

> ... although the contingent valuation method is a promising technique, the fact remains that the methodological challenge in conducting a CV study is considerable because it is often difficult to convey to respondents what a policymaker wants them to take into account in a way that is both theoretically and technically correct and also understandable and plausible (p. 297).

The Travel Cost Method

The travel cost method (TCM) has been used to value outdoor recreational sites and an extensive literature now exists which has utilised this methodology. Essentially the TCM uses variations in travel costs to a site to estimate demand for the site. If a recreational site is not priced the benefit consumer surplus estimate can be found by determining the area under the demand curve for the site. The basic underlying assumption of this approach is that the cost, including travel costs, incurred by people to consume outdoor recreational experiences can be taken as a surrogate price for the value of the experience and hence the recreational site (Burt and Brewer, 1971). If travel costs are an important determinant in visiting a site, variations in travel cost between regions to get to a site can help determine demand functions for the experience (McConnell, 1985). Clawson and Knetsch (1966) is one of the earliest references for the travel cost method. McConnell (1985) provides a useful survey of various econometric and conceptual issues attending the TCM. The following is a general stylised version of a travel cost model.

A per capita visitation function to a particular site that includes travel costs could take the following form:

$$NV_k / PL_k = f\left[Y_k, D_k, CV_k\right]$$

where:

NV_k = the number of visits to the site from k^{th} region or zone

PL_k = population of the k^{th} region

Y_k = the income level in the k^{th} zone

D_k = a vector of relevant socio-economic and/or demographic characteristics of the region

CV_k = the cost of visiting the site from the k^{th} region.

The costs should include the access fees, actual travel costs, a measure of time costs for the return trip to the site, and an estimate of the opportunity cost of time spent at the site. Total benefits to users of the site could be calculated by (McConnell, 1985):

$$AB = \sum_{k=1}^{K} PL_k \int_{CV_k}^{CV^*} f\left[Y_k, D_k, CV_k\right] d\,CV$$

where:

AB = the aggregate area under the site demand curves for all regions or zones

CV_k^* = the reservation or minimum price (cost) for the k^{th} region

An interpretation is that the aggregate benefits can be calculated as the area under site demand curves for all zones. A vector of site attributes and alternative sites can be included in the estimating equations to gauge the effects of substitute sites and changing site characteristics (Bowes and Krutilla, 1987). Estimating the value of site characteristics is the provenance of the hedonic travel cost method. That methodology will be described in the following section.

There are a number of theoretical and practical difficulties with the TCM. For example, if substitute sites are available and not considered, bias can be introduced into the benefits estimation (Dwyer *et al.*, 1977; Rosenthal, 1987). Similarly, omitting the time cost of travel to, from and at the site can result in an underestimation of the benefits. However, the appropriate cost to place on both travelling time and time at the site has not been resolved in the literature (Cesario 1976;

McConnell and Strand 1981; Wilman 1980). A common approach is to estimate the opportunity cost of time as some proportion of the wage rate. Another important problem with TCM relates to the issue of multi-site trips. Attributing all value to a single site when the trip included many sites results in an overestimation of benefits (Smith, 1979). McConnell (1985) discusses aspects of the econometrics of TCM at length, including problems such as the choice of the appropriate functional form to use in the estimating equations.

The travel cost model is by now a well known and accepted means to estimate the benefits of outdoor recreation. There is even TCM software available (Rosenthal *et al.*, 1986). However, the usefulness of TCM is questionable when it comes to estimating the value of marginal changes in the physical attributes of particular sites due to various forest management activities. As indicated earlier the TCM is most commonly used to estimate the gross benefits of single sites (ie. a waterfall, a campsite, or scenic vista). Long term forest planning requires both the physical and economic effects of changes in site attributes to be estimated over time. Simple travel cost models do not provide this sort of information but they can provide first approximations of the gross value of sites under current conditions. Recent developments combining hedonic pricing techniques with the travel cost model appear to be a more promising method to ascertain the effects of marginal changes in site attributes.

The Hedonic Travel Cost Method

Hedonic pricing is an indirect method of estimating the economic value of public goods. Economic values are estimated by describing the spatial characteristics and/or attributes of goods that are priced and attributing different use patterns to the nature of the site characteristics. The method has its roots in the works of Lancaster (1966), Tiebout (1956) and Rosen (1974) and has been used to estimate values for both public goods and bads (Hoch and Drake, 1974; Harrison and Rubinfield 1978).

Hedonic travel cost techniques attempt to estimate marginal values of particular characteristics by observing consumer choices among different recreational sites. Visitation rates are assumed to vary due to differences in site quality. Variations in costs reflect willingness to pay for different site qualities (Bowes and Krutilla, 1987). To better understand the approach consider the following Brown and Mendelsohn (1984) model. The assumption is that a consumer's choice of a recreational site is based on measurable characteristics of the site and the costs involved in getting there. A utility maximisation formulation of this problem subject to budget constraints is as follows:

$$U\left[Z_{11}, \cdots, Z_{LM}, NT, OG\right] \qquad 2.2.1$$

$$NT = \left[NT_m\right], m = 1, \cdots, M$$

where:

Z_{LM} = level of a given attribute L (eg. scenery, forest type, congestion level etc.) averaged over trips of length M.

NT_M = number of trips of length M

OG = other goods or services.

Assuming no entry or user fees the cost of a trip can be given as:

$$CV_M(Z) = \psi_M + \Psi\, KT(Z) + \alpha\phi\, HT(Z) \qquad 2.2.2$$

where:

$CV_M(Z)$	=	the total cost of the trip of length M providing a vector of site characteristics Z
ψ_M	=	the fixed cost of the trip of length M
Ψ	=	a constant cost per kilometer travelled
KT(Z)	=	kilometers travelled
α	=	the value of time, here set equal to the marginal wage rate.
ϕ	=	the cost of travel time, usually some proportion of the wage rate
HT(Z)	=	hours of travel.

The budget constraint can be written as:

$$Y = PS(OG) + \sum_{M=1}^{M} NT_m CV_m(z) \qquad 2.2.3$$

where:

Y	=	income
PS	=	price of other goods or services.

Utility maximisation subject to the budget constraints gives the following first order conditions.

$$\frac{\partial u}{\partial NT_m} - \lambda NT_m PZ_L = 0$$

$$(L = 1, \cdots, L), (m = 1, \cdots, M)$$

$$\frac{\partial u}{\partial NT_m} - \lambda CV_m(Z) = 0 \qquad 2.2.4$$

$$\frac{\partial u}{\partial OG} - \lambda PS = 0$$

The marginal price (hedonic value) of characteristic Z_{LM} per trip is:

$$PZ_L(Z) \equiv \Psi\left[\partial KT/\partial Z_L\right] + \alpha\phi\left[\partial HT/\partial Z_L\right] \qquad 2.2.5$$

The actual choice of sites expressed in terms of simultaneous equations is found by combining 2.2.3 and 2.2.4. This results in:

$$Z_{LM} = g(PZ, NT, W),$$

$$(L = 1, \cdots, L), (m = 1, \cdots, M)$$

and

$$NT_M = h(CV_M\,(Z), NT_q, W)$$

$$(m = 1, \cdots, M) \qquad q \neq m$$

where:

W = a vector of exogenous demand shift variables

Consumer surplus is calculated similarly to the simple travel cost method (Brown and Mendelsohn, 1984). For a given price change the consumer surplus is the integral of the product of the value of average characteristics times the number of trips:

$$AB = \int_{PZ_L^0}^{PZ_L^1} \sum_{m=1}^{M} \left\{g(PZ, NT, W) \cdot h(CV_m(Z), NT_q, W)\right\} dPZ_L \qquad 2.2.6$$

Brown and Mendolsohn used this model to estimate the value of steelhead salmon density in streams in the State of Washington. The approach has appeal to forest management planning problems since it can be used to infer value of site characteristics that are often under managerial control. For example, Bowes and Krutilla (1987) present two variations of the hedonic travel cost model investigating the dependence of recreational (hunting) values on the distribution of range forage and forest cover. They exhaustively describe the underlying theory and methodology. The hedonic TCM does not appear to be well known nor easily understood. Data requirements are large. Hedonic methods appear to be best suited to regions where there is significant variation in site quality and use (Bowes and Krutilla, 1987 p.6-45). The definition of the relevant zones to use in the analysis is unresolved and this can profoundly affect a HTC model's performance and benefit estimates (Smith and Karou, 1987). Smith and Karou also raise the issue/problem of determining the set of sites an individual considers in making recreation plans.

Making this benefit estimation technique operational requires a number of both implicit and explicit assumptions. Application of the methodology by public forest agencies would require a great deal of data to be collected and the required expertise is generally not readily available. Also, the approach does not account for non-use values. In Australia, where there appears to be a great deal of public concern over the management of native forests, non-use values may be substantial. CVM is more suited to estimating non-use benefits. However, CVM generally involve questions about the total value of a site, not the value of marginal changes. Freeman (1985) describes another technique called contingent ranking in which individuals are asked to rank different situations which are then analysed using a multinomial logit model.

The situations include explicit prices or costs of the environment good or service in question.

2.2.3 Forest Management Costs

While the identification of forest management costs may seem obvious, in practice it is a non-trivial task and therefore worthy of some comment. The travel cost, hedonic travel cost and contingent valuation methods can estimate the benefits of various forest resources. This emphasis concentrates only on the demand side of resource allocation. Matulich *et al.* (1987) criticise this focus of recreation economics with the statement - "... the profession seems more wedded to technique than to policy".

There does in fact appear to be a void in both the North American and Australian literature of comprehensive studies on cost structures in the provision of natural resources. Sedjo (1983) provides one of the few in forestry in his comparison of the economics of plantation growing in various parts of the world. Matulich *et al.* (1987) suggest this void in the literature is a "sin of omission or incompleteness [that] may be responsible for a number of conceptual weaknesses in the literature" - for example, distinguishing between "sustainable" economic yields and biological carrying capacity which are both subject to managerial manipulation. Also, there is little evidence to suggest management strategies, particularly in the public sector, are technically efficient or cost effective.

In public forestry in Australia it is difficult to obtain reliable cost data on even the wood growing portion of the enterprise, let alone the costs of providing various recreational and conservation benefits. Cost accounting in forestry is at the pre-conception stage. Even in the United States, where forest planning occurs under a more technologically advanced umbrella, it is only recently that the US Forest Service has embarked on a comprehensive cost accounting system (United States General Accounting Office, 1987; USFS, 1987). That cost accounting system has come under criticism for, among other things, its method of allocating costs through time (Selig and O'Toole, 1989).

Theoretical difficulties arise in the development of effective cost accounting systems for forestry. Foremost among these is the issue of joint costs. Essentially the problem is that forestry is a multiproduct operation which makes it difficult to fit into a simple accounting framework. For a given input a number of outputs may occur (eg. a silvicultural operation provides wood and may increase water flows; roads provide access to timber but also some forms of recreational opportunities). Efficiency criteria require that the benefits of each incremental forest output cover its own separable costs. The costs include those directly involved in the production of the service and the opportunity costs it imposes in the form of reduced production on other forest goods and services. How costs are allocated affects the profitability of particular activities. The problem of cost allocation has given rise to debate in the forestry economics literature since the allocation of costs to individual outputs can be arbitrary (Hof and Field, 1987; Bowes and Krutilla, 1979, 1987; Hof *et al.*, 1985).

Part of the reason for the difficulty of identifying costs of forest management probably relates to the small role that economists have traditionally had in public forest agencies. Chapter 3 discusses the issue at greater length. Here it can be emphasised that in public forestry there are not only problems identifying "correct" prices for stumpage and amenity resources, there are also difficulties identifying numerical values for the costs associated with forest management.

2.3 The Economics of Single Forest Stand Analysis

2.3.1 Introduction

The economic theory of forest management has dealt mainly with the problem of optimal rotation length as it relates to wood production; that is, the timing of when to harvest a stand of trees. Initial efforts date back as far as 1849 with Martin Faustmann's work on the valuation of forest land (Faustmann, 1849). Samuelson (1976) provides an excellent summary and intuitive explanation of the correct capital analysis required for single stand, timber only, optimal rotation calculations. Samuelson's description reviews a number of the mistakes that have been made by foresters and economists when they attempted to solve the optimal rotation problem. Incorrect approaches include maximising the internal rate of return, simple discounted cash flow analysis over one rotation period, and maximising the biological sustained yield of wood flows over time. These methods essentially ignore the opportunity costs involved with wood production, particularly the time value of monetary investments, and land rental costs.

The correct calculation of optimal rotation length determines the rotation period that maximises the net discounted value of the wood producing enterprise, excluding land rent but calculated over an infinite number of rotation periods; or maximises the net present value over the first rotation period but including land rent in the calculation (Samuelson, 1976).

Complete articulations of the mathematics of the problem are found in Hyde (1980), Bowes and Krutilla (1985), and Johansson and Lofgren (1985).

2.3.2 An Economic Model of Wood Production

The economic problem of managing an even-aged forest stand of trees is most simply represented by a model in which stumpage price, costs, interest rates, forest growth rates are known and unchanging over time, and the initial endowment is bare land. It is convenient to also assume that prices, including the interest rate, are determined by perfectly competing markets so that they represent true social valuations in an economic sense. Although these assumptions may seem heroic the results of this analytical approach provide an initial basis for considering forest management problems and as such a benchmark for comparison. Mathematically the problem is finding the age T which maximises the present value of growing and harvesting a stand of trees *ad infinitum*:

$$NPV = \underset{T}{Max} \left\{ \left[PV(T)e^{-rT} - C \right] / \left[1 - e^{-rT} \right] \right\} \qquad 2.3.1$$

where:

NPV =	net present value
C =	regeneration or establishment costs
V(T) =	the stand growth function with respect to wood production
P =	the wood price net of extraction costs (stumpage price)
e^{-r} =	the natural logarithm raised to the discount rate r

Assuming the function V(T) is continuously twice differentiable and strictly concave, the necessary condition for maximisation is:

$$PV'(T) - r\,PV\,(T) - NPV\,r = 0 \qquad 2.3.2$$

Rearranging 2.3.2 for interpretation gives the following:

$$PV'(T) = r\,(PV(T) + NPV) \qquad 2.3.3$$

$$r = PV'(T)\;/\;(PV(T) + NPV) \qquad 2.3.3'$$

The solution to 2.3.3 gives what is sometimes refered to as the Faustmann, rotation length $T_{F'}$. Equation 2.3.3 reveals that the stand should be harvested when the rate of change in its value equals the interest on its value plus the interest on the value of the forest land, NPV (see also Johansson and Lofgren, 1985 p.80). Or put another way, (2.3.3'), a timber stand should remain uncut until the rate of growth of the asset, which includes wood and land, equals the interest rate. This result is analogous to the intertemporally efficient cost benefit conditions mentioned in section 2.1, where the interest rate represents rates of return to other investments in the economy.

2.3.3 Comparative Statics of the Wood Only Model

As seen from equation 2.3.1 the optimal rotation is dependent on the stumpage price, the interest rate and management costs when costs are positive. An important policy question is: what happens to the optimal rotation period when stumpage prices, costs or the discount rate changes?

Johansson and Lofgren (1985, p.80-85) derive the following comparative static results:

$$\partial T / \partial P < 0 \qquad 2.3.4$$

$$\partial T / \partial C > 0 \qquad 2.3.5$$

$$\partial T / \partial r < 0 \qquad 2.3.6$$

An intuitive interpretation of these results is as follows. For 2.3.4, a once and for all increase (decrease) in stumpage price increases (decreases) the value of forest land which increases (decreases) the interest cost of the rotation period. The rotation length must therefore be shortened (lengthened) to adjust to the changed value growth of the stand. For 2.3.5, an increase (decrease) in the costs of management decreases (increases) the value of the forest land and hence decreases (increases) the interest costs. The rotation length must be lengthened (shortened) to adjust to the changed value growth of the stand. Management costs could be wage or regeneration costs. The general effect of a change in the interest rate is the same as a change in prices. For 2.3.6, the intuitive explanation is that when the interest rate is increased (decreased) the interest cost is increased (decreased). A forest owner must shorten (lengthen) the rotation period to adjust to the changed value growth.

Although these qualitative results are useful in a theoretical sense, resource managers are more likely to be interested in the degree to which their management practices would change when these parameter values change. These are empirical questions that must be examined for each set of biological and economic circumstance.

2.3.4 Other Generalisations From Wood Only Models

A number of authors have generalised wood production models such that the Faustmann results become special cases of their own. McConnell *et al.*, (1983) developed a model that determines optimal rotation age when both prices and costs can vary exogenously. Their only general result was that, given constant stumpage prices optimal rotation length increases (decrease) over time when regeneration costs increase more (less) rapidly than the discount rate. Newman *et al.* (1985) developed a model to examine the effects of changing prices and consider the importance of relativities in costs and price. They found that rotation lengths are sometimes longer and sometimes shorter than the Faustmann rotation when there is constant exponential growth in prices. The comparative statics of the Faustmann model only relate to the effects of a once off change in price. Heaps and Neher (1979) determined optimal rotation length when the rate of harvest is constrained. They developed a model, based on optimal control theory, in which the cost of harvest varied with the rate of harvest.

Nautiyal and Fowler (1980) examined the implications of imperfect stumpage markets for optimal rotation length. They hypothesised that large forest owners, like public forest agencies, may act in a monopolistic fashion and thus affect stumpage markets. Nautiyal and Fowler showed that profit maximising monopolistic owners would have slightly shorter than socially desirable rotation lengths.

However, public foresters often advocate a maximum sustained yield (MSY) rotation period; that is, a rotation period that maximises the volume flow of wood from a forest over time. The MSY rotation period is generally longer than the Faustmann rotation. Thus, given $V(T)$ as the wood growth function, the problem is to choose T to maximise $V(T)/T$. From the first order conditions, the optimal rotation for this problem is given by the solution to :

$$V'(T) = V(T)/T$$

Comparing this to the first order conditions for an economically optimal rotation, equation 2.3.3:

$$PV'(T) = r(PV(T) + NPV)$$

reveals that only when r approaches zero will the MSY model yield the optimal economic rotation.

2.3.5 Single Stand Analysis With Multiple Values

The above discussion considered the management of a single stand when only harvested wood is valued. It is now widely recognised that forested land has other values and that these values can be important to private landowners as well as public foresters. These other values, such as recreation opportunities, wildlife, water and various conservation values, are not typically priced in markets. Hartman (1976), in response to Samuelson (1976), adapted the Faustmann model to include a benefit function relating stand age to non-wood or amenity values. The general problem can be stated similarly to the wood-only case. A rotation period, T, needs to be chosen that maximises the value of the wood and amenity flows from the stand in perpetuity (from Bowes and Krutilla, 1985).

$$NPV = \underset{T}{Max} \left\{ \left[\left[PV(T)e^{-rT} + \int_0^T \left[a(n)e^{-rn} \right] dn - C \right] / \left[1 - e^{-rT} \right] \right\} \qquad 2.3.7$$

where:

$\int_0^T \left[a(n)e^{-rn} \right] dn$ = the present value of a flow of amenity outputs over the rotation evaluated at the start of a rotation.

The term a(n) is the amenity benefit flow at age n. The other terms are as defined previously. The first order condition for a maximisation of equation 2.3.7 is:

$$PV'(T) + a(T) - r\,PV(T) - r\,NPV = 0 \qquad 2.3.8$$

Rearranging 2.3.8 in a similar way to 2.3.3 gives:

$$PV'(T) + a(T) = r\,(PV(T) - NPV) \qquad 2.3.9$$

$$r = PV'(T) + a(T) \,/\, (PV(T) - NPV) \qquad 2.3.10$$

This condition reveals that the Hartman multiple-use rotation length, T_H, should occur when the rate of change in value including the amenity flow equals the interest cost on wood harvests plus the interest cost on land. NPV now includes the value of land for both wood and amenity values. The Faustmann result, T_F, from equation 2.3.3 is a special case of 2.3.8. If a(n) = 0 then the harvest would occur at the same time as the timber only result.

Hartman (1976) and Bowes and Krutilla (1985) show that the multiple-use harvest may occur before or after the Faustmann harvest depending on the nature of the amenity value function. For example, the solution to 2.3.7, T_H, is greater than the Faustmann solution, T_F, only if a(n) is monotonically increasing with n. However, it is not realistic to regard a(n) as increasing with n for all non-wood values. Some flora and fauna prefer young stands. The solution is essentially empirical and depends on which non-wood benefits are considered in the problem formulation. This point was first illustrated by Calish *et al.* (1978) using paired combinations of wood and seven different non-wood yield functions (cutthroat trout; non-game wildlife diversity, visual aesthetics, soil movement, black-tail deer, elk and water flow) and a single stand approach like Hartman. Their study was for the Pacific Northwest Douglas-fir region of the US and used a range of prices for the non-wood outputs. The study also demonstrated that the MSY rule of thumb management strategy does not, generally, do a good job of accommodating trade-offs in multiple-use forestry.

The initial state of the forest (ie. a(n)) can affect the result to such a large degree that there may be cases where it is never optimal to harvest the stand. Another interesting feature is that given the wide variety of possible values in the definition of amenity services, the first order conditions may be satisfied at a number of different ages (many local maxima or minima). This highlights that even disregarding the difficulties in measuring the physical quantities of the amenity service flows, the solution to the multiple-use problem is complex. Similarly, the comparative statics of the Hartman formulation are indeterminate at the analytical level. Unambiguous results like 2.3.4, 2.3.5, and 2.3.6 are not possible without assumptions about the amenity benefit functions. Even changes in the interest rate cannot be said to unambiguously lengthen or shorten the optimal rotation period (Bowes and Krutilla, 1985).

2.3.6 The Special Cases of Timber Mining and Forest Preservation

Two important polar cases exist as potential management alternatives for forests. Understanding them helps clarify the boundaries of efficient forest management. The first case is that of timber mining - treating the forest like a non-renewable resource such that there are no intentional silvicultural investments and in the most extreme case no commercially viable regrowth is expected. The second case is that of forest preservation - such that the non-wood attributes of the forest are considered so valuable as to disallow any harvesting in the area.

Johansson and Lofgren (1985, p.240-241) provide a straightforward conceptualisation of this problem. Harvesting a forest and using the land for wood production is socially worthwhile if the discounted sum of the current value of harvesting (π_C), plus the present value of all future (Faustmann) rotations (π_F) exceeds the total willingness to pay for preserving the forest from all time periods in the planning horizon (WTP):

$$\pi_c + \left\{\pi_F / \left[(1 + r)^{T^*} - 1\right]\right\} - WTP > 0 \qquad (2.3.11)$$

when the present value of π_F is not positive

$$\pi_F / \left[(1 + r)^{T^*} - 1\right] < 0$$

then ongoing timber management is inefficient and the problem is reduced to

$$\pi_c - WTP > 0$$

This is the case of timber mining. Ongoing timber management is inefficient and the WTP to preserve the forest does not exceed the value of extracting (mining) the current wood resources in the forest. If WTP > π_c then preservation is most efficient.

There are a few points worthy of special mention with respect to these management choices. Social preferences, for both wood products hence stumpage values, and preservation, may change over time. This could affect the relative values of the three terms in 2.3.11 thus changing the socially efficient outcome. Krutilla and Fisher (1975), for example, argue that wilderness is becoming increasingly scarce and thereby increasing in relative value over time. However, there is no guarantee that future generations would impute similar values to wilderness. This highlights the fact that economic analysis is for current decisions. Conditions may change tomorrow or next year which would make the optimal decision different.

Timber mining is sometimes considered to be bad land stewardship and not a valid option for public forest agencies. However, from an efficiency perspective it may be rational. In situations where mining is not considered an "option", forest preservation could in fact be the most efficient land use. Ongoing forest management could be so inefficient as to cause large efficiency losses to the economy, particularly in the case of slow-growing forests with large capital outlays required for regeneration (eg. Ontario, Canada see Anderson, 1979).

Another point worth noting is that stumpage price is implicitly given in the Johansson and Lofgren model. There are a number of issues about the determination of appropriate public stumpage prices, raised previously, that could affect the results. In fact, public pricing policy could be seen as implicitly reflecting an attitude about the economic renewability of forests. Low prices and price expectations could result in timber mining being the most appropriate economic management of the forest. Ironically, the WTP required to justify preservation is lower in this case. Higher stumpage prices increase the cost of preservation. Clearly, in this context the issue of stumpage price determination requires both theoretical and applied research.

The choice of discount rate can also profoundly affect the numerical outcome of 2.3.11. For example, with sufficiently high discount rates efficient ongoing timber management is not worthwhile and mining versus preservation becomes the economic choice. Porter (1982) investigates the subject of discount rates and forest preservation at greater length.

There is an important theoretical difficulty stressed by Johansson and Lofgren (1985) that should be recognised as a limitation in economic analysis of large-scale preservation versus timber harvesting cases:

> ... the evaluation of discrete or large policy changes is still an unresolved issue in welfare economics. Loosely speaking, if a policy change more than marginally affects the marginal utility of income of any individual, then there exists in general no unique monetary welfare change measure. This is so because the size of the change will depend on the particular path of integration between terminal situations. To circumvent this problem cost-benefit analysts often assume that each household is kept on its initial or preproject level of utility. If the sum of the so-called compensating variations of the individuals is positive, a project is assumed to be welfare improving. (The hypothetical income change that keeps an individual on the initial or preproject level of utility is called the compensating variation.) However, there exists no simple relationship between this criterion on the ability to compensate losers if changes are discrete. (p.246). (Silberberg (1972) investigates this issue in more depth.)

What is problematic is the definition of marginal change. All benefit-cost analyses need a context and reference point. They can only be made operational by assuming a particular context or reference point because what is marginal to the State, province or nation may not be marginal to individuals in a region or sub-region. It is generally accepted in cost-benefit analysis that if the winners can compensate the losers and still come out ahead then the project should go ahead.

2.4 The Economics of Multiple-Use Forestry with Stand Interdependencies.

The Hartman formulation illustrates some of the complexities involved at the analytical level of multiple-use forestry for a single timber stand. The theory discussed above ignores situations where interactions between stands affects the value of forest resources. In fact such interdependencies are common in forestry. Lohmander (1987) investigates the optimal harvesting strategy for a forest in which the probability of windthrow in any one stand is affected by the pattern and timing of harvests of the other stands. Wildlife have particular habitat requirements over large areas (eg. home ranges) which can be affected by the age structure of multiple timber stands. The logical unit of analysis of water production from forested areas is a catchment or drainage basin which again contains many timber stands.

The so-called units of production for achieving conservation goals in forest management are more controversial and difficult to measure. It can be argued that many conservation goals draw upon a common pool of biological and environmental (bio-environmental) indices (Mackey *et al.*, 1989). For many intangible forest outputs, indices can provide useful physical measures of the impacts of management. A number of bio-environmental indices of relevance to conservation goals in multiple-use forestry are identified below:

1. endemism - whether a biological unit is found only at one place, or within a specified landscape;
2. diversity - the number of types of a class of biological units found at a place or within a specified landscape;
3. abundance - the number of members of a biological unit found at a place or within a specified landscape;
4. area - this refers to both the total surface area of a place or specified landscape, and the extent to which the place is fragmented;
5. naturalness - the extent to which natural landcover and landscape processes have been

impinged upon by (usually) modern, 'western' landuse activity;

6. habitat suitability - the extent to which a place, or specified landscape, is suitable habitat for a given biological unit;
7. representativeness - the extent to which a place, or specified landscape contains samples of the bio-environmental variation found in a given region;
8. remoteness - the distance from, or measure of inaccessibility to, either access routes, habitation or cultural structures;
9. rarity - whether a place, or specified landscape, contains biological units that are uncommon, in that they are found only at a limited number of restricted sites.

Margules and Usher (1981) define these concepts more fully as conservation criteria as opposed to indices. In Australia, the indices have been seen as useful inputs for evaluating World Heritage criteria (Mackey *et al.*, 1989). Generally, places that have high scores for these indices are considered to have high conservation value by conservationists. Thus, for example, there is a conservation premium on places that have high numbers of endemic species; contain many different species with large populations; contain samples of all the major vegetation structural types in surrounding region; are largely undisturbed; cover a large area; and contain the most suitable habitat for a given fauna. Note, however, that from an economic perspective a high score on an index does not necessarily infer anything about the social value (eg. aggregate willingness to pay) for the attribute. The indices are simply measures of forest attributes contingent on stand interdependencies that are not as immediately obvious as wildlife home ranges or water catchments.

In the presence of significant stand interdependencies, single-stand analysis of the type discussed in the previous section could lead to non-optimal forest harvesting. Bowes and Krutilla (1985) developed an analytical approach to a multiple-use problem where stand interdependence was defined as amenity values related to the age class structure of the forest. A hypothetical data set was used to illustrate the effect on multiple-use values of harvesting strategies for a forest. They based their amenity values on indices of habitat suitability for wildlife and aesthetic quality. The indices were dependent on the mix of stand ages and the size of individual stands. Interdependencies based on the spatial distribution of stands did not enter the model. The management of eight stands of equal area and productivity in five 20 year age classes up to age 100 were considered over a 100 year time period.

The Bowes and Krutilla management problem took a typical form of a dynamic programming recursion; that is, choose the best action for each period based on the current stock and consideration of the impact of that decision on the value of the stocks in the next period. Or more generally, as Bellman (1957) put it:

> An optimal policy has the property that, whatever the initial state and decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision.

The Bowes and Krutilla multiple-use problem is:

$$NPV(X_t) = \max_{h_t,\, g_t \geq 0} \left\{ \left[A\left[X_t\right]\right) + B\left[H_t\right] \right] e^{-r} - C_t + NPV\left[X_{t+1}\right] e^{-r} \right\} \quad 2.4.1$$

where:

$A(X_t)$ = the sum of willingness to pay for the amenity services of the site in period t and depending on the stock vector X_t

X_t = the stock of vegetation held at the beginning of time t with $X_t(j)$ as the vector element of area of land with stock aged j. Unstocked land is $X_t(0)$. Note that X_t refers to the whole group of stands not to an individual stand.

$B(H_t)$ = the timber harvest value function in period t

C_t = the cost function in period t

$NPV(X_t)$ = the net present value of the future flow of harvests and amenity values from land with stock vector X_t on hand at time t.

$h_t(j)$ = a vector element giving the area of stock harvested at age j at end of time t.

$g_t(j)$ = a vector element of area grown to age j and left unharvested at end of time t.

The economic problem is to find the harvest sequence which maximises the net present value ($NPV(X_0)$) of the flow of wood and amenity services from the area given the initial forest endowments X_0. The interdependency of the amenity values due to age class structure is captured in the $A(X_t)$ term of equation 2.4.1. Close examination of 2.4.1 reveals that a recursive relationship of value exists in each time period, t. The value at any given time t, is based on the current net value and the value of the future flows based on the forest's subsequent condition ($NPV(X_{t+1})e^{-r}$). The model is thoroughly explained by Bowes and Krutilla (1985), including a description of equations which define stock allocation and progression through time, harvest volumes, and costs. Their analysis provides no simple generalisations as would be expected following discussion of the Hartman single-stand multiple-use model.

Bowes and Krutilla generate a number of scenarios in which stumpage price and discount rate vary. In their analysis demand and productivity were kept constant over time. At low stumpage prices some stands were harvested to provide more recreational benefits through increased diversity. With the higher discount rate intermediate prices resulted in complete harvesting but no further forest management. Neither the stumpage price nor the amenity value were sufficient to justify additional management. At the highest stumpage price the forest was managed on a renewable basis for wood production. It was shown that multiple-use forest management may not converge to a steady state in the long run. Depending on relative values, fluctuating harvests may be the norm with some stands managed on very short rotations and others preserved as old growth. In fact there may be a number of states of the forest that meet optimality conditions consistent with supply and demand equalibria.

At the analytical level there does not appear to be a general solution to the multiple-use management problem. What needs to be emphasised is that the qualitative nature of Bowes and Krutilla's solutions cannot be established without some numerical specifications. This is not unexpected given the analytical results of Hartman but it does contrast with the Faustmann results. Straight forward general solutions and steady states do arise from Faustmann but the approach is not relevant to multiple-use management. Multiple-use solutions for any given forest will depend on the initial endowments. So while the forester's goal of a steady state forest via a rule of thumb management principle like maximum sustained yield may be operationally simple and therefore appealing, only by accident will such a strategy be socially optimal according to economic efficiency criteria when multiple-use is a management objective.

Unfortunately, modelling interdependencies has computational and data difficulties. A commonly known difficulty associated with the use of dynamic programming is the "curse of dimensionality". Dimensionality essentially relates to the size of the problem to be analysed and is a function of the number of variables in the possible states. If there are M variables and each can take 5 values then the total number of possible states if 5^M (Norman, 1975). Consider the following, not unreasonable, example in a forest management context. There are 100 timber stands in the forest and 3 possible choices for each stand (leave, harvest and plant, harvest and leave for natural regeneration), in each planning period. With stand interdependencies, 3^{100} possible states must be evaluated for each planning period. This is not a trivial exercise for either the computer or the programmer. There are ways to reduce the dimensionality problem (eg. using Lagrange multipliers and reducing the number of values considered in each dimension), but they often have limited applicability (Norman, 1975).

2.5 The Linear Programming Approach

2.5.1 Background

Pointing out the difficulties of applying economic theory and quantitative analysis to forest management is not intended to suggest that such analytical approaches are futile. In fact the problems serve to highlight the desirability of a quantitative approach. Quantitative approaches require explicit assumptions and objectives. Forcing planners of public forests to reveal assumptions and objectives would allow those interested in scrutinising public forestry to discuss differences more rationally.

For example, industry and conservation groups may disagree on the numerical values of some wood and/or non-wood yields. Sensitivity analysis can be used to investigate the implications of different assumptions. Economic analysis of forestry problems can help ascertain the costs and/or benefits required to justify various policies.

While the theory outlined in previous sections showed cost-benefit analysis can in principle account for non-wood un-priced values, operationalising cost-benefit analysis to do so is difficult. This is due to problems in obtaining both biophysical and economic data. With respect to economic data it is possible to invert the problem and ask what prices non-wood values would have to be to induce changes in management strategies. Deficiencies in physical data can sometimes be overcome by using surrogate data or proxies for the environmental goods and services in question (eg. age classes as a measure of wildlife habitat suitability). Although this approach may not actually determine the socially optimal management plan it can provide information on the cost effectiveness of alternatives and force planners to justify their decisions in a thorough and systematic manner.

Mathematical programming in various forms has proven to be a useful decision-making aid for optimisation problems of the type mentioned in sections 2.3 and 2.4. The Bowes and Krutilla (1985) model outlined in the previous section used dynamic programming to solve their optimisation problem. However, it was shown that the practical application of dynamic programming (DP) to forestry problems can be computationally cumbersome and data intensive. Dynamic programming as described by Bowes and Krutilla would quickly become infeasible because of the large number of potential states and management options that must be evaluated for large tracts of public forests. In any event, the exact nature of many of the interdependencies that DP could be used to investigate are poorly understood anyway.

2.5.2 Linear Programming and the Multiple-Use Problem

Linear programming (LP) based optimisation does not have the same computational difficulties. LP has a long history in the forestry literature (Nautiyal and Pearse, 1967; Navon, 1971; Johnson and Scheurman, 1977; Johnson and Stuart, 1986; Johansson and Lofgren, 1985). It is not the purpose of this section to review this literature or to provide an explanatory text of linear programming. Rather, this section sets out the generalised linear multiple-use problem, with a view to clarifying its operational use in analysing long-term forest planning problems.

Basically an LP problem is one in which an analyst is trying to choose values of (X_1, X_2, ...X_n) to maximise or minimise an objective function subject to some (m) constraints. A standard way of writing a LP problem is:

$$\text{Max } Z = \sum_{j=1}^{J} C_j X_j$$

subject to linear constraints in the general form:

$$a_{mj} X_j \leq b_m \qquad (m = 1, \cdots, M)$$

and

$$X_j \geq 0$$

where:

C_j = the contribution to the objective function of activity j

b_m = the amount of resource m available

a_{mj} = amount of resource m required per unit of activity j

X_j = the level of activity j.

Adapting this sort of formulation to forest management problems like those described by equations 2.3.1 and 2.3.7 is relatively straight forward, but some simplifying assumptions are necessary. The necessity of these assumptions are fully explained in Johansson and Lofgren (1985, p.114). The first requirement is a finite planning horizon of T periods. A finite planning horizon can decrease the present value, however Johansson and Lofgren show that this loss is negligible if T is large enough. A finite number of T periods can also have implications on the condition of the forest after the planning horizon. If a steady state does not exist by the end of the planning horizon an ending inventory value or constraint may need to be introduced. The aim is to prevent the forest from being liquidated in the final LP planning period. Such an action would maximise the net present value in the finite time horizon but be incorrect in a long run analysis. The second assumption or requirement of an LP formulation is that of discrete time periods rather than continuous time (note that dynamic programming also involves discrete time periods).

Other important assumptions internal to LP include: linearity, non-negativity, divisibility, certainty, and a single objective function. All mathematical relationships in an LP must be linear in the choice variables. This also implies that all relationships between decision variables, constraints and the objective function must be proportional and additive. All choice variables must be non-negative and are assumed to be divisible. Linear programming is generally deterministic. This means that coefficients in the model are assumed to be known and certain. Uncertainty must be coped with through sensitivity analysis in which the problem is solved repeatedly with different coefficients. Chapters 5 and 6 address different aspects of the uncertainty issue. The concern over a single objective function rests with the view that some objectives are incommensurable and impossible to express in the same units. If used correctly, the LP approach can assist in identifying the opportunity costs and trade-offs of different management strategies which exist regardless of one's views about incommensurable objectives.[3] Kent (1989) gives a more detailed discussion of some of the strengths and weaknesses of linear programming that arise through the inherent assumptions of the technique.

Given particular conditions and assumptions a land owner maximising the present value of wood harvests from a forest will maximise social welfare. Consider then the following general LP formulation of a forest owner desiring to maximise the present value of timber flows from a forest (from Johansson and Lofgren, 1985, Chapter 6, p.112-121). The total forest area, A, is:

$$\sum_{i=0}^{n} X_{ti} = A \qquad 2.5.1$$

where:

X_{ti} = the initial endowments of forest lands; that is, X hectares of land at time t of age i. x_{to} is seeded bare land)

n = the oldest possible age class.

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3. Note that techniques like goal programming, or multiple-objective programming, essentially set objectives prior to analysis. The point of proper economic analysis is that it attempts to let social valuations determine management, not subjective interpretations or weightings of social values as determined by analysts or planners.

Bare land at the end of period 1 is:

$$X_{10} = C_{11} + C_{12} + C_{13} \ldots\ldots + C_{1n} \qquad 2.5.2$$

C_{ti} is the number of hectares cut in period t at age i. This implies that the hectares of forest at age i < n is what was left in the previous period less the current period cut. This is represented as:

$$X_{ti} = -C_{ti} + X_{t-1\ i-1} \text{ for all } t,\ i = 1, \ldots n-1 \qquad 2.5.3$$

When i = n it is assumed that the previous period's trees of age class n remain in age class n forever. That is:

$$X_{tn} = -C_{+n} + X_{t-1\ n-1} + X_{t-1n} \qquad 2.5.4$$

Growth after age n is assumed to be offset by tree mortality.

The initial conditions are defined as:

$$\bar{A} = \bar{x}_{00} + \bar{x}_{01} + \cdots x_{0n} \qquad 2.5.5$$

For ease of exposition Johansson and Lofgren write the conditions (2.5.1 - 2.5.5) in matrix notation.

$$Ix(0) = \bar{X}(0)$$

$$I\,x(t) - Bc(t) - Ax(t-1) = 0 \qquad (t = 1, \cdots, T)$$

where:

$$x(t) = \begin{bmatrix} x_{t0} \\ \vdots \\ x_{tn} \end{bmatrix} \qquad c(t) = \begin{bmatrix} 0 \\ c_{t1} \\ \vdots \\ c_{tn} \end{bmatrix}$$

and

I, A and B are (n + 1) * (n + 1) matrices

$$I = \begin{bmatrix} 1\,0 & \cdots & 0 \\ 0\,1 & & \\ \vdots & \ddots & \\ & & 1\,0 \\ 0 & & 0\,1 \end{bmatrix} \quad A = \begin{bmatrix} 0\,0 & & 0 \\ 1 & & \\ 0 & \ddots & \\ \vdots & \ddots & 1\,0\,0 \\ 0 & \cdots & 0\,1\,1 \end{bmatrix} \quad B = \begin{bmatrix} 0\;1 & \cdots & 1 \\ 0\,{-1}\;0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0\,{-1} \end{bmatrix}$$

A profit maximising forest owner would have the problem

$$\underset{c(t)}{\text{Max}}\ NPV = \sum_{t=1}^{T} P_t c'(t) G \qquad 2.5.6$$

subject to

$$\left[\begin{array}{cccccc|cccc} I & 0 & 0 & \cdots & 0 & & 0 & \cdots & & 0 \\ -A & I & 0 & \cdots & 0 & & -B & 0 & & \\ 0 & -A & I & & & & 0 & & & \vdots \\ \vdots & & \ddots & \ddots & \vdots & & \vdots & & & 0 \\ 0 & \cdots & & 0 & -A & I & 0 & \cdots & 0 & -B \end{array}\right] \begin{bmatrix} X(0) \\ \cdot \\ X(T) \\ \hline C(1) \\ \cdot \\ C(T) \end{bmatrix} = \begin{bmatrix} \bar{X}(0) \\ 0 \\ \vdots \\ \hline \vdots \\ 0 \end{bmatrix}$$

and

$x(t),\ c(t) \geq 0$

where the growth function can be $G = (0, g_1, g_2, \ldots g_n)$ and where $g_i > 0$ is the cubic metres per hectare at age i. $c'(t)C = c_{t1}g_1 + c_{t2}g_2 + \cdots c_{tn}g_n = c_{(t)}$ is the total cubic metres of wood in period t. $P_t \geq 0$ is the present value of the prices per cubic metre in period t. The linear programming approach requires that price be independent of the harvest level although prices could be a function of tree age. It can be argued that this is a reasonable long-run assumption since all forests would be price takers in the long run.

For every linear maximisation problem there exists a counterpart minimisation problem called the dual. The optimal values of the objective functions of these two problems will be identical (Chiang, 1984). In some cases the dual problem is easier to solve than the original (primal) problem. Solving the dual of a problem also identifies the opportunity cost or shadow price of using resources.

Johansson and Lofgren (1985, p.117) identify and solve the dual to the maximisation problem (2.5.6, 2.5.7). The dual is:

$$\min_{\lambda(0)} v = \lambda(0)\, \bar{x}(0)$$

subject to

$$\lambda(t-1)\, I - \lambda(t)\, A \geq 0 \qquad (t = 1, \cdots, T-1)$$

$$-\lambda(t)\, B \geq p_t G \qquad (t = 1, \cdots, T)$$

$$\lambda(t) \geq 0 \qquad (t = 0, \cdots, T)$$

where

$$\lambda(t) = \left[\lambda_{t0}, \lambda_{t1}, \cdots, \lambda_{tn}\right]$$

The λ_{ti}'s are the shadow prices or opportunity costs of land of age i at time t. Stated another way the dual problem is to minimise the value of the initial composition of forest land subject to the restrictions that at time t-1 land is at least as valuable as land at time t. Also, the shadow price of land at time t is at least as great as the present value of the wood plus the value of the seeded land (Johansson and Lofgren, 1985, p.117).

The solution to the dual problem is basically a restatement of the Faustmann solution (2.3.3); that is, harvest the stand if:

$$\lambda_{t0} + p_t g_i > \lambda_{t+1\ i+1}$$

which means a harvest should occur if the land rental plus the value of the growth is greater than the next period's land value. Johansson and Lofgren (1985, p.118-121) show that optimal management, in terms of rotation length, of the linear forest does not depend on the size and composition of the forest. Johansson and Lofgren state that this result is the justification of stand level (Faustmann) analysis of forest management problems. If there are increasing returns to scale with harvesting and other non-linear effects then stand level analyses would not be appropriate.

The approach has clear linkages to the forest economic theory set out in section 2.3. If only stumpage values are incorporated into the problem it is a multiple-stand Faustmann formulation. If non-wood outputs and economic values are incorporated it becomes analogous to the discrete time version of the Hartman formulation. Johansson and Lofgren go on to develop harvesting rules in which certain non-linear relationships are introduced into the management problem. In particular they considered the cost structure of timber harvesting where harvesting costs are a function of tree age (size). Needless to say the theoretical results become increasingly complicated (see also Heaps and Neher, 1979).

Given the state of knowledge about both physical effects of management and economic costs and benefits, the linear approach would appear to be the most feasible approach to analytical forest planning for public agencies. Opportunity costs of various forest management strategies can be evaluated by incorporating constraints on activities or non-wood values not included in the objective function. The US Forest Service has, roughly speaking, adopted this sort of LP approach to planning (Johnson *et al.*, 1986). The US Forest Service has attempted to estimate economic values for some non-wood values. If values for non-wood resources are not incorporated into the objective function the solution can be constrained to meet particular management objectives for those goods and services. Constraints specify the attainment of particular levels of activities or outputs. By comparing the results of unconstrained model formulations to constrained models the opportunity costs of management objectives for those un-priced resources can be estimated. This approach sidesteps the issue of valuing all forest resources in the initial problem formulation, yet still in principle allows an analyst to track physical effects of say, harvesting on other forest resources. To the best of this author's knowledge none of the Australian State forestry agencies have adopted this sort of approach to planning on an operational scale.

2.6 Summary and Conclusions

This chapter examined the economic theory of relevance to multiple-use management of public forest lands. Section 2.1 briefly clarified the notion of economic efficiency and identified the major features of CB analysis. Section 2.2 reviewed major valuation issues in forestry. Included in the discussion were stumpage values, the derivation of economic values for un-priced goods and the practical difficulties of determining forest management costs. The travel cost, hedonic travel cost and contingent valuation methods were reviewed. Although each technique is useful in a particular context, the methods require a great deal of expertise and data that is not likely to exist in many public forestry agencies. Also, the diffuse and varied nature of many un-priced forest goods and services presents some conceptual problems for ubiquitous applications of the techniques.

Section 2.3 identified the economic theory of relevance to the management of single forest stands inclusive of both wood and non-wood values. With wood as the only socially valuable output of a forest it was shown that the optimal economic Faustmann rotation is less than the foresters' preferred (MSY) rotation length unless the social time preference rate is zero. Depending on the nature of the non-wood benefit flows through time, optimal rotation ages inclusive of non-wood values may be more or less than the Faustmann rotation. There are no unambiguous generalisations about rotation lengths that arise from a single-stand formulisation of the multiple-use problem. The rotation problem solution is entirely empirical, based on each particular set of biological and economic circumstances.

Section 2.4 discussed the multiple-use planning problem when stand interdependencies exist. A model by Bowes and Krutilla (1985) with stand interdependencies was discussed. They used a hypothetical data set and a dynamic programming approach to model interdependencies arising from the forest age structure. Spatial relationships can also be important in multiple-use forestry analysis but was not included in the Bowes and Krutilla model. To this author's knowledge there are no empirical analyses of the multiple-use multiple-stand planning problem. Computational and data problems would exist with such an approach.

Section 2.6 discussed an operational approach to analytical forest planning. Linear programming is a standard, computationally efficient approach to large forest planning problems. The non-linear relationships that exist in many forest ecosystems are often poorly understood and in fact are a major stumbling block to quantitative scientific-based planning. In some cases the non-linearities may not be important for planners. In other cases the LP approach can be adapted through constraints which represent policy objectives for poorly understood resource/management interactions. So despite the non-linearities in forestry the linear framework is a practical methodology for considering multiple-use problems.

Under particular conditions, forest owners maximising the net present value of the goods and services from their land will maximise social welfare. Using this objective as a benchmark provides a point of departure for foresters to assess forest policy. The LP approach can, in principle, examine the implications of a wide range of constraints that arise out of concern for non-wood values. Given the limitations of both physical and economic data for forest planning, practical analytical techniques like LP are required to stimulate critical thought on forest management objectives. Unquestioning acceptance of rules of thumb management like MSY where multiple-use is the objective is not likely to result in efficient forest management.

The quantitative economic approach has not been adopted by most public forest agencies either in Australia or elsewhere. The following chapter reviews what public forest planners do in practice, examines the legislative impetus behind their actions and identifies some of the impediments to economic analysis in public forestry.

CHAPTER 3

PUBLIC SECTOR FOREST MANAGEMENT PLANNING IN PRACTICE

3.0 Introduction

This chapter has two major purposes. The first is to identify and describe forest management planning practices for a number of public sector forestry agencies.[4] This description is a precursor to the second major purpose of the chapter; that is, to articulate the major impediments to using the economic principles described in the previous chapter as a guide to forest management planning.

What forest planners have been trained to think about with respect to the planning of wood and non-wood resources is briefly reviewed in Section 3.1. Section 3.2 provides an historical perspective on current forestry planning practices in North America. Section 3.3 does the same for the States of Australia. Section 3.4 identifies some impediments to economic management including various data and computational problems and the apparent distrust, in some circles, of the use of economics for forestry problems. The chapter is summarised in section 3.5.

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4. It is not the purpose of this chapter to describe all the technical and administrative aspects of forest management. For example, disciplines such as forest mensuration (forest measurement) and organisational behaviour provide important inputs to effective forestry but this thesis is more concerned with long-term planning considerations.

3.1 An Overview of Forest Planning

According to Davis (1966):

> Forested lands are managed for a multiplicity of purposes, with usually one use, frequently timber production, dominant on a particular area. Forest lands can often be managed for several uses, sometimes on the same area and sometimes with different dominant uses assigned to separate areas. Management of the whole is directed to achieve the greatest total net benefit. A forest managed primarily for timber production can frequently, and with comparatively small adjustment, serve watershed, wildlife, or recreational purposes. In fact, a major use, well administered, often ensures others. In some situations, however, land uses are incompatible, one with another, and priority decisions must be made. Grazing, for example, often does not fit in with timber or recreational use. Recreation is sometimes so strongly the dominant use that timber cutting, grazing, and hunting must be entirely suppressed.

Forest planners have been traditionally trained to try to organise a forest to provide a steady flow of wood over time. They have the difficult task of balancing short-term fluctuations in demand, with "sustainable" longer-term wood flows whilst satisfying non-wood objectives mentioned above. Timber management often attempts to organise a forest to a so-called fully regulated normalised condition; that is, a forest in which there is a "progression of size and age classes so that harvestable trees in approximately equal volume are regularly available for cutting" (Davis, 1966).

A number of formulae were developed, particularly by early European foresters, to help estimate sustainable harvests. Examples of these include the following (from Davis, 1966).

Hundeshagen's formula:

$$Ya = (Yr/Gr)*Ga$$

where:

Ya	=	growth or yield obtainable in the forest
Yr	=	growth or yield in a fully or desirably stocked forest
Gr	=	growing stock in the fully stocked forest
Ga	=	growing stock in the actual forest.

Austrian formula:

Annual cut = I + (Ga - Gr)/a

where:

I	=	annual increment of wood growth
Ga,Gr	=	as defined previously
a	=	an arbitrary adjustment period.

Hanzlik formula:

Annual cut = (Vm/R) + I

where:

Vm	=	volume of mature timber above rotation age
R	=	adopted rotation period
I	=	annual increment of growth.

Simple area control:

Annual cut (hectares) = total area/rotation length

Forested land is rarely homogeneous enough to simply be divided up into relatively equal harvesting units. Hence the simple area control formula is rarely applied. These formulae, although rudimentary, did and in some places continue to provide foresters some assistance in determining annual allowable harvest levels. More complex analytical and quantitative procedures are now available and are being taught in forestry schools. This is reflected in the content of recent textbooks on forest management which emphasise mathematical programming and economic analysis (Davis and Johnson, 1987; Buongiorno and Gillies, 1987; Leuschner, 1984; Clutter *et al.*, 1983). These texts also recognise the multiple objectives of forest managers. Leuschner (1984) provides a more refined definition of forest management:

> ... the study and application of analytical techniques to aid in choosing those management alternatives that contribute most to organisational objectives.

The use of advanced analytical techniques for planning of public forests is not wide-spread. Rather than examining the training of forest managers, it is more important to determine what public forest planners actually do, what tools they use, and to what degree do economic principles influence them. The United States Department of Agriculture Forest Service (USFS) experience is perhaps the most well-known and studied. The following is a brief account of the USFS's planning history and current techniques.

3.2 North American Forest Planning

3.2.1 The US Forest Service Experience with Forest Planning

Iverson and Alston (1986) provide a historical summary of planning in the USFS and the following discussion is adapted from their work unless otherwise indicated. The USFS can trace its roots back to 1876 when an agent for forestry research was appointed for the Commissioner of Agriculture (Robinson, 1975). The Forest Service was created as a result of what is known as the *Organic Act* of

1897 and the *Transfer Act* of 1905. Its creation arose through a general concern about forest practices in the US in the later part of the 1800s. The 154 US National Forests currently comprise approximately 77.3 million hectares. Initial management was more of a stewardship nature (ie. custodial management) but has now evolved to a much higher level of complexity which involves attempts at quantitative integrated resource planning for both wood and non-wood values.

In 1911 guidelines were developed for the development of three types of plans: preliminary plans, working plans, and annual plans. Plans focussed on "working circles", areas of the forest managed on a sustained yield basis primarily to support local wood-based industries. The plans generally contained reports on wood inventories, condition of the standing stock, sustainable harvest levels and other important resource attributes in the area. The scope of the plans then, and even to a large degree now were a reflection of the views of Gifford Pinchot. He was appointed Chief Forester of the USFS in 1898 and has been credited as the driving force and the dominant philosophy behind forest management in the US. By the 1930's multiple-use considerations were becoming more important and controversial. A congressional report in 1933 called for more flexible multiple-use management that reflected national economic conditions. This represented a shift in emphasis of public land use planning to reflect desires for community stability and employment opportunities in the wood processing sector and was likely a response to the economic depression of the time.

Management plans prior to World War II were largely academic in the sense that suggested harvest levels were rarely attained because private lands were still able to supply wood at lower cost. After World War II management and management planning intensified as computer technology became available and biophysical data bases improved. From the 1920's to the 1950's the Hanzlik formula was used in many areas to assist in determining allowable harvests. However, the effects of harvesting the country's virgin forests were generating questions about the management of future forests (eg. rotation lengths and alternative management practices: Iverson and Alston, 1986; Robinson, 1975). Simple formulae such as Hanzlik's were not adequate to analyse the transition from old growth virgin forests to more regulated forests.

In the last three decades six pieces of legislation have had a profound affect on the way the US National forests are planned. The *Multiple-Use and Sustained Yield Act* of 1960 gave the US Forest Service legislative backing for a multiple-use philosophy it adopted to meet rising demand for wilderness preservation (Robinson, 1975). This Act also forced the USFS to think more seriously about multiple-use. The *National Environmental Policy Act* (NEPA) of 1969, forced consideration of environmental impacts of projects on federal lands. The *Clean Air Act and Clean Water Act* (1970-1977) affected forest harvesting activities; and the *Endangered Species Act* of 1973 gave endangered species habitat maintenance higher priority over other land uses (Davis and Johnson, 1987). However, it was the *Resources Planning Act* (RPA) (1974) and the *National Forest Management Act* (NFMA) (1976) that provided a mandate for planning on the National Forests. This has forced the USFS to prepare plans capable of withstanding court challenges from special interest groups.

A great deal of time and effort has gone into planning and at least one analyst (Behan, 1981) has gone so far as to suggest that the RPA/NFMA legislation be repealed to lower costs and "get forest management decisions out of the courts and back into the forest." To comply with the RPA/NFMA the USFS must meet the following requirements:

1. provide for multiple use and sustained yield of the products and services obtained from management in accordance with the Multiple-Use Sustained-Yield Act of 1960, and, in particular, include coordination of outdoor recreation, range, timber, watershed, wildlife and fish, and wilderness;

2. determine forest management systems, harvesting levels, and procedures in the light of all of the potential uses, and determine the availability of lands and their suitability for resource management;

3. provide for methods to identify special conditions or situations involving hazards to the various resources and their relationship to alternative activities;

4. consider the economic and environmental aspects of various systems of renewable resource management, including the related systems of the silviculture and protection of forest resources, to provide for outdoor recreation (including wilderness), range, timber, watershed, wildlife and fish;

5. provide for diversity of plant and animal communities based on the suitability and capability of the specific land area in order to meet overall multiple-use objectives. (USFS, 1988a).

To meet these requirements the USFS has developed a 10 step planning process which can been summarised as follows:

1. identification of public issues, management concerns, and resource opportunities. The "Issues and Concerns" step requires intensive public involvement to ensure that the public issues are actually those issues perceived by the public, and not just those perceived by the Forest Service;

2. development of planning criteria. Three forms of criteria will be developed. "Process" criteria guide the data gathering and analysis and the formulation of alternatives. "Decision" criteria guide the selection of the proposed alternative. In addition "public policy" criteria guiding all aspects of the planning process are identified;

3. inventory data and information collection. The interdisciplinary team[5] must determine what data is absolutely necessary, based on the issues and concerns;

4. analysis of the management situation. This analysis brings existing information together, puts it into a total Forest perspective, and states the problems the various alternatives should resolve. It examines supply analysis, market assessments for forest and rangeland outputs, and determination of suitability and feasibility;

5. formulation of alternatives. The alternatives must "reflect a range of resource outputs and expenditure levels." A "no-action" alternative (ie, continuing current management) is required, but a "no-harvest" or "no-use" alternative is not. The issues and concerns process becomes important here, as each "identified major public issue and management concern will be addressed in one or more alternatives." Each alternative will represent the most cost-efficient way of attaining the objectives set for that alternative;

6. estimation of effects of alternatives. The "physical, biological, economic, and social effects" of each alternative are to be estimated, including how each "responds to the range of goals and objectives assigned by the RPA Program";

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5. The Forest Service has experts from a variety of disciplines involved with planning for each National Forest.

7. evaluation of the alternatives. The alternatives are tested against the decision criteria developed earlier. The alternative or alternatives which best meet this criteria will be identified by the interdisciplinary team as the preferred alternative in the draft Environmental Impact Statement;

8. selection of an alternative. While the interdisciplinary team identifies a preferred alternative in the draft EIS, the Forest supervisor selects an alternative and the regional forester approves the "selected alternative" in the final EIS. The appropriate official must "document the selection with a description of the benefits, relative to other alternatives";

9. implementation of the plan. The Forest plan is the basis for developing multi-year programs and budgets. To aid in this process, the scheduling and location of management prescriptions will be identified;

10. monitoring and evaluation. The NFMA regulations contain several specific requirements for monitoring and evaluation. Plans must detail the timing, precision, and variables to be monitored (from Jameson et *al.*, 1982 p.7-8).

Jameson *et al.* (1982) describe the planning steps in much more detail. The USFS has interpreted the directives to include quantitative analysis. The analytical planning methods involve mathematical optimisation techniques like linear programming. Iverson and Alston (1986) discuss the development of three of these models: Timber Resource Allocation Method (Timber RAM, Navon, 1971), Multiple-Use Sustained Yield Calculation Technique (MUSYC, Johnson and Jones, 1979) and FORPLAN (FORest PLANning, Johnson *et al.*, 1986). Timber RAM, MUSYC and FORPLAN version I were essentially timber harvest scheduling models in which multiple-use considerations could only be accounted for through constraints on timber production or timber prescriptions.

FORPLAN version II was developed out of a desire to create a model more amenable to multiple-use and economic considerations. This means that non-wood values and prescriptions could be explicitly entered into the optimisation problem. There are generally 8 categories of information used in FORPLAN.

1. analysis areas or land units;
2. management prescriptions;
3. management activities that make up the prescriptions;
4. costs of the activities;
5. outputs and/or environmental effects;
6. benefits and/or costs of outputs and environmental effects;
7. objective function - value or output to be maximised or minimised;
8. constraints or management objectives that either are not or cannot be incorporated into the objective function.

FORPLAN is capable of generating a number of the reports required by the NFMA. These include growth, inventory and harvest reports and some financial summaries. In 1979 FORPLAN was designated as the primary planning tool for the USFS to quantify the integration of multiple-uses and examine the trade-offs of alternative management strategies. It is important to note that the USFS does not consider FORPLAN or other models as ends in themselves but rather as "aids in decision making ... managers must also consider other available information, public comment, and experience and exercise professional judgement in making decisions" (Robertson, 1987). More details on FORPLAN are given in Chapter 4.

The ongoing development of FORPLAN and its current use are not without difficulties. FORPLAN is difficult to learn to use properly and like most models it can be misused through poor objectives, data and interpretation. However, it appears that the USFS is committed to using FORPLAN at least because there is no better alternative available (Norbury, *pers comm.*). There does not appear to be any other examples of public forestry agencies committed to a quantitative planning model at an operational scale that can, in theory, examine multiple-use issues.

3.2.2 Forest Management in Canada

Public forest management in Canada is significantly different to that of its neighbour for a number of political, biophysical and demographic reasons. In Canada there are, relatively speaking, very few private holdings of forest land competing with the public sector. Most forests are owned by the provinces. Federal government ownership of forests is extremely limited, so much of its forestry-related activities are targeted at research questions rather than management *per se*. Forest management is practiced mainly by provincial agencies although in many regions there are moves for more corporate responsibility over forest renewal. For example forest management agreements in Ontario between companies and the province specify forest renewal targets.

There is a long history of concern over forest management, harvesting and renewal practices in Canada (Swift, 1983; Drushka, 1985; MacKay, 1985; Reed, 1978; Fellows, 1986). Reasons cited for so-called "bad management" (*viz.* only 46% of harvested areas are treated for regeneration) include unclear tenure, funding problems (Weetman, 1986) and a lack of economic and financial incentives for forest renewal (Pearse, 1985). The resultant condition is claimed to be forests that have been mined rather than actively managed on a renewable basis. Such an outcome is not necessarily inconsistent with private or social economic rationality. Potential biological renewability need not imply that any given forest be treated as a renewable resource in the economic sense. For discussions of this topic see Hyde, (1980), Lyon (1981), and Berck (1979). This possibility may be particularly relevant to the virgin forests of Canada. It may be that growth rates on some of the forest land in Canada are so low relative to those in more temperate climates that intensive managerial investments for future timber yields is not economically rational at current costs and stumpage prices (see Anderson, 1979; McKenney, 1986).

Management planning particularly for multiple-use has generally not been achieved through the use of quantitative analytical models like FORPLAN. The British Columbia Forest Service (BCFS) has investigated the USFS models Timber RAM, MUSYC, and FORPLAN. FORPLAN was found to be too difficult to understand and to require excessive resources for proper implementation. The BCFS uses MUSYC[6] to support its timber supply planning process (Dellert, 1986). The planning requirements of the BCFS are sufficiently different from the USFS so as to negate the need (at least historically) for quantitative multiple-use planning. Much of the forested parts of the province are located in remote areas and are managed primarily for wood production. The basic legislative underpinnings of the BCFS found in the *Forests Act* 1978 are as follows:

1. encourage maximum productivity of the forest and range resources in the Province;

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6. The Canadian Forestry Service has contracted researchers at the University of British Columbia to update and enhance the MUSYC code. Merckel has redeveloped the model and it should be available through the CFS (Merckel *pers comm.*). As of June 1990 the BCFS is considering dropping MUSYC as a planning tool. Such planning is performed centrally and perceived as a "black box" approach by district foresters who have to implement the plans (Gunton *pers comm.*).

2. manage, protect and conserve the forest and range resources of the Crown, having regard to the immediate and long term economic and social benefits they may confer on the Province;

3. plan the use of the forest and range resources of the Crown, so that the production of timber and forage, the harvesting of timber, the grazing of livestock and the realisation of fisheries, wildlife, water, outdoor recreation and other natural resource values are coordinated and integrated, in consultation and cooperation with other ministries and agencies of the Crown and with the private sector;

4. encourage a vigourous, efficient and world competitive timber processing industry in the Province; and

5. assert the financial interest of the Crown in its forest range resources in a systematic and equitable manner. (From Dellert, 1986).

The bureaucratic interpretation of the Act has been to establish Timber Supply Areas (TSA's) and Tree Farm Licences (TFL). The private sector manages the TFL's while the BCFS plans the management of each of the TSA's. According to Dellert (1986):

> ... A TSA Plan is developed by the Forest Service for each TSA every five years and includes timber, range, and recreation production targets, management direction and the location of 20-year harvesting areas for each licensee in the TSA. The timber supply analyses carried out to support the TSA Plan are done centrally, unlike the decentralised approach in the USA. ... Timber dominates in British Columbia's planning system and other resource values are recognised as constraints on timber harvesting. Timber harvesting plans are referred to other resource agencies for review and conflicts are normally settled through consultation and negotiation at a local level.

Whether or not integrated resource management planning will remain non-quantitative is likely to depend upon both political pressure and bureaucratic initiatives. As the USFS can attest, the use of quantitative models is costly. The BCFS has discovered this and appears at the time of writing not to be committed to this sort of planning.

Ontario, another province well-endowed with forests, albeit less so than BC, appears to be even less committed to quantitative analysis of the type employed by either the USFS or the BCFS. The Ontario Ministry of Natural Resources (OMNR) mandate includes management of lands, waters, timber resources, outdoor recreation, fisheries and wildlife. Forest management has been generally defined by three OMNR policies:

1. Sustained yield management policy. As defined by Ontario's Crown Timber Act sustained yield is:

> ...the growth of timber that a forest can produce and that can be cut to achieve a continuous approximate balance between growth of timber and timber cut. (Ontario Ministry of Natural Resources (OMNR), 1987, p.2).

2. Forest production policy. The forest production policy essentially means:

> ...an optimum continuous contribution to the economy of Ontario by forest-based industries requires quantification of a level of continuous timber supply (ie sustained yield), the time period in which to achieve the objective, and the necessary investment for activities such as provision of access, renewal and maintenances. (OMNR, 1987, p.5).

A target of 25.8 million cubic metres of annual wood harvest has been set for the year 2020.

3. Integrated resource management policy. The integrated resource management policy originated from the concept of multiple-use and has been defined as:

> ...the coordination of resource management programs and activities so that long-term benefits are optimised and conflicts between programs are minimised. (OMNR, 1987, p.7).

The *Crown Timber Act* (1982) and the *Environmental Assessment Act* (1975) provide the major legislative guidelines to forest management in the province. Timber management planning has developed under the direction of the above mentioned Acts and policies and is required for all crown (public) management units, company management units and forest management agreement areas (tracts of publicly owned forest that companies are responsible for managing). Timber plans are prepared for each management unit every 5 years. The plan covers a 20 year period but provides longer term direction, and detailed operations for the first 5 years of the plan. The planning process can be likened to the US 10 step approach although it is more clearly wood oriented:

1. assembly and analysis of background information;

2. determination of management direction for the management unit

   - establishment of management objectives and strategies,

   - selection of silvicultural system(s) and determination of silvicultural ground rules,

   - determination of maximum allowable depletion,

3. identification of potential areas of operations for the 20-year period of the timber management plan

   - identification of areas eligible for harvest, renewal and maintenance operations,

   - identification of preliminary areas of concern,

- determination of the type and general location of primary access system,

4. determination of operations for the five-year term of the timber management plan

   - determination of planned harvest,

   - determination of renewal and maintenance program,

   - selection of areas for harvest, renewal and maintenance operations,

   - identification of specific areas of concern,

   - determination of operations: harvest, renewal and tending operations; access. (OMNR, 1987, p.14).

Public review and participation in the planning process is encouraged. Non-wood values are maintained, enhanced or preserved through the establishment of modified management areas and areas of natural and scientific interest (OMNR, 1986).

In Ontario, a Forest Resource Inventory, in the form of forest stand maps, is the principle information source. The harvest for a 5 year period, called the Maximum Allowable Depletion (MAD), is determined by a method roughly analogous to the simple area control approach described in section 3.1. The OMNR has software available for microcomputers to perform the calculations and also a simulation model called Ontario Wood Supply and Forest Productivity (OMNR, 1986). Sometimes the MAD calculations are performed manually. Forest regeneration practices are generally based on standard silvicultural practices for the species. As mentioned previously, some studies have shown that standard silvicultural practices may not be economically rational on all sites (Anderson, 1979; McKenney, 1986). Although Ontario does have a framework and philosophy on integrated resource management, the use of analytical tools, inclusive of economic efficiency considerations, appears to be minimal.

Generally speaking, other provinces in Canada have similar legislation, philosophies and problems with forest management so forest policy in the other provinces is not reviewed here.

3.3 Forest Management Planning in Australia

Forestry in Australia has its own particular set of circumstances but it does exhibit some characteristics similar to Canadian experiences. Australia is a large country in area with a relatively small population and run on a federal parliamentary system similar to that of Canada. Unlike the expansive forests of Canada, commercial forests in Australia are generally only concentrated in coastal ranges, particularly along the eastern seaboard. Like Canada, primary responsibility for management of public forests rests with the States. Each State has developed its own legislative requirements for forest management practices. The general extent of the forests is described in Table 3.1.

The following is a brief summary of the legislative mandates and forest planning practices on the native forests for the six States of Australia. The Australian Capital Territory (ACT) and Northern Territory governments are not significantly involved with native forest management that includes wood production so they are not covered in this review. A recent Institute of Foresters of Australia Conference (September, 1989) was devoted to the subject of forest planning. More details on current forest planning practices in Australia are given in those Proceedings, particularly Drielsma (1989). As mentioned in Chapter 1, the Federal Government has established a Resource Assessment Commission (RAC) to investigate major

Table 3.1: Australian Native Forest, General Extent, 1986-87

	AUST	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
*Total native forest (sq. km)	408410	149590	52570	117960	0	26650	28470	32660	510
% of land area	5.4	19	23	7	0	1	44	2	21
*% by forest types									
Rainforest	5	2	<1	10	0	0	17	1	0
Eucalypt									
Productivity class I	6	8	9	2	0	6	16	0	0
Productivity class II	34	24	80	11	0	93	67	0	100
Productivity class III	29	54	11	28	0	1	0	0	0
Tropical Eucalypt & paperbark	16	0	0	35	0	0	0	75	0
Cypress pine	10	12	<1	14	0	0	0	24	0
*Ownership (%)									
Public									
- used for forestry	61	53	61	81	0	69	64	16	18
- forestry excluded	12	12	28	7	0	6	13	10	82
Private	27	35	11	12	0	25	23	74	0

Note: Total area @ 1987; proportions @ 1986, (100 hectares/sq.km)

Source: ABARE, 1988; ABARE, 1987

first inquiry is on forestry and its background paper is a Australian natural resource management issues. The RAC's useful overview of the current situation in Australian forestry (RAC, 1990).

3.3.1 New South Wales

The New South Wales Forestry Commission (NSWFC) was established through the *Forestry Act* of 1916. The major objectives of the Commission are:

1. The objects of the commission shall be:

   - to conserve and utilise the timber on Crown-timber lands to the best advantage of the State,
   - to provide adequate supplies of timber from Crown-timber lands for building, commercial, industrial, agricultural, mining and domestic purposes,
   - to preserve and improve, in accordance with good forestry practice, the soil resources and water catchment capabilities of Crown-timber lands,
   - to encourage the use of timber derived from trees grown in the State, and
   - consistent with the use of State forests for the purposes of forestry and of flora reserves for the preservation of the native flora thereon - to promote and encourage their use as a recreation; and to conserve birds and animals thereon;

2. In the attainment of its objects and the exercise and performance of its powers, authorities, duties and functions under this Act, the commission shall take all practicable steps that it considers necessary or desirable to ensure the preservation and enhancement of the quality of the environment (as stated in legislation passed by the State government and reported to the Senate Standing Committee on Trade and Commerce (SSCTC, 1981)).

According to Carron (1985), the NSWFC bureaucracy has interpreted this legislation as re-affirming the Commission's primary object of conserving and using timber on State forests and other crown-timber land to the best advantage of the State.

Approximately 3.8 million hectares of forest land is devoted to multiple-use that includes wood production. A further 4.8 million hectares can be used for wood production although it has not been specifically dedicated to that purpose. By 1988 there were 189 (599,428 hectares) nature reserves, 22 (59,880 hectares) State recreation areas and, 137 (35,012 hectares) flora reserves. New South Wales also has 68 (3,103,761 hectares) national parks (Mobbs, 1989).

Under the *Forestry Act*, policy has been broadly defined by the Indigenous Forest Policy (1976) and the Exotic Softwood Plantation Policy (1982). Specific objectives are given in management plans which cover 5-10 year periods. Operational plans detail harvesting practices and management impacts. Annual management plans provide feedback on the achievement of objectives (Drielsma, 1989).

Planning practices for the State's pine plantations have reached the level of quantitative analysis. A linear programming optimisation model called RADHOP was once used to schedule harvests of pine plantations (Donovan, 1982). However, the system is not currently in use (Turner, *pers comm.*). No similar decision support system has been developed for the native forests. The Commission does have a system for growth and inventory measurement on the native hardwood forests but no consistent analytical framework exists for investigating harvesting possibilities and investment potential or quantifying multiple-use problems.

3.3.2 Tasmania

Tasmania has been the focus of controversy on resource allocation many times, over hydroelectric development (see Saddler *et al.*, 1980 and Bates, 1984), World Heritage listings (Report of the Commission of Inquiry into the Lemonthyme and Southern Forests, Volume 1, 1988), and most recently over the potential establishment of an export pulp mill at Wesley Vale. It is often the use of the State's forests that is at issue.

Tasmania more than any other State in Australia relies on the wood products sector to contribute to the incomes of its people. The State government has attempted to promote activity in the industry through various incentive and subsidy schemes and has legislated agreements with wood-based firms (SSCTC, 1981). There are approximately 2.7 million hectares of forest in the State and the Tasmanian Forestry Commission is responsible for management of 1.8 million hectares which have been set aside for wood production (Drielsma, 1989). The State has 180 forest reserves totalling 113,813 hectares, and 13 national parks encompassing 851,140 hectares (Mobbs, 1989). The Tasmanian Forestry Commission (TFC) operates under the broad direction of the *Forestry Act* which was first enacted in 1920 and has since been amended. Working plans provide the major strategic direction for the four major forest concession areas in the State. Details on specific operations are given in management plans, forest management plans, and environmental effects studies (Drielsma, 1989).

The TFC has stated that it tries to manage the State's forests with the aim of ensuring stability in wood-based industries while maintaining acceptable environmental standards by:

1. the dedication to permanent forest use as State Forests of all productive forest lands not held under tenure as private property or as National Parks or other reserves. A minimum target area of 1,618,000 hectares has been accepted;

2. the continued protection of the forest estate from damage by fire, insects and disease;

3. extending the integration of use of forest products to reduce wastage, to provide an improved harvest of sawlogs, to service the expanding market for hard-wood pulpwood and to enable efficient programmes of forest regeneration to be undertaken;

4. regeneration programmes to cope with reforesting the increased area of forest harvested by integrated logging;

5. a steady annual programme of softwood areas where large units of softwood forest can be aggregated;

6. increased research activity to progressively improve forest health and growth and the techniques of forest regeneration and fire protection;

7. inculcating standards of forest management and harvesting so as to satisfactorily protect and maintain environmental forest values such as air and water quality, wildlife habitat, aesthetics, recreation, etc. (evidence given to the SSCTC, 1981).

The TFC does have simulation programs in operation for both its softwood and native forests which can be used to calculate long term yields (Leech, 1987). However, the Commission does not appear to have any models for quantitative analysis of timber harvesting and forest renewal investment decisions or multiple-use problems on an operational scale.

3.3.3 Queensland

The management of Queensland's native forests has also been controversial at times. For example, World Heritage listing of parts of the Wet Tropics in northern Queensland has caused considerable conflict between loggers, conservationists and the Queensland and Federal governments (Aiken and Leigh, 1987; Anon, 1988). Queensland has approximately 11.7 million hectares of forested land. The Queensland Forest Service (QFS) is responsible for the management of approximately 4.4 million hectares of forest. There are 257 State parks or various reserves totalling 141,640 hectares. The National Parks and Wildlife Service run the 317 National Parks in the State which comprise 3,522,129 hectares (Mobbs, 1989).

Forest planning occurs in a hierarchy of 4 levels: a state plan, strategic plans, forest group plans and, action plans. The state plan provides broad policy direction. Strategic plans deal with the management of general forest types throughout the State. The group plans and action plans provide details on specific management operations (Drielsma, 1989).

Although there was legislation as early as 1906 governing the reservation of State forests and national parks it was not until 1959 that a *Forestry Act* was enacted (Carron, 1985). The Queensland Forest Service's responsibilities include:

1. recommendation of lands for reservation as State Forests and Timber Reserves;

2. the management of State forests in a manner appropriate to the objective of producing timber;

3. determination of the maximum amount of timber which may be cut on a State forest during any period;

4. concomitant with the above, to give due regard to permitting grazing of the area, conserving soil and the environment, protecting water quality and promoting and encouraging recreational use;

5. the sale of timber from Timber Reserves, Forest Entitlement Areas and other Crown-owned land in the State and for managing this resource for the benefit of the community. (from SSCTC, 1981)

In 1976 the Forestry Act was amended to formalise the QFS's responsibility for multiple-use. This meant they had to

> ...give due consideration to water and soil conservation, environmental protection, grazing and recreation, in the management of State forests for wood production. (Carron, 1985).

Queensland also does not appear to have a formally recognised framework or quantitative model in place to examine multiple-use or forestry investment decisions on the native forests. They are developing a growth and yield model that will allow them to examine sustainable harvest levels (Leech, 1987).

3.3.4 South Australia

There are 130,000 hectares of softwood producing land in South Australia but no commercially productive native forest. Policy is broadly defined by the *Forestry Act* (1950-81) and centrally by the Chief Executive Officer and from assistant directors of the Woods and Forests Department. Details on operations are determined within local districts. Public forestry has primarily involved the establishment and maintenance of exotic softwood plantations to attain self-sufficiency in sawn timber markets. The State's policy is summarised as follows:

1. to see that there is established and maintained, within 1 per cent of the land area of the State which can support softwood growth, and consistent with other appropriate usage thereof, the maximum area of thrifty softwood plantation forests, so that:

- the wood needs of the State are met from within the State, so far as practicable,

- there be a wood resource within the State capable of supporting indefinitely a stable wood-processing industry;

2. to endeavour to continually improve the productivity and usage of this plantation resource towards maximum yield of wood as a primary aim, within a context of such multiple use as may be consistent therewith;

3. to encourage participation in the science and business of forestry by private individuals and companies, to such an extent, and in such ways, as the State Government may consider fit from time to time;

4. to maintain, within the care, control and management of the Woods and Forests Department, such sufficient forest reserve areas of generally forested lands or natural forest vegetation as may be needed to conserve the range of natural habitats of indigenous animals and plants thereon, for such of the protective, scientific, recreational and aesthetic needs of the community as it may be practicable to provide from time to time. (SSCTC, 1981)

South Australia has both short and long-term growth and yield simulation models to assist planning of the softwood resource (Leech, 1987). Multiple-use is generally not a significant issue on those lands in the way that it is on native forests in other States.

3.3.5 Western Australia

Although native forests in Western Australia (WA) occupy roughly 2.6 million hectares, this represents only about 1% of the total land area of the State. The *Forests Act* of 1918 provided the first legislated direction for the management of forests in the State. According to Carron (1985) the essence of the Act in terms of forest policy was

> ... that all prime timber be permanently reserved for forestry purposes; the principle of sustained yield should be applied to each mill so that the mills could have a guaranteed life, thus ensuring better social conditions for mill workers; appropriate silvicultural operations would be implemented to ensure regeneration of the best quality timber for the future; and plantations should be established to meet the softwood requirements of the State.

It was not until 1976 that the *Forests Act* was amended to formally recognise the Western Australian Department of Forestry policy of multiple-use. In 1984 the *Conservation and Land Management (CALM) Act* established the Department of Conservation and Land Management (CALM) as the State's primary agency responsible for both land management generally and forest management. The Department is responsible for managing 17 million hectares of public land, including roughly 15.2 million hectares of parks and reserves. A Strategic Plan outlines CALM's corporate strategy. Regional and Area management plans provide goals and objectives to land management within administrative regions. Issue and Operational plans detail management practices in districts for all relevant forest resources (eg. logging, research, wildlife management) (Drielsma, 1989).

There does not appear to be a quantitative method in operation by CALM to investigate long-term economic or multiple-use issues specifically on the native forests in a way that is similar to FORPLAN. A comprehensive study of land management in salt affected catchments in the south west of WA used a linear programming approach to broadly examine the trade-offs between different land uses including forestry (Bennett and Thomas, 1982). It may be possible to adapt the Bennett and Thomas approach for multiple-use problems but to the author's knowledge this has not occurred. A quantitative planning model exists to develop five year logging plans on the native forests. The department does have a model to investigate the economics of softwood production (Leech, 1987).

3.3.6 Victoria

Land management in Victoria has also been the subject of controversy in recent years. Various State agencies involved with land, soil and forest management and environmental matters have been amalgamated. In fact, recent developments in the State have made a case study on public forest planning, inclusive of economic principles, possible. The historical background to forest policy and planning is dealt with in Chapter 4.

3.4 Impediments to Quantitative Multiple-Use Planning and Economic Analysis

The previous discussion shows that multiple-use, or integrated resource management, is advocated as a major objective of public forestry in many jurisdictions. How policy manifests itself in management appears to depend not only on actual forestry legislation but also on bureaucratic interpretations. In Australia, as elsewhere, parks and reserves are often used to enhance, maintain or preserve various non-wood values. Timber harvesting activities are also modified to account for various non-wood values. The question of whether these approaches are too much, too little or just right to account for non-wood values depends on the context (ie. initial endowments and the non-wood values of interest).

It appears that the use of quantitative models to examine economic and biophysical trade-offs of various management strategies in a multiple-use context is rare. The theory presented in Chapter 2 indicates that properly conducted economic analysis should, in principle, account for various forest uses, not just wood. Why then have so few public forestry agencies attempted to incorporate economic theory and quantitative modelling into their planning practices? The following discussion identifies some of the reasons for this. Impediments include lack of legislative direction, data and computational problems, lack of appropriate expertise within the bureaucracies, high costs and, even a distrust of both modelling and economic analysis as paradigms to assist decision-making.

In the United States there is legislation which includes very explicit instructions on both the management and planning of the National Forests. For example, section 6(b) of the *RPA/NFMA Act*:

> In the development and maintenance of land management plans for use on units of the National Forest System, the Secretary shall use a systematic interdisciplinary approach to achieve integrated consideration of physical, biological, economic, and other sciences,

and section 6(g3) directs that the economic and environmental aspects of alternative strategies must be considered in the development of plans (see Le Master (1976) for a text of the *RPA/NFMA Act*). The lengthy instructions given to the Forest Service in the *RPA/NFMA Act* has resulted in an extensive and costly planning infrastructure, including the FORPLAN model, for the federally owned public forests in the US. Although the spirit of legislation and forest policy is broadly similar across the public agencies reviewed, only in the US has quantitative multiple-use planning occurred on an operational scale. Whether or not quantitative multiple-use planning would have occurred on such a grand scale without the explicit legislative impetus is difficult to know. Such explicit legislative mandates have not occurred either in Canada or Australia.

One of the most confounding problems for quantitative forest planning is a lack of both biophysical and economic data. Although it is dangerous to make sweeping generalisations about a problem common to most modelling exercises, multiple-use analysis is particularly plagued by data shortages. Scientific research and understanding has generally not reached the level of predictive capability necessary to answer long-term questions with reasonable certainty. Bowes and Krutilla (1987) discuss some of the empirical problems associated with physical production functions and economic benefit functions in the forestry context. There is typically very little hard evidence available about the response, over time, of non-wood outputs to timber harvesting or other silvicultural techniques. For example, what happens to water flows and quality 5, 10, 20, 50 or more years after timber harvests; what happens to various flora and fauna 5, 10, 20, 50 or more years after harvest? Timber growth and yield models are also difficult to obtain for some species. Many of the effects involve stand interdependencies that are highly uncertain. The Bowes and Krutilla dynamic programming approach, reviewed in Chapter 2, included stand interdependencies but it is not practical due to data and dimensionality problems.

Since it is impossible to model all multiple-use responses and values over time, careful consideration of which factors provide the most insight on multiple-use values is important for practical applications of quantitative planning. Forest outputs which inherently capture a wider range of uses and values should be modelled. In other words, due to the complexity of forests, proxy indicators of the general forest condition through time should be used for practical quantitative multiple-use planning (eg. a suitable range of age class outputs to capture various flora and fauna values).

Another important impediment to the use of mathematical modelling techniques is the level of expertise and budget required. Many public forestry agencies do not have either the quantitative skills or the budgets necessary for such planning exercises. Given the large number of people involved in land management, any shift in work practices can have repercussions throughout the entire bureaucracy. Agencies interested in operationalising quantitative planning need clear objectives, well co-ordinated planning teams, and a preparedness to spend the necessary money.

Forestry appears to be a profession marked by a distrust of the use of the tools of economics to aid decision-making. With respect to the influence of economists in the USFS Robinson (1975, p.270) points out:

> ...The absence of economists in the mainstream of agency decision making in the National Forest System is not an oversight. The institutional neglect reflects an underlying professional bias against modern economic analysis and economists on the part of the traditional foresters who still dominate the agency. The bias is to an extent inherent in professional forestry itself. Notwithstanding that economics is a component of silviculture - the centerpiece of traditional forestry - it has tended to be dominated, if not overwhelmed, by the biological aspects.

Fitzsimons (1986) has written a critique of cost-benefit analysis which may be indicative of the attitude of many foresters. She criticises the use of prices as reflections of social value and the use of discount rates in forestry analysis. While there are controversies among economists on factors like appropriate discount rates, such condemnations by non-economists often reflect misunderstandings about cost-benefit analysis, the underlying economic theories, and the role of cost-benefit analysis in decision making.

Reed (1979), formerly assistant deputy minister in charge of forestry for the Canadian federal government, has also been critical of the use of economic analysis in forestry:

> ...Why is it so difficult for people to see that provincial forests are a gift from nature, a fabulous stock of capital already in place? Annual maintenance and indeed improvement of that capital is essential for the protection of future generations. Part of the cost of harvesting a stand is its replacement, with a crop just as good and hopefully better. It is time to exorcise the ghost of Martin Faustmann, the German author who first popularised the discounted cash flow concept ... the discounted cash flow approach will not give you the correct answer concerning how much forestry to practice on public land.

Reed does not offer a method that will provide the "correct" answer but infers that high wood product prices and community stability are the primary reasons for intensifying forestry investments in Canada. Reed's concerns imply that the notion of long-run economic efficiency is irrelevant with respect to the growing of trees. One of his inherent assumptions is that maintenance or increases of employment in the forestry sector would be better for society than employment in other sectors. Another assumption appears to be that wood products have some merit good nature to them such that low prices, irrespective of the cost, is a necessary social goal.[7] While it is clear that certain aspects of forests have either merit or public good characteristics, it is not clear that wood products are one of them.

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7. As a point of clarification, public goods in their pure form, are generally available to all because there are no feasible ways of excluding any consumer and consumption by one consumer does not interfere with the amount available to all others. The definition of merit goods is more controversial. It could be stated that a merit good is a private good that has been endowed with the public interest, such that total production could be justifiably subsidised for perceived collective benefits. An example is that urban water supply provides a collective benefit in the form of public health. (Milliman, 1972).

It is the view of this author that economic analysis should be seen as an input to decisions on forest management. Due to certain theoretical and operational difficulties such as, lack of perfectly competing markets and problems in determining prices for non-marketed goods, it is unlikely to ever be seen as the sole input. A proper economic approach to forest management should provide an internally consistent and systematic way to help to clarify the choices in land use and management (see Freeman and Portney, 1989). So while commentators like Reed and Fitzsimons may disagree with the use of economics for forestry decisions they cannot deny the existence of trade-offs between different management choices. What economists can do is help identify the efficiency implications that will exist between different forest management paths. Whether or not foresters choose efficient paths is another matter.

Beyond even the use of economic analysis is a suspicion of the use of modelling techniques in general. According to Batini (1987) (referring to a linear programming cost-benefit model):

> ...This approach was not widely accepted for either government or private planning. Factors inhibiting acceptance included the doubts of the scientists, who knew that the analysts' numbers did not have the rigour of their own work. For many of them, modelling is mere speculation. There were also those individuals and decision makers who neither understood nor trusted the technicalities of mathematical models and those who clearly saw that their interests were not served by exposing their arguments and activities to analysis. Finally there was a concern that the 'soulless' analyst would have failed to consider, or to cater adequately for, humanity's real needs and values.

The distrust of modelling is an important impediment to the use of analytical tools on a widespread scale. In fact, it is often the case that politicians and interest groups use numerical analysis out of context in pursuit of their own narrow objectives. In these cases one can be sympathetic to the distrust. Perhaps not enough emphasis has been placed on the use of such tools as simply inputs to decision-making. With so much uncertainty involved in long-term forestry planning, results of quantitative exercises should only serve as information guides and strategic goals. They are means rather than ends in themselves. On the other hand, quantitative methods do force a type of analytical thinking on forest planners that may otherwise be lacking.

3.5 Summary and Conclusions

This chapter described the legislative background and planning practices of a number of public sector forestry agencies. What seems common to all agencies is the requirement to consider wood, environmental and other non-wood values when managing forests. The practices manifested by "due regard" to these goods and services vary by bureaucracy but are generally represented by the following policies:

1. the establishment of parks and flora and fauna reserves;
2. the modification of harvesting practices to account for such values as:
   - water quality and quantity,
   - aesthetics,
   - wildlife habitats,
   - improved regeneration,
3. the promotion of forest-based recreation in various forms;
4. the use of rotation periods that reflect biological maturity of commercial species;
5. attempting to maintain even wood flows over time within regions.

With the exception of the USFS it appears that the use of quantitative methods for multiple-use planning is not widespread in public forestry. It is interesting to note, however, that quantitative methods are more ubiquitous where forest trees are considered as wood crops (eg. simulation harvest models for exotic pines in South Australia). Perhaps pine trees are considered to be more of an economic asset than native tree species in Australia? The experiences of the USFS can provide lessons for other forestry bureaucracies desiring to be more quantitative and analytical about forest management even if legislative directives are not explicit. The FORPLAN model is available to users outside the USFS. Data uncertainties do not necessarily preclude the use of quantitative analysis but rather identify the need for sensitivity analysis. Sensitivity analysis can be used to identify variables that are particularly important management determinants for different objectives. Policy objectives that have been unquestionably and traditionally used by foresters may be found to be not as effective as previously thought. If foresters view this approach as a challenge rather than a threat then this may force the economic principles described in Chapter 2 to be more seriously considered.

Recent developments in Victoria could be a catalyst for more general consideration of quantitative techniques inclusive of economics in public forestry in Australia. The following chapter includes a description of an area in Victoria that is the first such case study for quantitative multiple-use planning in the State.

CHAPTER 4

FORMULATING A CASE STUDY IN PUBLIC FOREST PLANNING FOR AUSTRALIA

4.0 Introduction

This chapter provides background information on forest policy in Victoria, Australia and the formulation of a case study on the economics of public forestry in the State. Section 4.1 gives a short historical perspective on forest policy and management in Victoria. The perspective is useful to understand the circumstances which allowed the case study to occur. Section 4.2 provides a brief description of the Otways and a more detailed description of the West Barham catchment, the subject of the case study. The planning problem is formulated in section 4.3. The FORPLAN software, the analytical tool used for the case study, is described in section 4.4. The chapter is summarised in section 4.5.

4.1 A Brief Review of Forest Policy in Victoria

Victoria has about 5.2 million hectares of native forest and includes some of the fastest growing native species in Australia (*Eucalyptus regnans*, mountain ash; *E. delegatensis*, alpine ash; *E. nitens*, shining gum). The *Forests Act* 1958 required that the then Victorian Forests Commission protect and manage all State forests in Victoria. More specifically, the objectives as reported to the Senate Standing Committee on Trade and Commerce (SSCTC) included:

1. retention of the forest estate in perpetuity and its maintenance in a healthy condition;

2. protection of the forests from damage by wildfires and other damaging agencies, and protection of life and property and other public land and adjoining private land from damage by wildfire;

3. protection of stream environs and maintenance of water quality and soil stability;

4. provision of a continuing supply of hardwood and softwood sawlogs, pulpwood, and other forest produce at a level consistent with the growth of the forests: establishment of softwood plantations on land suitable and available for the purpose, as necessary to meet the community's needs for forest products;

5. conservation of landscape, wildlife habitat, flora and historic sites by appropriate planning and management, and by reservation of areas of special significance;

6. provision of opportunities and facilities for forest recreation and public education;

7. provision of opportunities for apiculture, forest grazing and extractive industries where appropriate;

8. advising and assisting Government agencies, municipalities and the community on all aspects of forestry, use of forest products, and the growing and care of trees; and

9. provision of advice and assistance on growing trees for commercial and farm amenity purposes on private lands. (SSCTC, 1981)

The previous chapter identified that these sorts of objectives are similar in spirit to most public forest agencies.

Land management, particularly forestry, practices have been under heavy public scrutiny in Victoria in recent years. Since the early 1970's the State government has had a Land Conservation Council (LCC), established by the *Land Conservation Act* 1970, which recommends land use for all public land. Public land has been zoned according to priority use as determined by the LCC. Greig (1986) reviewed the more recent forest policy developments in Victoria. In 1983 the Forests Commission was amalgamated with other natural resource agencies and the Department of Conservation Forests and Lands (CFL) was formed[8]. There was also a formal Inquiry into the Timber Industry which looked, in part, for ways to reconcile wood and non-wood interests in forests (Ferguson, 1985). The Inquiry provided the basis from which the government prepared a Timber Industry Strategy (TIS) for the State (Victoria, 1986). The TIS specifies a framework for the future management and planning of all forests in Victoria. The underlying principles of forest management that arise from the TIS are:

1. it must be economically viable with respect to the provision of wood and other market goods;
2. it must be environmentally sensitive with respect to the provision of non-market goods and services;
3. it must be sustainable with respect to the interests of future generations;
4. it must be assisted by public participation in the planning process. (Victoria, 1986, p.1)

With respect to the management of the native forests the government's main "criteria" are:

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8. In March 1990 the CFL underwent another amalgamation with other State environmental departments and is now officially called the Department of Conservation and Environment.

1. sustainable use of all goods and services;
2. dominance of sawlog production and utilisation in timber production activities;
3. multiple use management of the forests and integrated planning with effective public participation;
4. silvicultural practices consistent with sound ecological and economic management;
5. environmental care to conserve forests for future generations;
6. water catchment protection and management to safeguard water supply and quality, and minimise soil erosion;
7. commercial management of forestry production and utilisation activities geared to generating 4% return on funds invested;
8. comprehensive fire protection and management to safeguard public and private assets;
9. native forest research to concentrate on silviculture and management practices;
10. identification and maintenance of sites of natural, archaeological and historical significance. (Victoria 1986, p.31)

More details on each of these criteria or objectives can be found in the TIS (Victoria, 1986). Of particular relevance to this thesis are the government's desires for multiple-use management, integrated planning, and the achievement of a 4% real rate of return on forestry activities related to wood production. With respect to multiple-use, the government sees its objectives being met in the following ways:

1. procedures will be developed for integrated planning for multiple use of forests;
2. planning decisions will include an evaluation of all factors associated with forests;

3. management information systems will be developed to assist in the implementation of multiple use strategies. (Victoria 1986, p.38)

With all the above mentioned objectives and guidelines, the process of forest planning has become a more important and costly department function. Planning occurs within a hierarchy of government and CFL policy guidelines and instruments shown in Figure 4.1. The *Forests Act* 1958, *Land Act* 1958, *Crown Land (Reserves) Act* 1978 and *National Park Act* 1975 provides the legislative backing for the CFL but the Department is constrained by LCC recommendations on land-use. On lands available for wood production, management prescriptions and operations are controlled by department policies. These policies relate to the manner in which timber harvesting operations occur. Examples include: minimum rotation lengths, slope restrictions on timber harvests, the designation of buffer strips between streams and harvesting operations, and the reservation of habitat trees for some wildlife species. The policies attempt to ensure that various non-wood values are maintained in the State's native forests.

There are a number of specific directives for forest management plans. According to the TIS, forest management plans will:

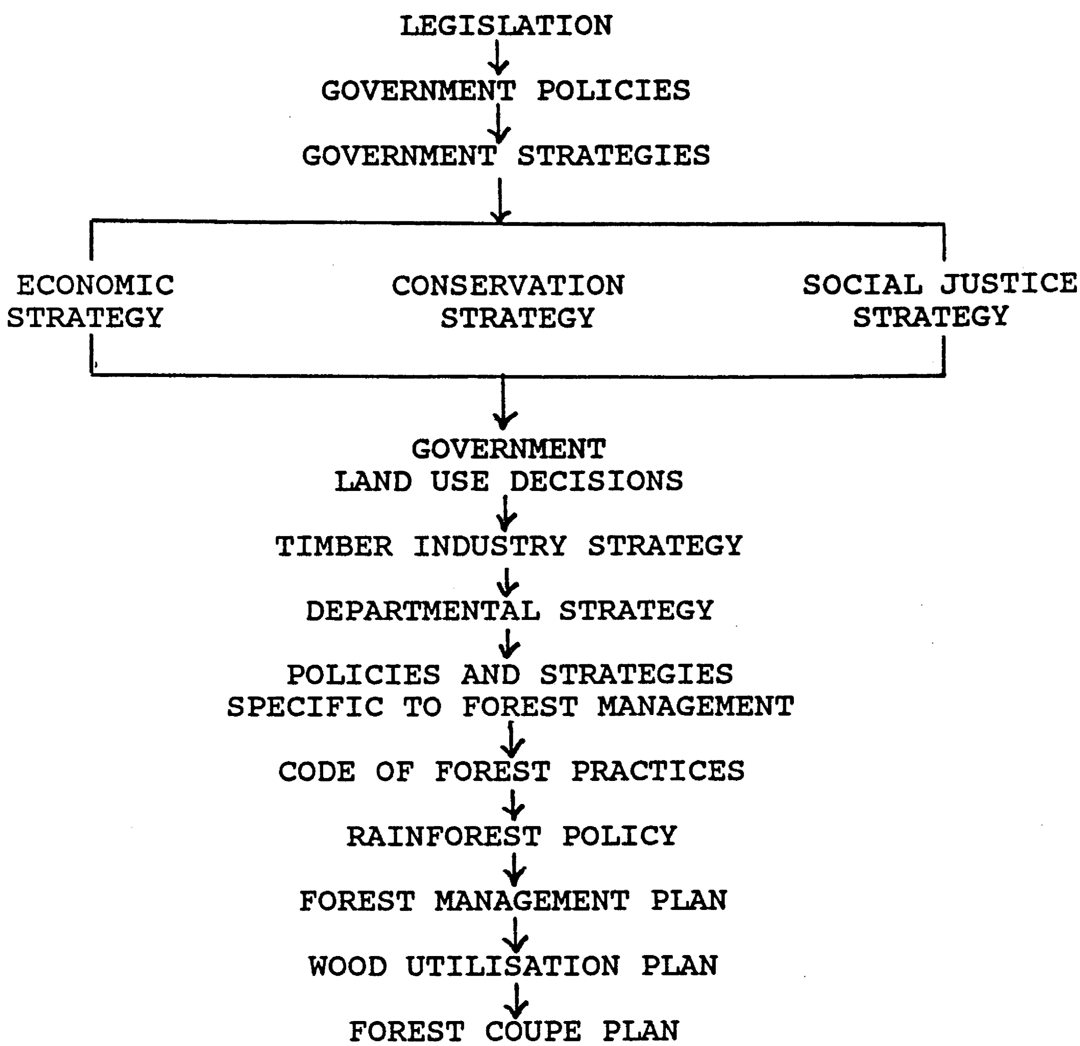
1. apply to forest management areas which are units for planning integrated management for the use and protection of the full range of forest values;

2. address the full range of values and uses of the forest including water catchment, flora, fauna, landscape and soil protection, as well as timber production, grazing and recreation;

3. apply for ten years with provision of revision after five years;

4. be produced with extensive opportunity for public consultation and participation; and

Figure 4.1 Outline of Forest Planning in Victoria



Source: (Victoria, 1986)

5. involve formulation, analysis of impacts, and public debate on various options for managing the forest.

Also each Forest Management Plan will contain:

1. summarised resource inventories of all relevant forest values and benefits including timber, water, flora, fauna, landscape and recreation;

2. an assessment of the economic, environmental and social factors relevant to the plan area;

3. land capability information, including the identification of physical constraints on particular activities or forms of land use, and the mapping of areas of similar physical capability for various uses;

4. a subdivision of the forest into management units which recognise specific resource values and uses, particularly areas where water yield and quality are of major importance;

5. documentation of present and possible future yields of goods and services, including trade-off analyses where goods and services compete;

6. specification of goods, services and values to be produced for the duration of the plan; and

7. a statement of actions designed to produce all goods, services and benefits to the levels required. (Victoria, 1986, p.92)

The Victorian government and CFL have developed an ambitious framework and numerous guidelines for forest management in the State. The interpretation of the TIS by forest managers and the resultant implications are not yet apparent since the Strategy has not been in place long enough. Twenty projects have been instituted to achieve various components of the TIS (Victoria, 1987). The projects include silvicultural trials evaluating clearfelling practices, development of commercial accounting systems, the development of a code of forest practices and a review of the royalty (ie. stumpage price) system. Another project is the development of a multiple-use forest management plan for the Otway Ranges in Victoria in cooperation with researchers at the Australian National University. Following TIS directives, the Otways Forest Management Plan is to specify what activities will be applied to the area and the outputs over a ten year period but due to the intertemporal nature of forests the planning horizon has to span 80 to 150 years (Duguid and Dargavel, 1988). To the author's knowledge the Otways project is the CFL's (and Australia's) first attempt at quantitative multiple-use planning. The CFL is developing a growth and inventory and value simulation model for softwoods (Forest Resources Information and Yield Regulation (FRIYR) Victoria, 1987) and growth and yield models for the hardwood native forests (Leech, 1987). However, no modelling capabilities are as yet available in the CFL to either simulate or optimise multiple-use management. The Otways project among other things, attempts to develop such a model. It should be noted that the analytical work is being done at the Australian National University. The US FORPLAN software has been installed on the University's VAX computer and has been (is) used as the model to examine the long-run trade offs of different forest resources in the Otways and thereby assist in developing a management plan for the region (Dargavel and Turner, 1989).

4.2 The Otways and the West Barham Catchment as a Case Study

The case study in this thesis originates in this CFL commissioned research, but is not itself a part of it. This section briefly describes the Otways and then provides more details on the case study area. The Otways are in the southern part of the CFL's Colac region. Figure 4.2 shows the Colac region in relation to the rest of the State. The Otways provides a relatively minor proportion of the

Figure 4.2 Regional Boundaries and Centres of the Victoria Department of Conservation, Forests and Lands

State's total wood production. Figures 4.3 and 4.4 show, from 1956/57 to 1986/87, the Otways share of hardwood production and total wood production relative to other regions in the State. Not all regions are shown in the figures. The Otways typify many forest regions in the State in that it is characterised by a number of competing demands. Timber millers, conservationists, and recreationists all have particular desires for forest management. The Otways also have eight proclaimed domestic water catchments.

Bartlett (1983) gives a historical account of land use and a qualitative description of forestry practices in the region. A more recent and detailed account of the region is found in Brinkman and Farrell (1989). Their report, part of the Otway project, summarises physical, biological, and climatic features of the region, gives a historical account of human impacts on the region and, describes current management practices. Table 4.1 summarises the designation of forested public land in the Otways.

For the case study it was decided to focus on a single catchment. A catchment is a logical unit to investigate the trade-offs between wood and water production. There is no information available on catchment interactions; that is, there is no biophysical or economic data on differences in costs, revenues or yields between catchments. Given this, a multi-catchment analysis would not increase the interpretive utility of the exercise, though it would, of course, produce different results. The West Barham catchment was selected for the case study (catchment 3 in Figure 4.5). The catchment has a temperate climate with good soils and relatively high annual rainfall (1500-2000 mm). Although one of the smaller catchments there are a number of reasons why it is the most appropriate area for analysis. The West Barham catchment primarily consists of

Figure 4.3 Percent Breakdown of Victorian Hardwood Production

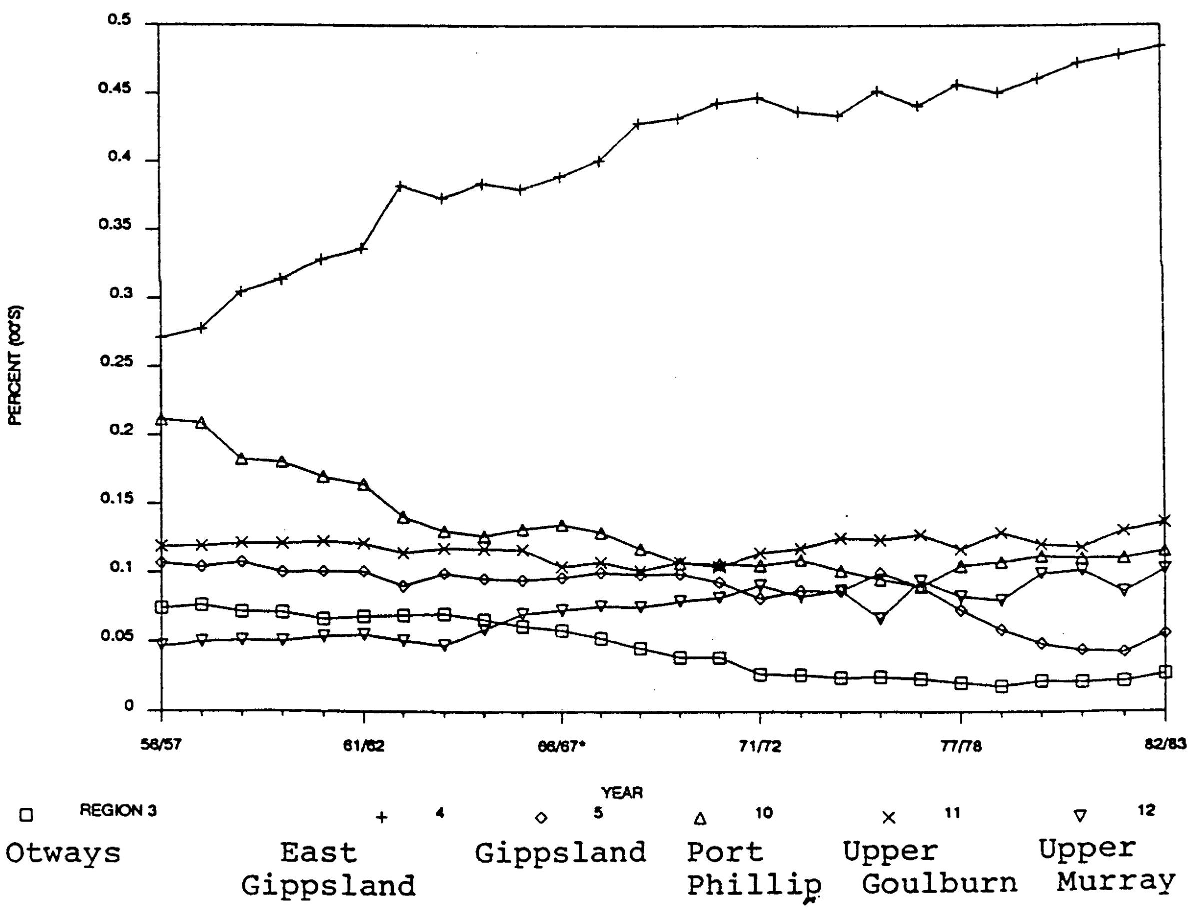
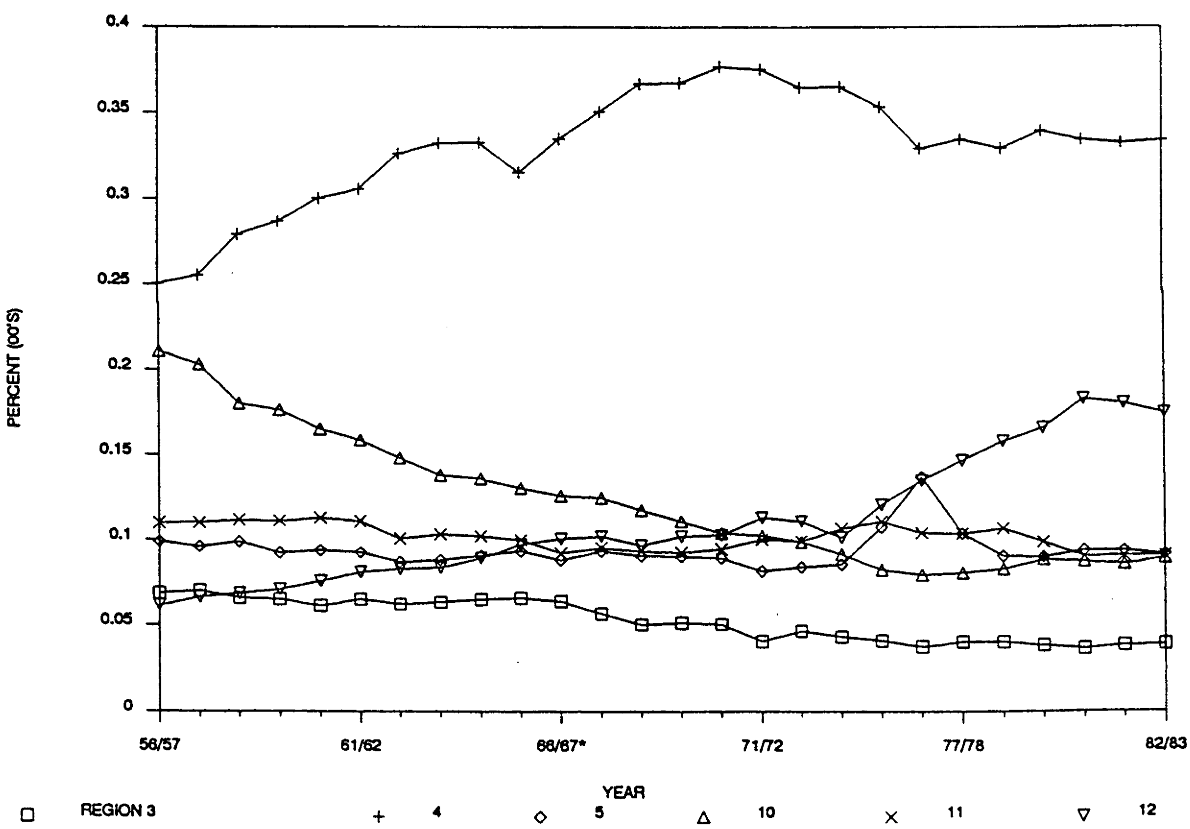


Figure 4.4 Percent Breakdown of all Wood Production



Otways | East Gippsland | Gippsland | Port Phillip | Upper Goulburn | Upper Murray

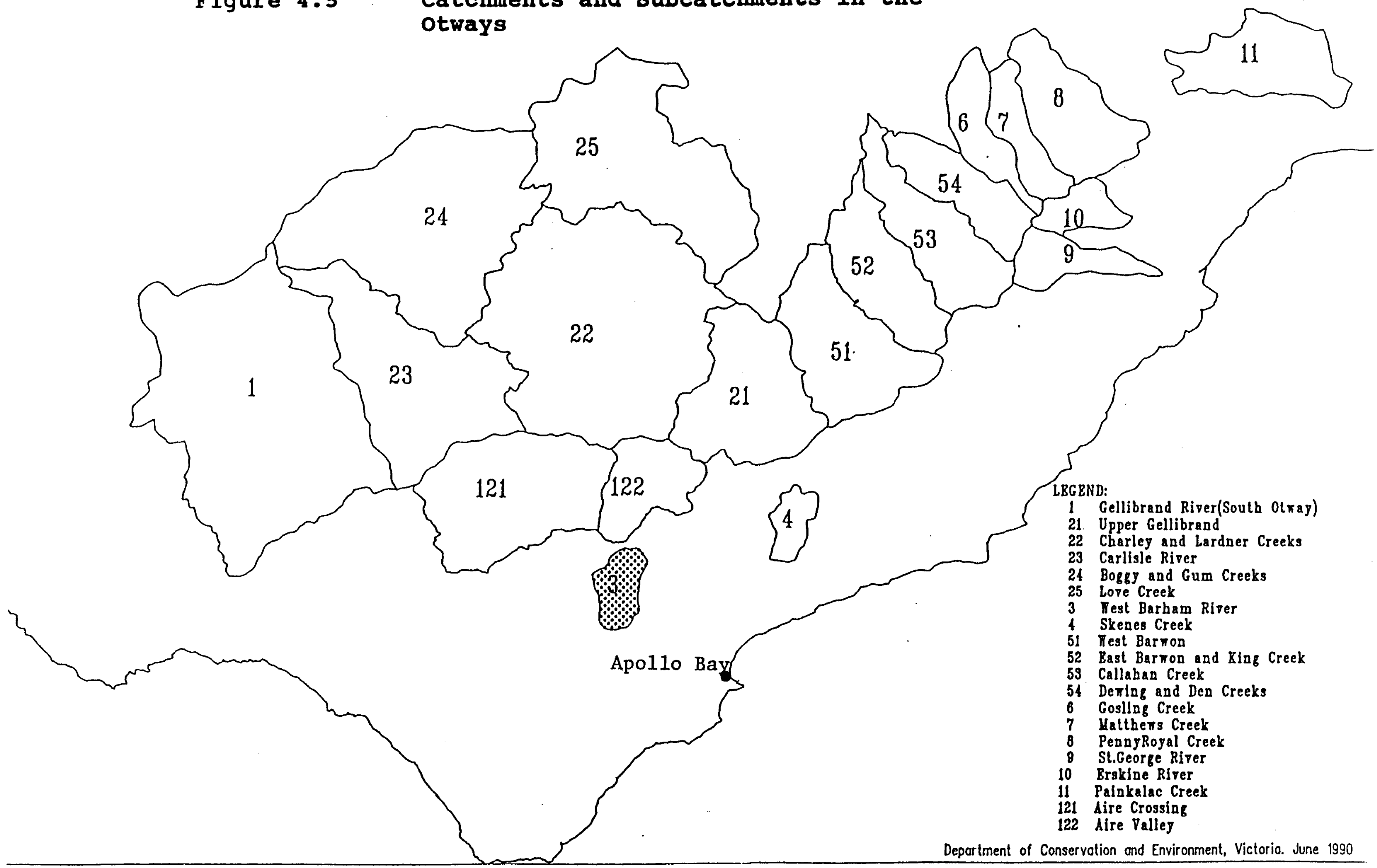
Table 4.1 Forested Public Land in the Otways

Land Use Category	**Area hectares**	**%**
<u>Areas Subject to Forest Management Plan</u>		
State forest (includes Hardwood Production Area, Forest Area, Uncommitted Land)	93,360	59.6
Softwood Production Areas - existing	5,470	3.5
Softwood Production Areas - proposed	750	0.5
Bushland Reserves*	4,310	2.7
Minerals and Stone, Utilities and Survey	190	0.1
Subtotal	104,080	66.4
<u>Parks, Reserves and Other Public Land</u>		
National Park	14,920	9.5
State Park	27,360	17.5
Regional Park	720	0.5
Flora Reserves, Flora and Fauna Reserves	6,550	4.2
Coastal Reserves	550	0.3
Education Areas	400	0.3
Water Production Areas	130	0.1
Streamside Reserves, Recreation Reserves	320	0.2
Scenic Reserves	490	0.3
Other Public Land	1,030	0.7
Subtotal	52,460	34.6
TOTAL	156,540	

Source: Brinkman and Farrell (1989)

* Low intensity timber production is permitted in Bushland Reserves, though for most discussions these areas are grouped with other reserves.

Figure 4.5 **Catchments and Subcatchments in the Otways**



mountain-type forests and relatively more inventory, growth and yield data are available for these forest types. Reasonable water flow estimates related to forest age are also available for this catchment. Both wood and water related information is of low quality for the foothill forests, a forest type predominant in other catchments in the Otways. The catchment is also large enough to contain a variety of age-classes which makes it useful to examine questions of forest preservation and forest age structure.

The West Barham catchment supplies water to the coastal community of Apollo Bay, a popular resort town whose population varies between 1,200 and 10,000 depending on the time of year. The town is situated on the Great Ocean highway approximately 3-4 hours drive from Melbourne. There are a number of parks and unique coastal features nearby that enhance the town's recreational and tourism value. The catchment comprises approximately 1033 hectares of various forest types ranging from 1980's regeneration to relatively untouched old growth forest. Some of the old growth forest and rainforest in stream gulleys are considered by some as having unique conservation values due simply to their existence and condition relative to the rest of the Otways (Brinkman, *pers comm.*). The management problem as developed in Chapter 2 is to optimise the forest output levels over time, given possible management prescriptions, costs and revenues. The following section describes the problem formulation and database in more detail.

4.3 Formulation of the Planning Problem

As part of the Otway project a geographic information system (GIS) database was assembled by the CFL which describes the current state of the catchment. Duguid *et al.* (1990) describe the GIS and the FORPLAN model for the Otways as a whole. For the purposes of analysis the data available dictated aggregation into 12 forest types as follows. (Some forest types were labelled to identify their timber strata in relation to the general Otway region.)

1. mature/overmature forest, high productivity (192 ha);
2. mature/overmature forest, lower productivity (35 ha);
3. 1980's regeneration with overwood (15 ha);
4. 1980's regeneration with no overwood (46 ha);
5. 1970's regeneration with no overwood (42 ha);
6. 1919/26 ash forest, timber strata 2 (35 ha);
7. 1919/26 ash mix forest, timber strata 8 (8 ha);
8. 1919/26 ash/mix forest, timber strata 1A (117 ha);
9. 1919/26 mixed forest, timber strata 3A (35 ha);
10. 1890's forest, timber strata 7 (178 ha);
11. scrub type forest, mainly non-eucalypt (69 ha);
12. gully, non-commercial, and rainforest -- called reserve forest (261 ha).

Each of the forest types has different potential timber yields (in cubic meters/hectare - m^3/ha) over time. It should be noted that area 12, reserve forest, was assumed to have no commercial timber volumes in the analysis. Current CFL policy does not allow logging on this type so there are no data on timber volumes. The implications of this for analysis are identified in Chapter 5. Estimates of timber volumes over time for particular prescriptions were generated by the CFL STANDSIM model (Incoll, 1983) and are fully reported in McKenney and Brinkman (1988). The analysis considers three categories of timber harvest volumes, sawlog class A (highest quality), sawlog class B and C (medium quality), and residual roundwood or pulpwood (lowest quality). After discussions with regional CFL staff, it was decided to include sawlog class D yields in the residual category.

The age of forest stands affect water flows (megalitres/hectare - ML/ha) in the catchment. Essentially water flows decrease for 30 years after harvest and then slowly increase to maximum levels at approximately age 150 years. The data, obtained from Moran (1988), was specifically developed for analysing the impact of timber harvesting on water flows in Otway catchments. Four of the timber strata listed above do not have age explicitly stated as is required to estimate water flows. After discussions with regional forest staff in the Otways it was decided to assume age 150 for the mature/overmature and reserve forest types (areas 1, 2 and 12). Area 11, scrub forest was assumed to be age 100. Much of this forest type in the region was agricultural land abandoned prior to the turn of the century. Water quality was not explicitly modelled. There is no information on the long-term impacts of different harvesting regimes on water quality. However, the approach allows investigation of the opportunity costs, in terms of wood forgone, of increasing stream buffers or putting limits on the annual harvests due to concerns over water quality. The modelling of these policies in FORPLAN can be interpreted as a proxy for the water quality issue.

Given the lack of data on conservation values, age classes were used to monitor forest evolution. The area available in various age classes are linked to the scheduling of timber harvests over time. Different types of flora and fauna prefer different age classes. After discussions with wildlife ecologists it was decided to monitor the hectares available in 6 age class categories: less than 20, 21 - 40, 41 - 80, 81 - 100, 101 -140, and greater than 140 years. These age classes approximate the successional curves exhibited by several guilds of higher order vertebrates (eg. arboreal mammals and small diurnal birds) (Keast *et al.*, 1985; Davey and Norton, 1990). Using age classes as a proxy for conservation values describes conditions of the forest and hence avoids the need to explicitly model variables such as wildlife densities. Such data is extremely scarce in Australia[9].

To summarise, the forest outputs considered in this case study are:

1. harvested sawlogs class A (m^3/ha);
2. harvested sawlogs classes B and C (m^3/ha);
3. harvested residual roundwood (includes D class sawlogs) (m^3/ha);
4. water flows (ML/ha);
5. hectares of standing forest, age class 1, 0 - 20 years;
6. standing forest, age class 2, 21 - 40 years;
7. standing forest, age class 3, 41 - 80 years;
8. standing forest, age class 4, 81 - 100 years;
9. standing forest, age class 5, 101 - 140 years;
10. standing forest, age class 6, greater than 140 years.

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9. It can be argued that age classes also reflect aesthetic values; that is, the older the trees the more aesthetically pleasing the forest. Although research on these values has occurred in North America, very little such research has occurred in Australia. See Brown and Daniel (1986) and Hall and Buhyoff (1986) for scenic beauty values of timber stands, and Sorg and Loomis (1984) for a comparative review of wildlife, wilderness and recreational values in the US. Ferguson and Grieg (1973) report the results of a study of recreational demand in a forested region in Victoria and conjecture about the implications of different management alternatives on recreational values. Reynolds and Sinden (1979) examined the trade-offs between amenity (tree cover) values and agricultural production in northern New South Wales. Ekanayake (1987) reports the results of a study of 136 local households, also in Northern New South Wales, of recreational and existence values associated with eucalypt woodlands that are threatened with dieback disease. He hypothesised an Australia-wide application of his results would give an average per person benefit (existence value plus the option of uncertain recreational visits) of roughly $27/person for preserving eucalypt woodlands.

The current mapping of the 12 timber stands distinguished into the 6 age classes is as follows:

Forest type	Age Class
3 + 4 + 5	0 - 20 years
none	21 - 40 years
6 + 7 + 8 + 9	41 - 80 years
10 + 11	81 - 100 years
none	101 - 140 years
1 + 2 + 12	> 140 years

As mentioned previously the management problem is to optimise the various output levels over time, according to some criterion and given possible management prescriptions for each stand, costs and revenues. The possible management prescriptions are:

1. no timber harvest;
2. sawlog and residual wood harvest with natural regeneration;
3. sawlog only harvest with natural regeneration;
4. sawlog and residual wood harvest with seeding regeneration;
5. sawlog only harvest with seeding regeneration;
6. sawlog and residual wood harvest with planting regeneration;
7. sawlog only harvest with planting regeneration.

Natural regeneration is not allowed under current CFL policy, but is included as a possibility in this study to consider as wide a range of options as possible and to determine the opportunity cost of the policy. Sawlog only harvests refer to timber harvests of sawlog classes A and, B and C. Current CFL policy does not allow for any residual wood (pulpwood) harvests. Again this was included in the analysis here to estimate the opportunity cost of the policy.

The CFL is just beginning to develop a forestry financial accounting system, so a major task of the Otway project was to identify the costs of forest management. Two types of costs have been identified, per hectare and per cubic meter. The costs apply to the management prescriptions identified above. CFL fixed overhead costs were not available to include in the study. Both costs and revenues are based on data provided by the CFL and summarised by Brinkman (1988). The only revenues arising in the analysis were for harvested timber, or stumpage fees. They are:

1. sawlog class A $50/m^3$;
2. sawlog class B and C $27/m^3$;
3. residual $7/m^3$;
4. scrub forest initial harvests $50/m^3$.

The FORPLAN model was used to investigate the management problem as set out in this section. The following section describes the FORPLAN model in detail. A reproduction of the basic FORPLAN model used for the analysis is given in Appendix 4.1a and 4.1b. Appendix 4.1a provides the actual FORPLAN model formulation including costs and revenues. Appendix 4.1b provides the timber and water yields for all the possible prescriptions over time.

4.4 The FORPLAN Model[10]

4.4.1 Introduction and Background

FORPLAN is essentially a matrix generator and report writer for linear programming optimisation problems in

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10. Much of this section is adapted from an article submitted to *Australian Forestry* by the author, Multiple-use planning: an application of FORPLAN to an Australian forest.

forestry. All references to FORPLAN are to FORPLAN version II unless otherwise stated. Earlier US Forest Service models such as Timber RAM (Resource Allocation Method, Navon, 1971) and the Multiple Use Sustained Yield Calculation model (MUSYC, Johnson and Jones, 1979) and even FORPLAN version I were essentially timber supply models that could only represent multiple-use considerations through constraints on timber production. FORPLAN has evolved to what is now called FORPLAN version II. (Version II, release 12 was installed on the Australian National University's VAX 8700 computer.) The version II FORPLAN model attempts to portray multiple-use considerations within a timber scheduling model. The model is capable of representing non-timber land and non-timber prescriptions, outputs and values over long periods of time (Johnson *et al.*, 1986).

FORPLAN is an arduous package to learn. The software itself contains over 256 FORTRAN subroutines and is not written to be user-friendly. Much of the documentation is in the following references:

1. an overview by Johnson *et al.* (1986a) provides a general introduction;
2. A User's Guide by Gilbert *et al.* (1985) gives the exact technical requirements and conventions;
3. a mathematical programmers guide describes the LP aspects of the model in detail (Johnson and Stuart, 1986);
4. a structure and options guide for version II has been drafted to explain, with examples, possible planning problems and FORPLAN solutions (Johnson *et al.*, 1986b). This guide is not generally available but the version I structure and option guide is an acceptable substitute (Johnson and Crim, 1986).

An informative history of the development of FORPLAN is available in a publication by Iverson and Alston (1986) entitled, *The genesis of FORPLAN II: an historical and analytical review of USDA Forest Service planning models.* The proceedings of a workshop and two symposia about FORPLAN are available. The workshop proceedings provide technical advice gained from using and developing FORPLAN models in the US (USFS, 1986a). Papers cover topics such as the difficulties of large FORPLAN models and concerns on translating results for field implementation. The symposium proceedings contain articles evaluating FORPLAN from ecological, economic and operations research perspectives (USFS, 1986b; USFS, 1988).

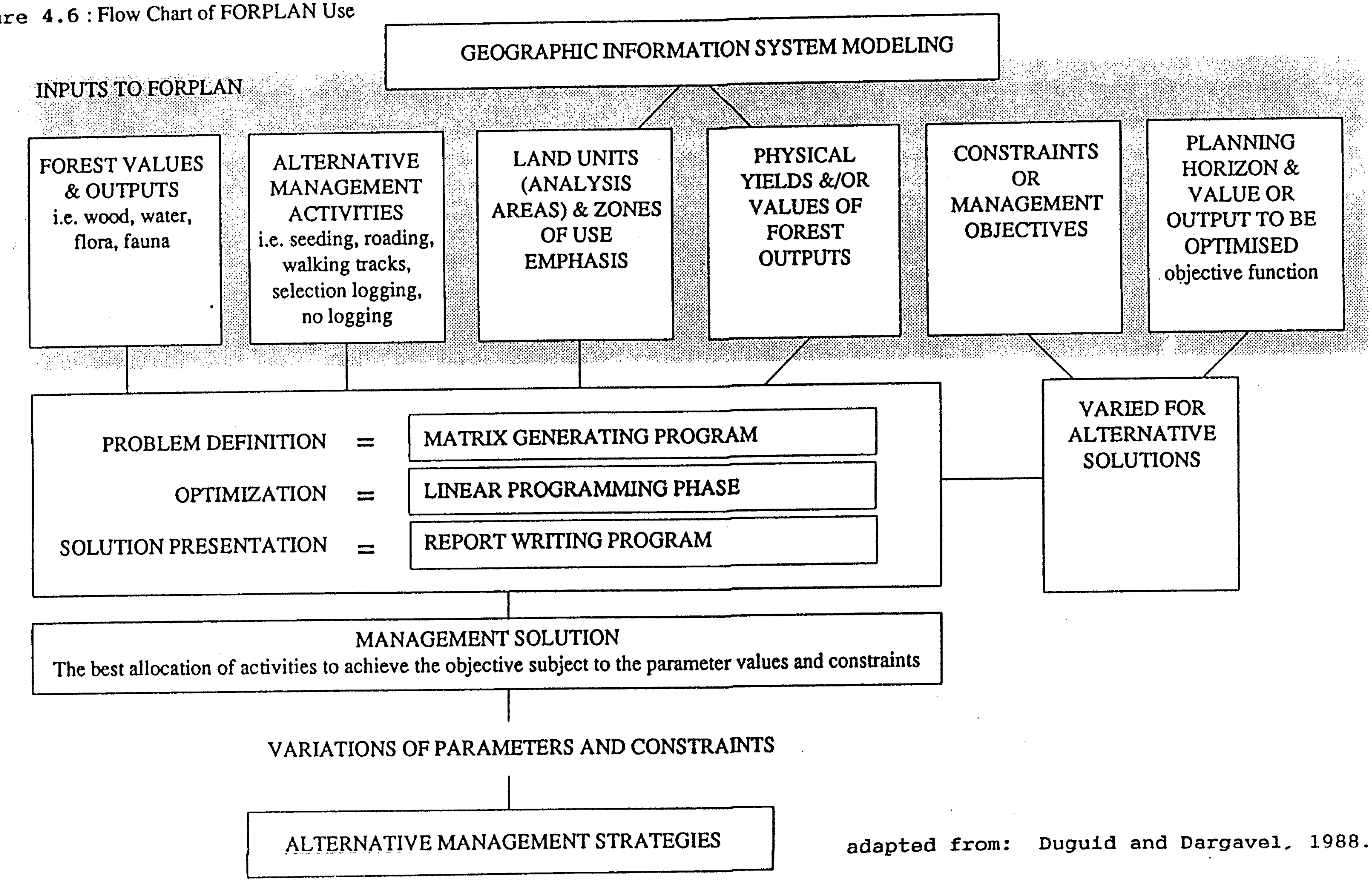
4.4.2 The FORPLAN Package

The FORPLAN model is a package or modelling structure. The framework is general enough that model formulations can be tailored to biological and economic circumstance for each forest. Alternative management strategies can be developed based on sets of assumptions about biophysical relationships and economic values. Figure 4.6 illustrates the various inputs to FORPLAN and how alternative management strategies can be developed. These inputs are reviewed and some computational considerations and concerns are presented in this section.

Forest Uses and Outputs

Forests are capable of a wide range of outputs (ie. wood, water, wildlife, recreational opportunities, various non-commercial and environmental outputs). FORPLAN allows the analyst to define any output desired within the limits of LP analysis (Kent, 1989, see also section 2.5). The outputs can be measured in physical terms and/or in dollars. This is useful for economic analysis because opportunity costs can be calculated for various forest policies even when prices for amenity services are not

Figure 4.6 : Flow Chart of FORPLAN Use



adapted from: Duguid and Dargavel, 1988.

available. For example, in the current debate about Australian native forest management there is a call by some groups, to have either 150-200 year rotations to promote particular wildlife species or remove some forests from timber production altogether. FORPLAN provides a framework to systematically examine some of the implications of such policies.

Land Units

For planning purposes land is divided into units or analysis areas; that is a collection of non-contiguous land units. Identification of land is usually based on its characteristics or attributes in relation to the forest resources or services under consideration (eg. timber classes, soil types, geology, vegetation types, water catchments, recreation opportunity zone). FORPLAN allows up to 6 levels of land characterisation. Geographic information systems (GIS) can be used to generate analysis areas. The case study used area estimates (hectares in each analysis area) generated by the Otway Project GIS. Land units in FORPLAN should be large enough to be realistic management decision units in the forest. Note that different analysis areas can have different potential management choices or prescriptions in FORPLAN if desired.

Management activities, Prescriptions and Timing Choices.

Management activities are those individual actions that comprise prescriptions affecting one or all of the forest outputs over time. These prescriptions directly or indirectly affect potential yields (eg. tree improvement on timber yields, retention of habitat trees on arboreal mammals and timber yields, and timber harvesting on some measures of water quality). FORPLAN allows the user to define prescriptions for any or all of the outputs and vary the timing choices for the prescriptions. For example, a clearfell and plant silvicultural regime for an analysis area could be defined as potentially occurring at any time between ages 40 to 80 or 20 to 100.

Biophysical Yields and Economic Values

The yield values are the actual physical estimates of the resource flows over time and their responses to management prescriptions. If desired, monetary values and value trends can be linked to yields. Typically, timber growth and yield models or hydrological models are run exogenously to FORPLAN and those results are input into the FORPLAN yield file. Sensitivity analysis, based on the confidence levels of the original models requires the yields in FORPLAN to be changed and the matrix generation phase to be repeated. Uncertainty about economic values over time has to be dealt with in the same fashion.

Constraints for Management Objectives

Constraints can be used in FORPLAN to force the linear programming solution to maintain particular levels of resources (eg. a non-declining wood flow may be desired over time; a particular habitat type could be preserved for wildlife, minimum water flows may be a management objective). Constraints can also be placed on prescriptions. Changing the level of a constraint can be done without rerunning the matrix generator. This is an important computational consideration on large problems.

In developing FORPLAN models, constraints should be used with care as there can be a tendency for forest planners to guide the model to a pre-determined solution. A FORPLAN model could then merely be a technological justification for the status quo.

Planning Horizon and Model Objective Function

The time horizon is particularly important in forestry planning because of the dynamics of both the biological and economic systems. FORPLAN allows planners to easily consider, not solve, uncertainties about these dynamics through sensitivity analysis.

In FORPLAN the planning horizon is divided into a maximum of 20 periods. The usual convention for long term planning is 10 to 20 periods of 10 years each, making a planning horizon of 100 to 200 years. This allows consideration of at least one to one and a half rotations for slower growing species. However, the time horizon could be much shorter, for example, five 2 year periods or ten 1 year periods. The planning horizon should reflect the objectives of the analysis. There is a considerable increase in computer time required to generate the matrix when the planning horizon is increased. For example doubling the time horizon from 100 years to 200 years in the West Barham required a roughly fourfold increase in CPU time for the matrix generation phase.

The time horizon is also important in economic analysis of forest management strategies. The discount rate can have profound implications on optimal management strategies when the objective is to maximise net present value (NPV). A discount rate is used to bring all costs and benefits back to the present. The higher the discount rate the lower the relative value of future benefits (and costs). All activities in FORPLAN are assumed to occur in the middle of the planning periods. The discounting therefore occurs in years 5, 15, 25, 35, 45 in a 50 year planning horizon with five 10 year periods.

FORPLAN organises and calculates all the relevant information for the linear programming optimisation phase into rows and columns for the linear program. Linear programming maximises or minimises an objective function. When NPV is maximised the LP chooses and schedules activities and prescriptions in the forest such that no other feasible solution will produce a greater NPV. Non-financial objective functions are also allowed in FORPLAN (eg. maximise timber or water production).

4.4.3 Some Computational Considerations, Technical Conventions and Other Concerns

The implications of different model structures in terms of computational efficiency is summarised in Table 4.2.

Table 4.2: Some Computational Considerations for FORPLAN Users

	Rows	Columns	number of nonzero elements	number of unique nonzero elements
Matrix generator	S	VS	VS	N
Linear programming solution	VS	N	S	VS
Report writer	S	N	N	N

S - sensitive, VS - very sensitive, N - not sensitive
(from Johnson and Crim, 1986)

Of importance to large-scale forestry problems is the fact that matrix generation is very sensitive to the number of columns and nonzero elements. This can occur when a large number of possible decision choices are given in the model structure (eg. possible silvicultural prescriptions and timing choices) for each analysis area. American experience has shown that model size can be a problem. This can be costly in terms of required computer time if sensitivity analysis is desired to gauge the effect of uncertainty on management strategies. Johnson and Stuart (1986) describe various linear programming problem formulations of FORPLAN that can affect model size and are available to FORPLAN users in the US. The two dominant LP approaches to forest management planning have been called model I and model II (Johnson and Sheurman, 1977). It should be noted that there is a distinction between model I and II and FORPLAN Version I and II. Model I and II refer to particular LP formulations. Version I and II refer to particular FORPLAN packages.

Activities in model I refer to the complete set of actions (prescriptions) on a given land area for the entire planning horizon. This means that land areas or management units given in the initial conditions will be tracked over the entire time horizon. In model II activities essentially apply only from regeneration to harvest. Regeneration classes are lumped together which can result in original management units not being tracked through time. The definition of land classes with the level identifiers is therefore particularly critical with model II. The use of model I or II also has computational consequences which can be important in large problems. Model II formulations result in more rows in the LP while model I formulations generate many more columns. Most versions of FORPLAN are only capable of Model I LP formulations including the version installed on the ANU VAX computer and used in this case study. To the author's knowledge only Version II Release 9 and PC FORPLAN (an IBM personal computer version of FORPLAN) are capable of model II formulations.

The general form of a model I problem is as follows (from Johnson and Stuart, 1986):

$$\text{Max} \sum_{s=1}^{S} \sum_{i=1}^{I_s} \sum_{k=1}^{K_i} B_{sik} X_{sik}$$

subject to land area constraints:

$$\sum_{i=1}^{I_s} \sum_{k=1}^{K_i} X_{sik} = \text{Area s} \qquad \text{for all } s = 1, \cdots, S$$

and

$$X_{sik} \geq 0$$

where:

X_{sik} = hectares assigned to timing choice k of prescription i of land area (analysis area) s.

B_{sik} = contribution to objective function (per hectare) of timing choice k of prescription i on analysis area s.

S = number of analysis areas

I_s = number of possible prescriptions for analysis area s

K_i = hectares in analysis area s.

The variable B_{sik} is the per hectare contribution to the objective function from timing choice k of prescription i on analysis area s and can be expressed as:

$$B_{sik} = \sum_{o=1}^{0} \sum_{j=1}^{J} \frac{G_{sikjo} \cdot V_{jo}}{(1 + r)^{T}}$$

where:

G_{sikjo} = the amount of output (activity) o produced (used) per hectare in period j by timing choice k of prescription i on analysis area s.

V_{jo} = the price or cost per unit of output (activity) o in period j.

J = number of periods over which the objective function applies.

O = the number of outputs and activities in the problem.

r = the interest rate to discount costs and revenues

T = the number of years for discounting (In FORPLAN discounting occurs in the middle of a planning period).

Recall the Johansson and Lofgren (1985) theoretical linear forest formulation discussed in Chapter 2 (section 2.5).

$$\underset{c(t)}{\text{Max}}\ NPV = \sum_{t=1}^{T} P_t c'(t) G \qquad 2.5.6$$

where P_t is the present value of stumpage prices and $c'(t)G$ is total supply of roundwood in period T. G corresponds to the timber yields and C_{ti} to the area (forest stand) harvested in period t of age i. The FORPLAN model I formulation is a more general version of the Johansson and Lofgren model in that non-wood values can be incorporated into the objective function. There is forestry jargon in the FORPLAN description of variables (eg. prescription, timing choice, analysis area) but that is a necessary adaption to defining real world decision choices for the LP.

When non-wood values are included in the objective function of the LP formulation the management problem is analogous to a discrete time version of the Hartman multiple-use problem discussed in Chapter 2 but with multiple stands.

The USFS experience in forest planning models has shown that more data does not necessarily improve decisions or cognisance of forest systems. By starting simply and building in complexity gradually, a clearer understanding of resource interactions may result when developing constraints and including outputs in the model (Norbury, *pers comm.*)

An important limitation of FORPLAN is that it does not have any inherent capability for modelling stand interdependencies. In forestry interdependencies imply that the value of various outputs or services depend on the pattern and timing of timber harvests of other nearby stands. In other words there are non-linear response curves to management practices. Response curves in LP are necessarily proportional and additive. For example the response of wildlife to timber harvesting is assumed to be the same whether 1 hectare or 100 hectares is harvested. For some resources this type of linear assumption may be reasonable, for others it may not. It is possible to develop constraints to account for some non-linear relationships. For example adjacency constraints on timber harvests may be a useful proxy for wildlife considerations that arise out of stand interdependencies but this is a laborious and difficult task on a large model (Meneghin *et al.*, 1988). As mentioned in Chapter 2, Bowes and Krutilla (1985) developed a dynamic programming model of a multiple-use problem with stand interdependencies but used hypothetical data to generate illustrative results on a small problem. The large data requirements and computational problems associated with any approach to modelling interdependencies make such exercises difficult especially for large forestry problems.

The flexibility of the FORPLAN package can actually be both an advantage and disadvantage. The structure of the conventions of the package are not always apparent and this can make the modelling exercise extremely frustrating. New users and users without ready access to the USFS FORPLAN headquarters in Fort Collins, Colorado have difficulty understanding the complex technical conventions of the model. Aspiring users of FORPLAN, especially those outside the USFS, would be hard pressed to understand the conventions and jargon without some training.[11]

Consider, for example, that production of different forest resources are characterised by varying degrees of complementarity. FORPLAN should be able to represent this complexity easily; however, structuring the West Barham FORPLAN model to do this proved difficult. Part of the reason for this difficulty is that resource flows can be represented in at least three ways; time dependent, age dependent, and sequence dependent yields. It appears that in many North American FORPLAN models most resource flows are defined as only occurring in conjunction with or dependent on some primary output on pre-specified land types (eg. sediment or water flows associated with timber harvests). However, it is clearly desirable to model resource flows both dependent and independent of other outputs (eg. water flow from both logged and unlogged land). Although this may sound trivial, much experimentation was required before an acceptable method was found to model both water flows and age classes on all land types regardless of whether timber harvests occurred in the planning horizon or not. Eventually dummy timber yields of zero were found to be required for the no logging

11. The author attended a FORPLAN training course in Fort Collins in October 1988.

prescription. This implies water and age class flows are modelled as always dependent on timber harvests.

4.4.4 Summary of FORPLAN Use

The FORPLAN matrix generator takes all the data and organises it into coefficients for the rows and columns for the linear programming optimisation phase. Once the LP package solves the matrix the FORPLAN package has a report writer that interprets the solution information and presents it in a readable fashion. For example, reports can be generated that describe all outputs and activities over time. Financial reports describing costs and revenues over time can also be produced for the entire forest and individual analysis areas.

FORPLAN is a flexible planning tool, but highly dependent on the imagination of the analyst/user. Once the jargon and structure is understood, a forest planner or analyst could, in principle, examine trade-offs between many forest resources or perceived services over time provided data or data estimates are available.

4.5 Summary and Conclusions

This chapter briefly reviewed forest policy developments in Victoria which have brought about an interest in quantitative multiple-use planning and economic efficiency. The State appears committed to an approach to forest planning which includes economic analysis. The pilot planning study in the Otways commissioned by the CFL attests to the State's interest in examining the utility of a more analytical approach to planning.

Section 4.1 described the Otways and West Barham catchment in general terms. Section 4.2 more specifically identified the planning problem and data available for analysis of the West Barham catchment. The FORPLAN linear programming model is the tool of analysis for the case study and it was described in section 4.4. The results of a FORPLAN analysis of the West Barham catchment are presented in the following chapter. The results arise from a formulation of a FORPLAN model that has the characteristics described in section 4.3. The FORPLAN model and data used in the study are reproduced in Appendix 4.1.

While economic analysis to many only includes commercial interests, it can in principle examine non-commercial values. The derivation of economic values for many forest outputs or services is difficult but theoretically not insurmountable. It is likely that most forest managers have neither the expertise nor the means to obtain economic values for many un-priced forest outputs. The framework for analysis presented in section 4.3 recognises this limitation. The case study formulation is a standard one, whereby the opportunity costs, in terms of the value of wood production forgone can be calculated for different management strategies. These opportunity costs may arise over management adaptations to non-wood concerns like water and conservation issues. To the author's knowledge, explicit inclusion of non-wood resources like water and forest age class flows as a proxy for conservation values in a linear programming format has not been done elsewhere for a native forest in Australia.

This approach is an operational adaptation to limited information and can be used to inform, though not necessarily resolve, the forest planning problem. The approach more clearly illuminates valuation problems and the trade-offs involved in multiple-use forestry. This in turn may force public resource managers to be more explicit in formulating their objectives.

CHAPTER 5

RESULTS OF THE WEST BARHAM CASE STUDY

5.0 Introduction

This chapter presents the results of the analysis of the West Barham catchment as formulated in the previous chapter. The purpose here is not to develop an actual management plan for the West Barham but rather to analyse the long-run planning problem and the linear programming (LP) treatment of it via a case study and sensitivity analysis using FORPLAN. Since FORPLAN generates such a large amount of information presenting the results in a coherent fashion is a formidable task. Only the major managerial inputs and output flows for the catchment over time are reported. A base case is necessary for comparative purposes. The base case used here represents an unconstrained view in which any management activity can occur in any period on any land type and the objective is to maximise the net present value of the forest where only wood is given economic value. This is the case appropriate to what public sector forest management should do if wood was the only socially valued output from forests. In the base case there are no constraints in FORPLAN other than the feasibility constraints.

Section 5.1 presents the results of the base case, a case which introduces various constraints to represent current Department of Conservation, Forests and Lands (CFL) forest policy in the catchment, and other scenarios intended to investigate the implications of non-wood oriented strategies. Section 5.2 presents the results of sensitivity analyses on base case parameter estimates such as discount rate, stumpage values, costs and timber yields. An examination of the sensitivity of results to varying parameter estimates is crucial to interpreting the implications of uncertainty for management. Section 5.3 presents the results of similar sensitivity analyses on the CFL case. Section 5.4 presents the results of a number of additional model experimentations investigating other management options for the catchment. Section 5.5 summarises the chapter and identifies some important conclusions.

5.1 Basic Results

All cases discussed here have a 100 year time horizon divided into 10 ten year periods unless otherwise stated. All parameter estimates, including the 4% discount rate and stumpage values, are used not because they are necessarily the correct values, but rather because they are the best estimates available or they are the values managers currently use.

5.1.1 Base Case

The base case acts as a point of departure for comparison against all other cases. The base case, presented in Table 5.0 shows what the optimal management plan would be if wood was the only socially valuable forest output. For each of the 10 planning periods the Table shows the areas of timber harvest, silvicultural prescription(s) associated with harvest, expected water flow for the period, hectares of forest in each of the monitored age classes and the cumulative present net worth of the management strategy. The age class reports are for the middle of the period before a timber harvest if a harvest occurs in that period on that land. Note that the age class is reported even if a harvest does not occur. So even though the non-wood outputs are not given economic value, the physical effects on non-wood resources of a

Table 5.0 Base Case

Output/ activity	Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest (ha)	600	111	61	600	0	103	600	0	61	642
Prescription	P	P/N	P	P	-	P	P	-	P	P
Water yield (0's ML)	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
Hectares in age class 0-20	103	661	711	172	661	600	103	703	600	61
21-40	0	42	61	600	111	172	600	0	103	642
41-80	195	0	0	0	0	0	69	69	69	69
81-100	247	0	0	0	0	0	0	0	0	0
101-140	0	69	0	0	0	0	0	0	0	0
140	488	261	261	261	261	261	261	261	261	261
Cumulative present net worth ($000s)	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360

P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

maximise net present value strategy are shown in the Table. Comparisons with non-wood oriented strategies are therefore more meaningful.

In the base case most of the forest is harvested in the first three periods under a planting regeneration program with 30 year pulpwood oriented rotations. The rotation length can sometimes be inferred in the summary tables by observing the periodicity of timber harvests (eg. 600 hectares of timber harvest in periods 1, 4 and 6). However, in some cases it is not easy to ascertain rotation lengths from this sort of summary. Other FORPLAN output (not shown) provides more detailed reports on silvicultural prescriptions and rotation lengths for each analysis area. Two forest types (scrub and reserve) are exceptions to the 30 year rotation periods. The 69 hectares of scrub forest is harvested in the second period and left to regenerate naturally. This is shown in Table 5.0 as the natural regeneration prescription (N) in period 2. In period 2 the 69 hectares is shown in the age class 101-140. Scrub forest is assumed to be age 100 to start with and is therefore part of the 81-100 age class. After the harvest the 69 hectares is lumped into the youngest age class and by period 7 is shown on its own in age class 41-80. This natural regeneration prescription indicates that the current cost structure does not justify intensive management of this type.

It is sometimes difficult to keep track of individual analysis areas via the age class structure since a number of analysis areas may be lumped into a single age class. The format of the tables is to give a general indication of the age structure for the entire catchment, not to separately record the age of each analysis area in each planning period. Where a single analysis area is the only component of an age class, it is possible to clearly track the area through time. An example of this is the reserve forest type. In the first planning period the 488 hectares in the oldest age class is comprised of the reserve (261 ha) and the mature/overmature (227 ha) forest types. The mature/overmature forest is harvested in the first planning period but the reserve forest type is left unharvested and is shown in the oldest class for the entire period.

As mentioned in the previous chapter timber volumes are unknown on the reserve forest type so no volumes were entered in the model. FORPLAN therefore treats reserve forest as bare land in so far as wood values are concerned. Conversion to plantation is allowed but not prescribed because it is not economic.

In the base case water flows decrease approximately 28% by period three and then fluctuate between 64000 megaliters (ML) and 75000 ML per period compared to the first period's 88000 ML flow. In the first period four of the six age classes are represented. After the harvest of 69 hectares of scrub forest in the second period only 3 age classes are represented, the two youngest and the oldest which happens to be the reserve forest.

The cumulative net present value of the base case is $2,360,000 over the 100 year planning horizon. So given current costs, stumpage prices and a 4% discount rate and expected growth rates, this is the maximum value of wood production possible from the catchment. Over 60% of this value occurs in the first period. Although the last period's harvest is the largest in any one period its contribution to the objective function is only about $55,000, an indication of the effect of a discount rate on future benefits and costs.

5.1.2 Current Policy Case

Clearly it is not the case that actual forest management in Victoria is based upon an unconstrained net present value maximisation, recognising wood as the only socially valuable forest output. The Victorian Department of Conservation Forests and Lands (CFL) has a mandate to manage for "all" forest resources. In practice this means timber harvesting operations are modified, reduced or eliminated, in some areas. These practices generally reflect CFL objectives with respect to flora, fauna, recreation, water and other conservation values. Current policy in the West Barham catchment can be summarised as:

1. minimum 60 year rotations;
2. maximum 25 hectare per year harvests in the catchment;
3. no pulpwood harvests. This corresponds to the sawlog class D and residual roundwood output;[12]
4. no natural regeneration allowed.

These policies can be easily represented in FORPLAN through constraints on management. The rotation constraint only requires the changing of one number in the section of FORPLAN code that specifies the potential timing of harvests. The other 3 constraints are each two lines of FORPLAN code in the section that is specifically devoted to constraints. Table 5.1 presents the results of this CFL case compared to the base case. As expected the NPV decreases and management strategy changes significantly to meet current policy constraints.

In the CFL case seeding regeneration with 70 year rotation periods becomes the preferred management prescription on harvested land. The harvest pattern is adapted to account for the maximum harvest level and minimum harvest ageconstraint. An interesting result

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11. Currently the CFL does allow sawlog class D harvests however, the proportion of pulpwood output that constitutes class D is small enough to be irrelevant. Creating a separate class D output would not increase the interpretive utility of the exercise.

Table 5.1 Base Case and Current (CFL) Policy Case

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest (ha)	A	600	111	61	600	0	103	600	0	61	642
	B	250	250	100	0	0	42	61	250	250	100
Prescription	A	P	P/N	P	P	-	P	P	-	P	P
	B	S	S	S	-	-	S	S	S	S	S
Water yield (0's ML)	A	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	B	8782	8313	7411	6826	6769	7067	7420	7863	7848	7313
Hectares in age class 0-20	A	103	661	711	172	661	600	103	703	600	61
	B	103	311	500	350	100	0	42	103	311	500
21-40	A	0	42	61	600	111	172	600	0	103	642
	B	0	42	103	311	500	350	100	0	42	103
41-80	A	195	0	0	0	0	0	69	69	69	69
	B	195	35	0	42	103	353	561	600	350	100
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
101-140	A	0	69	0	0	0	0	0	0	0	0
	B	0	157	69	69	69	0	0	0	0	0
140	A	488	261	261	261	261	261	261	261	261	261
	B	488	488	361	261	261	330	330	330	330	330
Cumulative present net worth ($000s)	A	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
	B	789	1043	1051	1051	1052	1072	1091	1159	1205	1218

A - base case, B - current CFL policy constraints.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

is the 70 year rotation period. The growth in value between 60 and 70 years is sufficient to make the delay in harvest worthwhile. However, cumulative NPV is almost half of the base case. In the CFL case water flows decrease but not as rapidly as or to the extent of the base case. The lowest flow occurs in the fifth period and is 23% lower than the first period flow. The minimum 60 year rotation means the third age class category (41-80 years) is more highly represented in this scenario. A result of the no natural regeneration constraint is that the scrub forest is not harvested. This can be seen in Table 5.1 by observing the 69 hectares of scrub forest aging over time. From the third period it is the only forest type in the fifth age class and eventually comprises part of the oldest age class. In the base case this type is harvested in period 2 and left to regenerate naturally. The harvest of the mature/overmature forest type, which is 227 hectares of the 488 hectares in the oldest age class, is delayed to the second and third planning periods due to the 25 hectare/year harvest constraint. This delay is a result of the high cost and low productivity of this type relative to 1919/26 and 1890's forest.

The fact that NPV has decreased in the CFL case does not in itself suggest the strategy is non-optimal. Non-wood resources have value but their value are only represented in the model indirectly as constraints rather than directly in the objective function like wood values. The difficulties of estimating un-priced values was discussed in Chapter 2. The CFL currently has no information on the economic value of non-wood resources. For similar reasons I will not attempt to incorporate non-wood values in the objective function. It is also the case that typical public forest agencies would not have the capability to estimate the economic value of most non-wood outputs and this thesis is attempting to illustrate an operational approach to using economic principles in forest planning. The point is that it is not necessary to have perfect information on economic values to use economic principles when planning.

However, instead of introducing a number of constraints all at once, as in the CFL case, it is better to use constraints one at a time on the base case. This enables a planner to examine results systematically and be more discerning and analytical when determining future forest policy. This approach clarifies the trade-offs between different forest resources arising from each policy separately. For example, introducing each CFL policy constraint separately in the base case showed the no pulpwood constraint as having the largest impact on NPV. This no pulpwood policy arises out of conservation objectives. By clarifying these objectives the CFL may be able to identify more cost efficient policies. Table 5.1a summarises the NPV impact of each of the CFL policy constraints.

Table 5.1a The Impact of Individual Constraints on the Net Present Value of Management

Case	NPV ($)	Percentage Difference From Base Case (%)
Base case	2360000	-
No natural regeneration	2356000	-.2
25 hectares/Year	2060000	-13
Minimum 60 year rotation	1977000	-18
No pulpwood	1407000	-40
CFL case (all constraints)	1218000	-48

5.1.3 Water Case

To gauge the implications of greater consideration of water flows a minimum 7500 ML/year constraint was placed on the base case. The value of West Barham water at various levels of supply is unknown. Domestic consumption is currently only 120 ML/year. This is considerably less than current flows. A 7500 ML/year flow is greater than the minimum flow reached in the CFL case so it should provide a good indication of the economic implications of a more water oriented strategy. Table 5.2 presents the results of this scenario in comparison to the base case.

The 7500 ML/year minimum flow constraint is binding in three of the planning periods. The cumulative NPV decreases by less than $100,000. The strategy is, however, much more complex than the base case in the sense that harvests occur every period and both planting and seeding prescriptions occur with varying rotation lengths. As mentioned previously it is sometimes difficult to ascertain the rotation lengths directly from the results tables, especially when solutions are complex. In the water case rotation lengths on regenerated land vary between 20 and 40 years. The age class distribution is more concentrated in the 2 youngest and the oldest age classes. The 69 hectares of scrub forest is only partially harvested in the final period. This is shown by following the 69 hectares as it ages from the fifth to sixth class throughout the planning horizon. A plausible generalisation based on this LP run is that water flow constraints and management regimes oriented more towards water production can be expected to have more complicated timber harvest schedules. However, as shown in Table 5.2, these regimes do not necessarily have a high opportunity cost if variable rotation lengths are accepted. Similar experimentation with the CFL case revealed that preserving the mature/overmature (old-growth) forest is a relatively cost-effective means of increasing water flows. A 7500 ML/year constraint on the CFL case decreased the solution value from $1,218,000 to $1,162,000 (approximately -5%). The constraint was binding in 5periods and primarily achieved by not harvesting the mature/overmature forest type.

Table 5.2 Water Flow Constraint

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest (ha)	A	600	111	61	600	0	103	600	0	61	642
	B	600	42	470	183	459	103	550	42	553	183
Prescription	A	P	P/N	P	P	-	P	P	-	P	P
	B	P/S	S	P/S	P/S	P/S	P/S	P/S	S	P/S/N	P/S
Water yield (0's ML)	A	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	B	8866	7597	7653	7649	7822	7500	7875	7500	7679	7500
Hectares in age class 0-20	A	103	661	711	172	661	600	103	703	600	61
	B	103	661	642	512	653	642	562	653	592	595
21-40	A	0	42	61	600	111	172	600	0	103	642
	B	0	42	61	191	50	61	141	50	111	141
41-80	A	195	0	0	0	0	0	69	69	69	69
	B	195	0	0	0	0	0	0	0	0	0
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
101-140	A	0	69	0	0	0	0	0	0	0	0
	B	0	69	69	69	69	0	0	0	0	0
140	A	488	261	261	261	261	261	261	261	261	261
	B	488	261	261	261	261	330	330	330	330	247
Cumulative present net worth ($000s)	A	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
	B	1599	1634	1854	1990	2127	2157	2236	2238	2275	2287

A - base case, B - minimum 7500 ML per year water flow constraint.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

5.1.4 Constrained Harvesting Cases

Non-wood and non-water multiple-use considerations are in many respects more difficult to deal with. Not only is there very little information on what the values are in either an economic or physical sense, we do not know how they depend on the age composition of the catchment. However, it is possible to introduce constraints on the harvests of various forest types. This is consistent with arguments on forest practices put forward by the conservation movement in Australia. The NPV loss implications of a number of these constraints are shown in Table 5.3 for both the base case and CFL case. The values in Table 5.3 represent the opportunity costs, in terms of the reduction in maximised NPV, of not allowing timber harvesting on four forest types: mature/overmature, 1890's, 1919/26 and 1970's regeneration. The NPV's can be converted to perpetual annuities using $a = r(NPV)$, where a is the annuity value and r is the discount rate. Thus, for example, the NPV costs of not allowing harvesting on the mature/overmature forest type under the assumptions of the base case is $2234/hectare or $89/ha/year. An annual value may be a more comprehensible method of reporting these costs to the public. Conservation groups could, for example, be asked to pay an annual amount (eg. tax levy) to compensate the State.

The results indicate what compensation would have to be such that the State would be indifferent to harvesting or setting aside. In other words, the values are the amounts that potential beneficiaries of such acts should be willing to pay to justify the acts on allocative efficiency grounds. The additional constraints imposed in the CFL case lower the opportunity costs of disallowing harvesting on the various forest types. On the mature/overmature type the opportunity cost is just $326/ha or $13/ha/year. The differences in Table 5.3 for each case are due to cost and yield variations across forest types. The mature/overmature is both relatively costly to harvest and low in timber productivity so it has the smallest opportunity costs of preservation in both the base case and the CFL case. The opportunity cost rankings of the mature/overmature, 1919/26 and 1890's forest types reflect the current and future potential timber values in an obvious way. The lower ranking of the 1970's forest is because there is a considerable period of time required before appreciable volume growth occurs and such future benefits are discounted.

Table 5.3 NPV Costs of Preserving Different Forest Types

Case	Mature/overmature	1890s	Forest Type 1919/26	1970s
Base	2234 (89)	3809 (152)	6010 (240)	1475 (59)
CFL	326 (13)	1685 (67)	3705 (148)	491 (20)

Notes: Units are present value dollars per hectare set aside, bracketed values refer to perpetual annuities.

These results hold where the area set aside has no effect on stumpage price. If wood prices increase as a result of a forest being removed from wood production then this approach underestimates the economic cost of harvest constraints. This follows from arguments about prices being independent of harvest (Johansson and Lofgren, 1985). If stumpage prices are market based this would relate to availability of substitute wood products to consumers. In Australia stumpage prices are typically administered prices so they do not act as social valuation signals to forest managers. Under conditions where large timber volumes are involved, prices may not be independent of harvest but in the case of the West Barham, or any individual forest, this is unlikely, particularly in the long run.

5.2 Sensitivity Analysis of the Base Case

Given the inherent uncertainty on all data inputs, sensitivity analysis should be an essential aspect of forest planning. This section presents the results of a number of variations in parameter estimates on the base case. The parameter estimate variations include stumpage prices, timber yields, costs and the discount rate. These are the major inputs into this forest planning problem from an economic perspective. Some of this analysis serves to empirically validate the comparative statics of the Faustmann rotation problem presented in Chapter 2.

5.2.1 Changing the Timber Yields

The growth and yield estimates were perturbed from the base case by plus and minus 30%. Plus and minus 30% roughly approximates the 95% confidence limits of the timber yields in the area (Brinkman, *pers comm.*). Results are shown in Table 5.4 compared to the base case. Although planting remains the preferred silvicultural prescription the harvest schedule does differ in both scenarios from the base case. In the higher productivity case the only managerial change is that an area that was harvested in the third period in the base case is harvested in the first period. This of course affects the flow of non-wood resources over time. When timber yields go up 30% the rotation length remains 30 years. When yields decrease 30% the rotation period increases to 40 years and the scrub forest is harvested in the third period rather than thesecond. The asymmetry on the change in rotation length is not unexpected given the length of the planning periods and the yields in FORPLAN. The timber yields used in the FORPLAN yield file do not increase linearly over time. The variations in average annual water flow over the planning horizon were slightly greater in the lower productivity example, 2766 ML versus 2498 ML in the base case and 2534 ML in the increased yield scenario. The 40 year rotation

Table 5.4 Changing Timber Yields

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest	A	615	111	46	615	0	88	615	0	46	657
(ha)	B	600	111	61	600	0	103	600	0	61	642
	C	600	42	130	0	600	103	0	0	661	42
Prescription	A	P	P/N	P	P	-	P	P	-	P	P
	B	P	P/N	P	P	-	P	P	-	P	P
	C	P	-	P/N	-	P	P	-	-	P	P
Water yield	A	8875	7464	6394	7325	6941	6341	7425	7047	6364	7559
(0's ML)	B	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	C	8866	7597	6737	6222	7327	7120	6310	6100	7521	7224
Hectares in	A	103	661	726	157	661	615	88	703	615	46
age class 0-20	B	103	661	711	172	661	600	103	703	600	61
	C	103	661	642	172	130	600	703	103	0	661
21-40	A	0	42	46	615	111	157	615	0	88	657
	B	0	42	61	600	111	172	600	0	103	642
	C	0	42	61	600	642	172	69	600	703	42
41-80	A	195	0	0	0	0	0	69	69	69	69
	B	195	0	0	0	0	0	69	69	69	69
	C	195	0	0	0	0	0	0	69	69	69
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
	C	247	0	0	0	0	0	0	0	0	0
101-140	A	0	69	0	0	0	0	0	0	0	0
	B	0	69	0	0	0	0	0	0	0	0
	C	0	69	69	0	0	0	0	0	0	0
140	A	488	261	261	261	261	261	261	261	261	261
	B	488	261	261	261	261	261	261	261	261	261
	C	488	261	261	261	261	261	261	261	261	261
Cumulative	A	2058	2108	2139	2861	2861	2922	3145	3145	3152	3229
present net	B	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
worth ($000s)	C	956	971	986	986	1371	1405	1405	1405	1490	1493

A - increasing timber yields 30%, B - base case, C - decreasing timber yields 30%.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

in the decreased yield case allows water flows to decrease to their lowest per hectare value thus creating the greater variation. The rotation length also results in more age class 2 (21 - 40 years) being represented through the planning horizon. Cumulative NPV was $869,000 (37%) more than the base case in the increased yield scenario and $867,000 (37%) less in the decreased yield case.

The yield change cases are not directly comparable to any Faustmann comparative statics results since those refer to changes in prices, costs or the discount rate, not the wood growth function. Nevertheless, an intuitive explanation of the rotation length differences is obvious. Increasing (decreasing) yields has the effect of increasing (lowering) the opportunity cost of managing the land for wood production. Adjusting to the new value growth of the forest is achieved by lowering (increasing) the rotation length.

5.2.2 Changing the Cost Structure

Sensitivity analysis on costs is useful on two grounds. Firstly, there is inherent uncertainty in the data itself, since the CFL is only just beginning to track costs and develop an accounting system. Secondly, cost perturbations, in particular decreases, could reflect technological changes that are identified through research and development. If management on particular forest types changes significantly due to cost perturbations managers may gain insights to direct more management oriented research. Table 5.5 presents the results of changing the cost structure by both plus and minus 30% compared to the base case. Again this sensitivity analysis attempts to roughly account for the 95% limits on the numerical estimates of costs. The timing of harvests changes in both scenarios relative to the base case. With increased costs the rotation length increases to 40 years and the scrub forest does not get logged. With decreased costs the

Table 5.5 Changing Costs

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest	A	600	42	61	0	600	103	0	0	661	42
(ha)	B	600	111	61	600	0	103	600	0	61	642
	C	684	42	46	615	42	46	615	42	46	615
Prescription	A	P	P	P	-	P	P	-	-	P	P
	B	P	P/N	P	P	-	P	P	-	P	P
	C	P/N	P	P	P	P	P	P	P	P	P
Water yield	A	8866	7597	6883	6685	7879	7685	6853	6606	7988	7655
(0's ML)	B	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	C	8728	7147	6305	7312	7046	6350	7410	7158	6456	7503
Hectares in	A	103	661	642	103	61	600	703	103	0	661
age class 0-20	B	103	661	711	172	661	600	103	703	600	61
	C	103	730	726	88	661	657	88	661	657	88
21-40	A	0	42	61	600	642	103	0	600	703	42
	B	0	42	61	600	111	172	600	0	103	642
	C	0	42	46	684	111	46	615	42	46	615
41-80	A	195	0	0	0	0	0	0	0	0	0
	B	195	0	0	0	0	0	69	69	69	69
	C	195	0	0	0	0	69	69	69	69	0
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
	C	247	0	0	0	0	0	0	0	0	69
101-140	A	0	69	69	69	69	0	0	0	0	0
	B	0	69	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	0	0
140	A	488	261	261	261	261	330	330	330	330	330
	B	488	261	261	261	261	261	261	261	261	261
	C	488	261	261	261	261	261	261	261	261	261
Cumulative	A	1326	1345	1360	1360	1881	1926	1926	1926	2041	2046
present net	B	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
worth ($000s)	C	1719	1758	1787	2395	2423	2444	2631	2640	2646	2704

A - increasing costs 30%, B - base case, C - decreasing costs 30%.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

rotation period is 30 years except for the scrub forest which is harvested in the first period and left to regenerate naturally. In addition the 15 hectares of 1980's regeneration with overwood is harvested in the first period. In the lower costs scenario timber harvests occur every period. In both cases average annual water flow variations over time are less than the base case, 2260 ML and 2415 ML in the increased costs and decreased costs scenarios respectively compared to 2498 ML in the base case. Age class flows differ from the base case due to the different harvest schedule. The change in the 69 hectare scrub forest harvest provides the most noticeable change in age class distribution. With increased costs the scrub forest is not logged and eventually becomes part of the oldest age class. In the lower costs scenario the scrub forest is harvested and left to regenerate naturally in the first period. In this case the regenerated scrub forest type is 90 years old by the end of the planning horizon. The change in NPV is as expected in both cases. Increased costs decrease NPV $315,000 (13%) and decreased costs increase NPV $348,000 (15%).

Recall the Faustmann comparative static result $\partial T/\partial C > 0$ reported in Chapter 2 that says increased (decreased) costs will lengthen (shorten) the rotation period. The results from the increased cost scenario verify this expectation but in the decreased costs case the rotation period stays generally the same, relative to the base case. This outcome arises from the problem formulation; that is, the 10 year planning periods are too long to show up changes in rotation lengths of less than 10 years.

5.2.3 Changing the Discount Rate

The appropriate discount rate to use for public investment analysis is a matter of much debate. It can be said that economists not only disagree about the numerical value to use but also on the manner in which it should be calculated. Lind *et al.* (1982) give a comprehensive discussion of the issues surrounding this debate including the problem of intergenerational equity. The problem of determining an appropriate social discount rate has not been resolved. The Victorian timber industry strategy requires the CFL use 4% and this value was used in both the base and CFL cases. It was decided to examine the implications of two higher discount rates on management strategies. This could reflect either a higher social time preference rate or higher opportunity costs of public investments. Table 5.6 presents the results of scenarios using 8% and 12% discount rates compared to the base case. In both cases natural regeneration is the preferred silvicultural option after all harvests. Except for the scrub forest type, which is harvested and thereafter left unlogged, the preferred rotation period is 20 years. Under both discount rates the scrub forest is harvested in the first period. One other exception to the 20 year rotation period occurs in the 8% case. In that plan the 1980's regeneration is harvested in the third period and then managed on a 50 year rotation basis. This result is due to the cost, yield and future growth rate structure being sufficiently different to other forest types. In both cases average annual water flows per period vary approximately 850 ML less than the base case. Also, in both scenarios the NPV remains essentially the same from the third period onwards. This illustrates the impact ofhigher discount rates on long-term projects. Higher social time preference rates and/or opportunity costs of capital could mean intensive forest management to produce larger trees for solid wood products is not worthwhile. However, if stumpage values increase substantially as treediameter increases this result could change. Total NPV is 34% less and 46% less in the 8% and 12% discount rate cases respectively.

Table 5.6 Increasing Discount Rate

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest	A	669	42	661	42	661	42	661	42	661	42
(ha)	B	600	111	61	600	0	103	600	0	61	642
	C	669	42	661	42	600	42	600	103	600	42
Prescription	A	N	N	N	N	N	N	N	N	N	N
	B	P	P/N	P	P	-	P	P	-	P	P
	C	N	N	N	N	N	N	N	N	N	N
Water yield	A	8720	7134	7459	7087	7474	7146	7550	7221	7617	7277
(0's ML)	B	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	C	8720	7134	7459	7087	7360	7055	7443	7278	7581	7199
Hectares in	A	103	730	711	703	703	703	703	703	703	703
age class 0-20	B	103	661	711	172	661	600	103	703	600	61
	C	103	730	711	703	703	642	642	642	703	703
21-40	A	0	42	61	69	69	0	0	0	0	0
	B	0	42	61	600	111	172	600	0	103	642
	C	0	42	61	69	69	61	61	0	0	0
41-80	A	195	0	0	0	0	69	69	69	69	0
	B	195	0	0	0	0	0	69	69	69	69
	C	195	0	0	0	0	69	69	130	69	0
81-100	A	247	0	0	0	0	0	0	0	0	69
	B	247	0	0	0	0	0	0	0	0	0
	C	247	0	0	0	0	0	0	0	0	69
101-140	A	0	0	0	0	0	0	0	0	0	0
	B	0	69	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	0	0
140	A	488	261	261	261	261	261	261	261	261	261
	B	488	261	261	261	261	261	261	261	261	261
	C	488	261	261	261	261	261	261	261	261	261
Cumulative	A	1254	1268	1277	1277	1277	1277	1277	1277	1277	1277
present net	B	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
worth ($000s)	C	1504	1528	1550	1550	1551	1551	1551	1552	1552	1552

A - 12% discount rate, B - base case, C - 8% discount rate.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

The results are as expected following the Faustman comparative statics result $\partial T/\partial r < 0$. Increasing the interest cost on the enterprise decreases the value of the land for wood production. The optimal rotation length is shortened to account for the changed value growth.

5.2.4 Increasing Stumpage Values

FORPLAN can be used to examine the implications on management if stumpage values rise (fall) in the future reflecting increased (decreased) scarcity and higher (lower) real prices. Although some evidence suggests rising real prices for high quality sawlogs, world wide investments in forest plantations and technological innovations in the utilisation sector may act to counter price rises (Sedjo, *pers comm.*). Nevertheless, two scenarios of increased real stumpage prices are presented in Table 5.7. Sawlog stumpage prices were increased 2% and 5% per annum for the first 50 years of the planning horizon and then left constant. These scenarios represent the view that large diameter trees will command higher prices for a finite period after which price levels stabilise and remain constant. Given that pulpwood is easier and cheaper to grow and demanders probably have more flexibility in terms of substitutes, pulpwood prices were assumed to remain constant over time. In the 5% per annum increase (pai) case all areas including the reserve forest are converted into plantations and managed on a 40 year rotation basis. Recall that the reserve forest type is treated as bare land in the unconstrained base case because there are no data on current timber volumes. In period 5 when the formerly reserve type is harvested, sawlog values have grown to $450/m^3 for class A sawlog and $243/m^3 for class B and C. This scenario provides a first approximation of the sort ofstumpage values required to justify conversion of non-commercial forest areas to intensively managed commercial plantations under this cost and yield structure. The

Table 5.7 Stumpage Price Increases

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest	A	838	0	0	0	1033	0	0	0	1033	0
(ha)	B	600	111	61	600	0	103	600	0	61	642
	C	661	42	0	69	661	42	0	0	730	42
Prescription	A	P	-	-	-	P	-	-	-	P	-
	B	P	P/N	P	P	-	P	P	-	P	P
	C	P	P	-	N	P	P	-	-	P/N	P
Water yield	A	8075	5590	4582	4481	6379	5413	4080	3884	6090	5413
(0's ML)	B	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	C	8900	7648	6775	6448	7535	7103	6209	6052	7599	7192
Hectares in	A	103	838	838	0	0	1033	1033	0	0	1033
age class 0-20	B	103	661	711	172	661	600	103	703	600	61
	C	103	661	703	42	69	730	703	42	0	730
21-40	A	0	0	0	838	838	0	0	1033	1033	0
	B	0	42	61	600	111	172	600	0	103	642
	C	0	42	0	661	703	42	69	730	703	42
41-80	A	195	195	0	0	0	0	0	0	0	0
	B	195	0	0	0	0	0	69	69	69	69
	C	195	0	0	0	0	0	0	0	69	0
81-100	A	247	0	195	195	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
	C	247	0	0	0	0	0	0	0	0	0
101-140	A	0	0	0	0	195	0	0	0	0	0
	B	0	69	0	0	0	0	0	0	0	0
	C	0	69	69	69	0	0	0	0	0	0
140	A	488	0	0	0	0	0	0	0	0	0
	B	488	261	261	261	261	261	261	261	261	261
	C	488	261	261	261	261	261	261	261	261	261
Cumulative	A	332	332	332	332	9324	9324	9324	9324	10708	10708
present net	B	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
worth ($000s)	C	1633	1662	1662	1718	3073	3131	3131	3131	3415	3415

A - 5% per annum increase in sawlog prices, for 50 years, B - base case, C - 2% per annum increase in sawlog prices, for 50 years.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

1919/26 harvest is delayed to the fifth period due to its increase in value over time. Water flows decrease to less than half the first period's flow by period eight. Age class flows obviously change significantly in this case. By the sixth period and thereafter the entire catchment is managed on a 40 year rotation basis as one large plantation.

Under the 2% pai scenario the reserve forest remains unlogged as in the base case. This scenario has the general effect of bringing some harvests forward, increasing the rotation age to 40 years and delaying the scrub harvest. The scrub forest harvest (69 hectares) is delayed until the fourth period to capture the increase in value and left to regenerate naturally on a 50 year rotation basis. Average annual water flows decrease approximately 2850 ML in this case from the first period flows compared to 2498 ML in the base case. The per period age class distribution varies in this case relative to the base case only due to the different timing of harvest on some forest types.

NPV in both the 2% and 5% cases is clearly larger than the base case but the accumulation over time is markedly different in the 5% case. Under that scenario most benefits do not occur until the fifth period. A larger investment is needed in the first period to generate the longer term benefits. It is not appropriate to directly compare these results to the Faustmann comparative statics result $\partial T / \partial P < 0$. The comparative statics result apply to once and for all changes in prices not evolving prices. The Newman *et al.* (1985) model mentioned in Chapter 2 suggests the long-run rotation period is sometimes longer and sometimes shorter than the Faustmann rotation length when prices increase exponentially. In both cases here the optimal rotation length generally increases to 40 years from 30 years in the base case.

5.2.5 Changing the Time Horizon

Moving from the linear forest as expressed in Chapter 2 to a FORPLAN formulation the time horizon goes from infinity to some finite *N* years (10 ten year periods in the models used here). Johansson and Lofgren (1985) show the effect on NPV can be negligible with a large enough *N*, but perhaps of more interest to planners is whether changing *N* affects the optimal management strategy. Table 5.8 compares the results of the first ten periods of a scenario where the planning horizon was set at 200 years to the base case. In fact, the optimal management strategy does change slightly in this model formulation. In the 200 year planning horizon the scrub forest harvest is delayed to the third period and the 42 hectares of 1970's regeneration is managed on a 30 year rotation basis rather than 40 years as in the base case. The variations in water flow and age classes are minor relative to previously discussed scenarios. The change in harvest schedule decreases the cumulative NPV approximately $1000 by the tenth period.

5.3 Sensitivity Analysis on the CFL Case

This section provides some insights into the effects of uncertainty using the CFL case as the basis for comparison. The constraints in the CFL case may lead to counter-intuitive outcomes when sensitivity analysis is performed. Since this case closely mimics current policy, an investigation of this possibility was deemed relevant. The impact of increasing costs, increasing timber yields, increasing the discount rate, increasing stumpage price and increasing the planning horizon was examined. As mentioned previously four constraints were introduced to reflect current policy in the catchment:

1. minimum 60 year rotations;
2. maximum 25 hectare per year harvests in the catchment;

Table 5.8 Extended Planning Horizon

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest (ha)	A	600	111	61	600	0	103	600	0	61	642
	B	600	42	130	600	42	61	600	42	61	600
Prescription	A	P	P/N	P	P	-	P	P	-	P	P
	B	P	P	P/N	P	P	P	P	P	P	P
Water yield (0's ML)	A	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	B	8866	7597	6737	7407	7017	6318	7327	7063	6416	7439
Hectares in age class 0-20	A	103	661	711	172	661	600	103	703	600	61
	B	103	661	642	172	730	642	103	661	642	103
21-40	A	0	42	61	600	111	172	600	0	103	642
	B	0	42	61	600	42	130	669	42	61	600
41-80	A	195	0	0	0	0	0	69	69	69	69
	B	195	0	0	0	0	0	0	69	69	69
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
101-140	A	0	69	0	0	0	0	0	0	0	0
	B	0	69	69	0	0	0	0	0	0	0
140	A	488	261	261	261	261	261	261	261	261	261
	B	488	261	261	261	261	261	261	261	261	261
Cumulative present net worth ($000s)	A	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
	B	1511	1540	1570	2087	2111	2135	2295	2302	2310	2359

A - base case, B - first 10 periods of a 200 year planning horizon.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

3. no pulpwood harvests;
4. no natural regeneration allowed.

5.3.1 Increasing Costs

Table 5.9 presents the results of increasing costs 30% in the CFL case. The only consequence is the non-harvest of the lower productivity mature/overmature forest type (35 hectares) in the third period. This can be seen by observing that the third period harvest is only 65 hectares and the amount of land in the oldest age class is 35 hectares greater than the CFL case from the third period onwards. Raising costs 30% has made logging the low productivity mature/overmature forest uneconomic, given natural regeneration is not allowed. This results in an increase in water flows over time relative to the CFL case. There is a $129,000 decrease in NPV in this scenario. *A priori* expectations from the Faustmann comparative statics results would suggest an increase in the rotation length. However, as identified earlier in the base case sensitivity analyses, the length of the planning periods can hide small changes in optimal rotation lengths.

5.3.2 Increasing Timber Yields

Increasing timber yields 30% affects the management strategy more profoundly than increasing costs. Table 5.10 presents the results of this scenario compared to the CFL case. Planting with a 60 year rotation period becomes the preferred silvicultural prescription after timber harvests on some forest types. However, seeding is still used on some analysis areas or portions of the original analysis areas. To know which analysis areas had seeding operations requires additional FORPLAN output not shown here. Essentially the seeding operation with a 70 year rotation period was prescribed for a portion (61 hectares) of the mature/overmature forest in period 2. This enabled two other analysis areas totalling 61 hectares to be harvested

Table 5.9 Increasing Costs on CFL Case

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest (ha)	A	250	250	100	0	0	42	61	250	250	100
	B	250	250	65	0	0	42	61	250	250	65
Prescription	A	S	S	S	-	-	S	S	S	S	S
	B	S	S	S	-	-	S	S	S	S	S
Water yield (0's ML)	A	8782	8313	7411	6826	6769	7067	7420	7863	7848	7313
	B	8782	8313	7411	6912	6900	7204	7546	7970	7935	7347
Hectares in age class 0-20	A	103	311	500	350	100	0	42	103	311	500
	B	103	311	500	315	65	0	42	103	311	500
21-40	A	0	42	103	311	500	350	100	0	42	103
	B	0	42	103	311	500	315	65	0	42	103
41-80	A	195	35	0	42	103	353	561	600	350	100
	B	195	35	0	42	103	353	561	565	315	65
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
101-140	A	0	157	69	69	69	0	0	0	0	0
	B	0	157	69	69	69	0	0	0	0	0
140	A	488	488	361	261	261	330	330	330	330	330
	B	488	488	361	296	296	365	365	365	365	365
Cumulative present net worth ($000s)	A	789	1043	1051	1051	1052	1072	1091	1159	1205	1218
	B	716	935	940	940	940	959	976	1039	1081	1089

A - current CFL policy, B - increasing costs 30%.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

Table 5.10 Increasing Yields on CFL Case

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest	A	250	250	100	0	0	42	61	250	250	100
(ha)	B	250	250	100	-	-	42	250	250	161	-
Prescription	A	S	S	S	-	-	S	S	S	S	S
	B	P	P/S	P	-	-	S	P	P/S	P/S	-
Water yield	A	8782	8313	7411	6826	6769	7067	7420	7863	7848	7313
(0's ML)	B	8782	8313	7411	6826	6769	7067	7668	7831	7453	6886
Hectares in	A	103	311	500	350	100	0	42	103	311	500
age class 0-20	B	103	311	500	350	100	0	42	292	500	411
21-40	A	0	42	103	311	500	350	100	0	42	103
	B	0	42	103	311	500	350	100	0	42	292
41-80	A	195	35	0	42	103	353	561	600	350	100
	B	195	35	0	42	103	353	561	411	161	0
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
101-140	A	0	157	69	69	69	0	0	0	0	0
	B	0	157	69	69	69	0	0	0	0	0
140	A	488	488	361	261	261	330	330	330	330	330
	B	488	488	361	261	261	330	330	330	330	330
Cumulative	A	789	1043	1051	1051	1052	1072	1091	1159	1205	1218
present net worth ($000s)	B	1002	1326	1332	1332	1332	1360	1516	1620	1664	1664

A - current CFL policy, B - increasing timber yields 30%.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

in period 8 at the minimum allowable harvest age and still meet the maximum allowable harvest constraint. The two other analysis areas were 1980's regeneration. The silvicultural prescription for them was seeding with a 60 year rotation period. This outcome is again due to the relativities between current costs and yields and potential future growth rates working within the constraint structure. The harvest pattern over time is the same as the CFL case until period 7. The deviation from the CFL pattern, in combination with the shorter rotation period, decreases the water flows for the remainder of the planning horizon and affects the distribution of the first three age classes. NPV increased $446,000 (37%) over the CFL case.

5.3.3 Increasing the Discount Rate

Increasing the discount rate to 8% affects the CFL strategy in two general ways. Table 5.11 presents these results. Firstly, the rotation period on harvested land is decreased to 60 years on the majority of analysis areas. Portions of some analysis areas are managed on a 70 year basis to ensure the maximum allowable harvest constraint is met in some periods. Secondly, the 35 hectares of lower productivity mature/overmature forest becomes uneconomic to log. This can be seen by observing the timber harvest in period 3 and the age class 6 relative to the CFL case from the fourth period onwards. Over the planning horizon average annual water flows vary slightly less under this plan, 1899 ML to 2013 ML in the CFL case. The shorter rotation period means the amount of land in the 41 - 80 age class is not as great in the later periods. However, there is more land in the oldest age class in this plan than the CFL case. NPV decreases $395,000 (32%) with an 8% discount rate. *A priori* expectations from the comparative statics of the Faustmann model are generally met; that is, an increase in the discount rate decreased the optimal rotation length.

Table 5.11 Increasing the Discount Rate on the CFL Case

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest	A	250	250	100	0	0	42	61	250	250	100
(ha)	B	250	250	65	0	0	42	250	250	126	-
Prescription	A	S	S	S	-	-	S	S	S	S	S
	B	S	S	S	-	-	S	S	S	S	-
Water yield	A	8782	8313	7411	6826	6769	7067	7420	7863	7848	7313
(0's ML)	B	8799	8327	7411	6912	6900	7204	7788	7933	7496	6971
Hectares in	A	103	311	500	350	100	0	42	103	311	500
age class 0-20	B	103	311	500	315	65	0	42	292	500	376
21-40	A	0	42	103	311	500	350	100	0	42	103
	B	0	42	103	311	500	315	65	0	42	292
41-80	A	195	35	0	42	103	353	561	600	350	100
	B	195	0	0	42	103	353	561	376	126	0
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
101-140	A	0	157	69	69	69	0	0	0	0	0
	B	0	192	69	69	69	0	0	0	0	0
140	A	488	488	361	261	261	330	330	330	330	330
	B	488	488	361	296	296	365	365	365	365	365
Cumulative	A	789	1043	1051	1051	1052	1072	1091	1159	1205	1218
present net worth ($000s)	B	684	807	811	811	811	814	820	823	823	823

A - current CFL policy, B - 8% discount rate on CFL case.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

5.3.4 Increasing Stumpage Value

Under a scenario with 2% per annum increases in sawlog values for 50 years, planting becomes the generally preferred silvicultural option with 60 year rotation periods. Table 5.12 summarises these results. Although the harvest levels are the same as the CFL case for the first three periods, the pattern and timing of harvest on individual analysis areas is different. This can be seen by comparing the age class flows, in particular the first three periods of age classes 41-80, 81-100, 101-140 and >140. In this case the mature/overmature forest comprises the largest portion of the first period harvest (see age class 6 in periods 1 and 2). In period 2, 1919/26 and 1890's forest comprise the majority of the harvest. In the CFL case this harvest sequence is reversed. It is the relative increase in stumpage value and volume on the 1919/26 and 1890's forest type in the first few periods that is responsible for this reversal. The mature/overmature forest type does not have any net growth over time so it was harvested immediately. This result illustrates the importance of considering price and volume changes in conjunction when determining harvesting strategies. It could be inferred that with increasing prices and given harvesting constraints, logging operations should first occur on forests having the lowest value increments. However, the results are empirical and depend on the relativities between costs and value increases. In this scenario harvesting the scrub forest becomes worthwhile and occurs in the fourth period. There are of course trade-offs with non-wood resources. Water flows decrease both more rapidly and in absolute terms than the CFL case. Age class flows change due to the timing and harvest of the mature/overmature and scrub forest and the shorter rotation length.

Table 5.12 Increasing Stumpage Prices in the CFL Case

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest	A	250	250	100	0	0	42	61	250	250	100
(ha)	B	250	250	100	69	-	103	250	250	100	69
Prescription	A	S	S	S	-	-	S	S	S	S	S
	B	P	P	P	P	-	S	P	P	P	P
Water yield	A	8782	8313	7411	6826	6769	7067	7420	7863	7848	7313
(0's ML)	B	8602	8098	7353	6680	6306	6601	7090	7190	6766	6435
Hectares in	A	103	311	500	350	100	0	42	103	311	500
age class 0-20	B	103	311	500	350	169	69	103	353	500	350
21-40	A	0	42	103	311	500	350	100	0	42	103
	B	0	42	103	311	500	350	169	69	103	353
41-80	A	195	35	0	42	103	353	561	600	350	100
	B	195	172	0	42	103	353	500	350	169	69
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	100	0	0	0	0	0	0	0
101-140	A	0	157	69	69	69	0	0	0	0	0
	B	0	247	69	69	0	0	0	0	0	0
140	A	488	488	361	261	261	330	330	330	330	330
	B	488	261	261	261	261	261	261	261	261	261
Cumulative	A	789	1043	1051	1051	1052	1072	1091	1159	1205	1218
present net worth ($000s)	B	101	761	1344	1376	1376	1484	1820	2047	2109	2117

A - current CFL policy, B - 2% per annum increase on sawlog stumpage prices for 50 years.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

5.3.5 Increasing the Time Horizon

As with the base case, increasing the time horizon to 200 years in the CFL case affects the management plan. Table 5.13 presents the results of the first ten periods of this scenario compared to the CFL case. Until period 7 the management strategy is the same as the CFL case, except that planting occurs instead of seeding on some areas. On those areas, where planting occurs a 60 year rotation period was selected. Water and age class flows are only affected by this change from the seventh period onwards. By the tenth period the average annual water flow is some 300 ML less than the CFL case. Cumulative NPV is $9,000 (1%) less in this scenario by period ten but of course slightly larger by the twentieth planning period ($1,231,000, not shown).

5.4 Additional Model Experimentation

A number of additional analyses were performed to investigate some issues that appear to be relevant to the general forest management planning problem in Australia. In this section minimum allowable rotation period, maximum annual allowable harvests, and the effects of stumpage price and discount rate increases on the opportunity costs of preserving various forest types are examined.

5.4.1 Minimum Rotation Length

In considering the minimum allowable rotation issue six different scenarios were compared to the base case: minimum 40, 60 and 80 years and minimum 80, 100 and 120 years including a "no natural regeneration" constraint. The 60 year rotation constraint case shows the impact of this CFL policy on the base case. A "no natural regeneration" constraint was used on the 80-120 year cases for two related reasons. First, separate model

Table 5.13 Extended Planning Horizon on CFL Case

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest (ha)	A	250	250	100	0	0	42	61	250	250	100
	B	250	250	100	0	0	42	250	250	61	100
Prescription	A	S	S	S	-	-	S	S	S	S	S
	B	P/S	P/S	S	-	-	S	P/S	P/S	S	S
Water yield (0's ML)	A	8782	8313	7411	6826	6769	7067	7420	7863	7848	7313
	B	8782	8313	7411	6826	6769	7067	7660	7824	7326	7033
Hectares in age class 0-20	A	103	311	500	350	100	0	42	103	311	500
	B	103	311	500	350	100	0	42	292	500	311
21-40	A	0	42	103	311	500	350	100	0	42	103
	B	0	42	103	311	500	350	100	0	42	292
41-80	A	195	35	0	42	103	353	561	600	350	100
	B	195	35	0	42	103	353	561	411	161	100
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
101-140	A	0	157	69	69	69	0	0	0	0	0
	B	0	157	69	69	69	0	0	0	0	0
140	A	488	488	361	261	261	330	330	330	330	330
	B	488	488	361	261	261	330	330	330	330	330
Cumulative present net worth ($000s)	A	789	1043	1051	1051	1052	1072	1091	1159	1205	1218
	B	747	973	981	981	981	1002	1109	1185	1196	1209

A - current CFL policy, B - current CFL policy with a 200 year planning horizon.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

experimentation showed that natural regeneration becomes the prefered silvicultural choice for all forest types for any rotation of 80 years or greater. Second, the CFL is considering the possibility of 80-120 year rotations in the native forests but current policy does not allow natural regeneration as a silvicultural treatment. A 200 year time horizon was used in all of these scenarios to eliminate the influence of the shorter planning horizon. Sensitivity analysis on both the base case and the CFL case showed that the 100 year horizon influences the optimal strategy. Also, harvests on some analysis areas would not occur in a 100 year planning horizon with some of these minimum rotation length scenarios.

Tables 5.14 and 5.15 report the results of the first ten periods in the planning horizon for the first four of these scenarios. Essentially as soon as a forest type meets the minimum age qualification it is harvested. Under the 40 and 60 year scenarios planting is still the preferred management option except for the scrub forest which is harvested and left to regenerate naturally. In the minimum 80 year rotation case natural regeneration is preferred on all harvested land. The cost of the constraints were $57,000 (3%) in the 40 year case, $383,000 (16%) in the 60 year case and $594,000 (25%) in the 80 year case.

Table 5.15 also shows the implications of a no natural regeneration constraint on the minimum 80 year rotation scenario. Seeding becomes the preferred silvicultural method and the scrub forest is not logged. The effect of the no natural regeneration constraint on NPV is only $36,000 over the 100 years, relative to the minimum 80 year rotation case allowing natural regeneration. However, the difference in NPV between the unconstrained base case and the "minimum 80 year rotation/no natural regeneration" case is $630,000, 27% less. It is the rotation length

Table 5.14 Minimum 40 and 60 year Rotation

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest (ha)	A	600	-	69	-	42	61	600	0	0	0
	B	600	111	61	600	0	103	600	0	61	642
	C	600	-	111	61	600	-	42	61	600	-
Prescription	A	P	-	N	-	P	P	P	-	-	-
	B	P	P/N	P	P	-	P	P	-	P	P
	C	P	-	P/N	P	P	-	P	P	P	-
Water yield (0's ML)	A	8866	7514	6568	6168	6369	6749	7753	6980	6247	6211
	B	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	C	8866	7514	6644	6316	7414	6921	6247	6273	7499	7056
Hectares in age class 0-20	A	103	661	600	69	69	42	103	661	600	0
	B	103	661	711	172	661	600	103	703	600	61
	C	103	661	600	111	172	661	600	42	103	661
21-40	A	0	42	103	661	600	69	69	42	103	661
	B	0	42	61	600	111	172	600	0	103	642
	C	0	42	103	661	600	111	172	661	600	42
41-80	A	195	0	0	42	103	661	600	69	69	111
	B	195	0	0	0	0	0	69	69	69	69
	C	195	0	0	0	0	0	0	69	69	69
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
	C	247	0	0	0	0	0	0	0	0	0
101-140	A	0	69	69	0	0	0	0	0	0	0
	B	0	69	0	0	0	0	0	0	0	0
	C	0	69	69	0	0	0	0	0	0	0
140	A	488	261	261	261	261	261	261	261	261	261
	B	488	261	261	261	261	261	261	261	261	261
	C	488	261	261	261	261	261	261	261	261	261
Cumulative present net worth ($000s)	A	1511	1511	1516	1516	1545	1571	1977	1977	1977	1977
	B	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
	C	1511	1511	1543	1566	2146	2146	2164	2182	2303	2303

A - minimum 60 year rotation, B - base case, C - minimum 40 year rotation.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

Table 5.15 Minimum 80 year Rotation

Output/ activity		1	2	3	4	5	6	7	8	9	10
					Planning Period						
Timber harvest	A	405	195	-	-	-	-	42	61	405	195
(ha)	B	600	111	61	600	0	103	600	0	61	642
	C	405	264	-	-	-	-	42	61	405	195
Prescription	A	S	S	-	-	-	-	S	S	S	S
	B	P	P/N	P	P	-	P	P	-	P	P
	C	N	N	-	-	-	-	N	N	N	N
Water yield	A	8871	7844	6966	6668	6800	7134	7559	7903	8349	7816
(0's ML)	B	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	C	8671	7698	6503	6116	6235	6591	7053	7435	7919	7416
Hectares in	A	103	466	600	195	0	0	0	42	103	466
age class 0-20	B	103	661	711	172	661	600	103	703	600	61
	C	103	466	669	264	0	0	0	42	103	466
21-40	A		42	103	466	600	195	0	0	0	42
	B	0	42	61	600	111	172	600	0	103	642
	C	0	42	103	466	669	264	0	0	0	42
41-80	A	195	195	0	42	103	508	703	661	600	195
	B	195	0	0	0	0	0	69	69	69	69
	C	195	195	0	42	103	508	772	730	669	264
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
	C	247	0	0	0	0	0	0	0	0	0
101-140	A	0	69	69	69	69	0	0	0	0	0
	B	0	69	0	0	0	0	0	0	0	0
	C	0	69	0	0	0	0	0	0	0	0
140	A	488	261	261	261	261	330	330	330	330	330
	B	488	261	261	261	261	261	261	261	261	261
	C	488	261	261	261	261	261	261	261	261	261
Cumulative	A	662	1526	1526	1526	1526	1526	1550	1572	1691	1730
present net	B	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
worth ($000s)	C	778	1685	1685	1685	1685	1685	1710	1733	1758	1766

A - minimum 80 year rotation with no natural regeneration constraint, B - base case, C - minimum 80 year rotation.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

constraint that most profoundly affects the objective function value, not the natural regeneration constraint.

Average annual water flow variations were greatest with 60 and 40 year rotation scenarios (approximately 2700 ML and 2600 ML respectively) and in the 80 year scenario with the natural regeneration constraint 2550 ML. The variation between the highest and lowest decade's flow is about 2500 ML in the base case. It is possible to conclude that these minimum rotation length constraints would not have a profound effect on water flows, at least relative to the base case. However, as far as age classes are concerned, the third age class (41 - 80 years) is much more represented in the 60 and 80 year scenarios than in the base case. The economic question is whether or not the additional area in that age class is worth the cost.

The 100 and 120 year minimum rotation scenarios allowed first rotation harvests at age 80. This follows current policy. The 100 and 120 rotation age constraints were for subsequent harvests. The pattern of harvest was no different to the 80 year scenario for the first 80 years of the planning horizon so the results are not reported. In these cases the second harvests do not occur until the second half of the planning horizon. NPV was $1,572,000 (33%) less than the base case, at the end of ten periods for both of these cases. In the longer rotation scenarios, the older age classes are represented but there are periods in which the younger classes are not represented.

5.4.2 Maximum Allowable Annual Harvests

As mentioned in the previous chapter there is no empirical evidence on the effects of timber harvesting on water quality in the Otways. However, the CFL has an unwritten policy of not harvesting more than 25 hectares per year from the catchment due to the perception that any harvests above this amount would decrease water quality.

Three scenarios are presented here to illustrate the management implications of different maximum annual allowable harvests. In fact this approach is an indirect proxy for investigating both the water quality issue and some conservation issues (eg. the effects of disturbance on wildlife). Often the ultimate effect of management for many non-wood objectives is a restricted timber harvest.

Table 5.16 shows the effects of the 25 hectare/year constraint on the base case. This constraint represents current policy in the catchment. The constraint is binding in 6 of the 10 periods. Planting is the preferred regeneration technique and, while not easily apparent from the table, 30 and 40 year rotation periods are used on the planted land. The scrub forest harvest is spread over two periods with natural regeneration again the preferred management option. What is apparent from observing the age class structure in the first three periods is that the harvest of older less productive forest is delayed. This constraint decreases the average annual water flow variation to 1900 ML compared to about 2500 ML in the base case. The NPV cost of this constraint is $300,000 (13%).

Changing the maximum annual harvest constraint to 10 and 5 hectares per year affected the output flows and management significantly. A "no natural regeneration" was included as initial analysis revealed an increased reliance on natural regeneration the greater the harvest constraint. Again this was to more closely resemble current forest policy and previous analysis showed a "no natural regeneration" constraint to be, relatively speaking, of minor importance. Table 5.17 shows the results of both the 5 and 10 hectare per year harvest constraint including the no natural regeneration constraint. These two scenarios resulted in the most complex management plans for the West Barham presented thus far.

Table 5.16 Twenty Five Hectare per year Harvest Constraints

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest (ha)	A	600	111	61	600	0	103	600	0	61	642
	B	250	250	250	250	250	225	228	228	225	250
Prescription	A	P	P/N	P	P	-	P	P	-	P	P
	B	P	P	P/N	P/N	P	P	P	P	P	P
Water yield (0's ML)	A	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	B	8782	8313	7508	7023	6936	6887	6868	6899	6936	7018
Hectares in age class 0-20	A	103	661	711	172	661	600	103	703	600	61
	B	103	311	500	500	500	500	475	453	456	453
21-40	A	0	42	61	600	111	172	600	0	103	642
	B	0	42	103	250	272	272	297	272	247	250
41-80	A	195	0	0	0	0	0	69	69	69	69
	B	195	35	0	0	0	0	0	47	69	69
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
101-140	A	0	69	0	0	0	0	0	0	0	0
	B	0	157	69	22	0	0	0	0	0	0
140	A	488	261	261	261	261	261	261	261	261	261
	B	488	488	361	261	261	261	261	261	261	261
Cumulative present net worth ($000s)	A	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
	B	1019	1379	1461	1659	1813	1908	1968	2009	2038	2060

A - base case, B - maximum 25 hectare per year harvest constraint.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

Table 5.17 Maximum 5 and 10 Hectare per year Harvest Constraints

Output/ activity		Planning Period 1	2	3	4	5	6	7	8	9	10
Timber harvest	A	100	100	100	100	100	100	100	100	100	100
(ha)	B	600	111	61	600	0	103	600	0	61	642
	C	50	50	50	50	50	50	50	50	50	50
Prescription	A	P	P	P	P/S	P	P	P/S	P/S	P	P
	B	P	P/N	P	P	-	P	P	-	P	P
	C	S	S	S	S	S	S	S	S	S	S
Water yield	A	8676	8533	8270	8006	7910	7952	7979	7942	7922	7965
(0's ML)	B	8866	7451	6420	7318	6921	6368	7418	7027	6391	7552
	C	8626	8542	8467	8391	8297	8222	8165	8146	8154	8112
Hectares in	A	103	161	200	200	200	200	200	200	200	200
age class 0-20	B	103	661	711	172	661	600	103	703	600	61
	C	103	111	100	100	100	100	100	100	100	100
21-40	A	0	42	103	161	200	200	200	200	200	200
	B	0	42	61	600	111	172	600	0	103	642
	C	0	42	103	111	100	100	100	100	100	100
41-80	A	195	95	0	42	76	76	76	76	76	76
	B	195	0	0	0	0	0	69	69	69	69
	C	195	145	0	42	103	153	203	211	200	200
81-100	A	247	0	0	0	0	0	0	0	0	0
	B	247	0	0	0	0	0	0	0	0	0
	C	247	0	95	45	0	0	0	42	61	65
101-140	A	0	247	242	142	69	0	0	0	0	0
	B	0	69	0	0	0	0	0	0	0	0
	C	0	247	247	247	242	0	0	0	0	0
140	A	488	488	488	488	488	557	557	557	557	557
	B	488	261	261	261	261	261	261	261	261	261
	C	488	488	488	488	488	680	630	580	572	568
Cumulative	A	490	908	1074	1195	1292	1357	1403	1438	1458	1472
present net	B	1511	1545	1570	2087	2087	2139	2298	2298	2305	2360
worth ($000s)	C	242	497	708	815	869	910	940	964	981	992

A - maximum 10 hectare per year harvest constraint, B - base case, C - maximum 5 hectare per year harvest constraint.
P = planting, N = natural regeneration, S = seeding P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period; age class reports are for middle of period before harvest if a harvest occurs in that period.

It is not easy to ascertain from Table 5.17 the variety of rotation periods chosen to meet the harvesting constraint. The Table does show, via the age class structure, that many analysis areas were divided into smaller units during the planning horizon. FORPLAN output not shown here identifies rotation lengths on each analysis area. In the 10 hectare/year case rotation lengths on harvested land ranged from 30 to 70 years on harvested areas. In the 5 hectare/year case rotation lengths on harvested land ranged from 20 to 100 years. In both scenarios the NPV decreased substantially, $888,000 (38%) and $1,368,000 (58%) from the base case for the 10 hectare and 5 hectare cases respectively.

The change in water flow and age class structure is worth noting. Under both scenarios the mature/overmature forest is not harvested, indicative of its low timber value. In fact with the 5 hectare/year constraint, the 1890's forest (part of the 81 - 100 year age class in period 1) harvest is delayed to the later half of the planning horizon. For both of these scenarios a larger proportion of forest is in the older age classes than any other scenario. Average annual water flow variations are just 766 ML and 514 ML for the 10 hectare and 5 hectare cases respectively. This variation is much smaller than any previous scenario.

The increase in water flow and higher representation of old age classes does not necessarily imply these are the best multiple-use strategies for the West Barham. Clearly the loss in NPV is substantial relative to other cases. As stated earlier it is unlikely that high water production is important in the catchment for domestic consumption. Also given the natural annual variation in water flow it is unlikely that maintaining high water flows is crucial for recreational and/or environmental reasons. However, insofar as water quality or other values are affected by logging, the proxy indicator of restricting timber harvests can be used to get a first approximation of the benefits required to justify such policies. If the major reason for restricting harvests are water quality then the costs of water treatment due to logging would need to be weighed against the loss in timber values. What is clear from this example is that as logging is restricted, for whatever reason, the optimal timber harvest schedule can be expected to become very complex. In the West Barham it appears that the most cost effective means to achieve annual harvest constraints is to restrict logging on the oldest forest types. It is interesting to note that the management of the oldest forest types is the most controversial aspect of wildlife conservation in Australia.

5.4.3 Harvesting Constraints

In Section 5.2.4 the opportunity costs of preserving various forest types was identified. That analysis assumed constant stumpage prices over time and a discount rate of 4%. If stumpage prices rise in the future or a higher discount rate is preferred or appropriate the cost of preservation is affected. In order to examine these implications four scenarios were developed for the base case and the CFL case. No logging constraints were introduced on various forest types to each of these scenarios and compared to the values shown in Table 5.3. The first scenario, shown as A2 and B2 in Table 5.18, considers a situation in which sawlog prices increase 2% per annum for 50 years. The second scenario, shown against A3 and B3, considers a once off 50% price rise on sawlogs. The third and fourth scenarios consider higher discount rates of 8% and 12% using current prices through time.

Table 5.18 summarises the findings of these analyses as both net present value costs and perpetual annuities. In all cases the costs of preservation are highest with 1919/26 forest, followed by 1890's, mature/overmature and

Table 5.18 NPV Costs of Logging Bans

Case	Forest Type Set Aside ($/hectare) Mature/overmature	1970s	1890s	1919/26
A1	2234 (89)	1475 (59)	3809 (152)	6010 (240)
A2	3317 (133)	2372 (95)	4987 (200)	7756 (310)
A3	2783 (111)	1799 (72)	5126 (205)	8819 (352)
A4	1057 (85)	589 (47)	2302 (184)	4402 (352)
A5	876 (105)	339 (41)	1913 (230)	3665 (440)
B1	326 (13)	491 (20)	1685 (67)	3705 (148)
B2	1354 (54)	1402 (56)	2972 (119)	5609 (224)
B3	717 (29)	807 (32)	2846 (114)	6033 (241)
B4	92 (7)	36 (3)	966 (77)	2659 (212)
B5	52 (6)	16 (2)	648 (78)	2069 (248)

Notes: Total net present value/hectare for the forest type set aside, values in brackets are the perpetual annuity value associated with the net present value.

A1 - unconstrained base case, constant prices, 4% discount rate
A2 - unconstrained 2% pai in sawlog values, 4% discount rate
A3 - unconstrained 50% increase in sawlog values, 4% discount rate
A4 - unconstrained base case, constant prices, 8% discount rate
A5 - unconstrained base case, constant prices, 12% discount rate
B1 - CFL case, constant prices, 4% discount rate
B2 - CFL case, 2% pai in sawlog values, 4% discount rate
B3 - CFL case, 50% increase in sawlog values, 4% discount rate
B4 - CFL case, constant prices, 8% discount rate
B5 - CFL case, constant prices, 12% discount rate.

1970's. The rankings reflect current and future yields and costs of management. Four points are worthy of special mention with regard to Table 5.18. First, if stumpage prices rise in the future, reflecting increased scarcity, conservation costs are increased. The two price rise scenarios had different relative preservation costs across the forest types. The 50% price rise case had a higher cost of preservation on some forest types than on others. Again this reflects relativities between current yields, future growth rates, costs, and stumpage values. In the CFL cases the relative rankings within and between cases also arise from the inter-connections between constraints, results of which may not be derivable except from this sort of explicit quantitative modelling. The second point worth mentioning is that conservation costs are very sensitive to forest type considered. Third, conservation costs are lower when additional management constraints are imposed (the CFL case). It can be noted that the fact that preservation costs are lower with CFL policy as a reference point can be interpreted as indicating that this is not the appropriate reference point for this sort of evaluation; that is, unless the CFL strategy can be shown to be the socially optimal strategy in the first instance, inclusive of wood and non-wood values in the objective function. Fourth, the NPV of conservation costs is decreased with a higher discount rate, particularly on the mature/overmature and 1970's forest types. This is due to the fact that the value of the land for timber production is significantly decreased with higher discount rates. However, it is demonstrated that the annuity costs actually rise on some forest types with higher discount rates. This indicates how important the selection of an appropriate discount rate is with respect to the preservation issue. There are boundary discount rates within which the present value of development costs and benefits outweigh the perpetual stream of preservation benefits (Porter, 1982).

5.5 Summary and Conclusions

This chapter presented the results of an LP treatment of an Australian forest planning problem using a FORPLAN analysis of the West Barham catchment in the Otway Ranges of Victoria as a case study. The results show that even with imperfect information an economic framework can inform planners of implications of various management strategies on wood and non-wood forest outputs. Insights on the nature of trade-offs may not arise without attempts at quantitative analysis. There will always be difficulties in identifying policy for fuzzy objectives but this does not eliminate the fact that trade-offs exist in forest management. The framework utilised here could in principle be used for any forest region. Since the approach helps to clarify the trade-offs involved in forestry it should force planners to more clearly articulate objectives and justify final strategies and general policy. For example, the 30 year pulpwood oriented rotation periods selected by FORPLAN in the base case may seem short to foresters but they are simply a reflection of current costs and stumpage values. The FORPLAN model should not be criticised for selecting an outcome that differs from current policy. That outcome arises from the relative prices of pulpwood and sawlogs as decided upon by the CFL and the costs of management. Since prices are determined bureacratically, not competitively, it is not possible to know whether these reflect proper social valuations.

The approach can be summarised as follows:

1. a so-called "unconstrained" formulation of the planning problem was developed given the timber yield, cost and revenue information, and forest type area statements. This provides a benchmark case for comparison against all others;

2. the tracking of non-wood outputs, water flow and important age classes in this case study, was incorporated into the model;
3. a set of constraints were developed to represent the current policy situation. This allows the planner to examine current and future implications of current policy. Constraints should be introduced separately to better understand implications;
4. sensitivity analysis was performed on various data input parameter values. This allows an analyst to determine what data long-term planning is particularly sensitive to;
5. the implications of other forest management options were investigated (eg. minimum rotation lengths, maximum harvest levels, removing some forest types from timber production).

This approach allows for a more systematic and analytical investigation of the planning problem than has been traditionally used by public forest agencies. However, it should be made clear that the approach is not simple or costless nor does it actually resolve the planning problem. The development of a suitable FORPLAN model for this problem proved to be a time-consuming exercise (many hundred person-hours), data collection problems aside. This is an important practical consideration for operationalising the approach for widespread adoption.

At the US Forest Service FORPLAN headquarters in Fort Collins, Colorado there are approximately 5 people (as at December 1988) solely devoted to helping the US National Forest planning teams with technical FORPLAN problems. Each National Forest has 20 or more people heavily involved in the planning process. This is not meant to imply that the US Forest Service is approaching forest planning as described in this chapter. The US Forest Service is decentralised with respect to planning so each planning team has a great deal of autonomy and therefore different approaches. Nevertheless it should be clear that this sort of planning exercise is not a trivial task. Organisations would have to be committed to the approach, if for nothing else but continuity of personnel, to run a model like FORPLAN. The approach would also require organisationally-backed data collection procedures and reasonable expectations about the results. Reasonable expectations arise out of a thorough understanding of both economic and LP theory and the limitations thereof.

In the case of the West Barham catchment, as with many native forest areas in Australia, most knowledge is concentrated on the wood resource. However, there are often severe data problems on not only timber growth and yields but also on current wood inventories. Knowledge about non-wood values is even poorer. This emphasises the need for proxy values or indicators when undertaking quantitative planning. The various model runs in this chapter attempted to provide an approach to the planning problem that is generally applicable and not specific to the West Barham. Results on other forest areas will of course vary due to biological and economic circumstance.

Using an unconstrained base case provides a benchmark for comparative purposes. Without such a benchmark, insights on the effectiveness of policy tools will not be well understood. For example, in comparing the unconstrained base case to the current policy (CFL) case (Table 5.1), a 50% drop in NPV is accompanied by only slight increases in water flows, and only the 41 - 80 year age class is more highly represented in relation to the base case.

Some of the solutions presented in this chapter verified the general theoretical results of the Faustmann model presented in Chapter 2. For example, increasing the discount rate decreased the rotation length and increasing costs increased the rotation length. In other instances sensitivity analysis did not result in management changes that would be expected. For example, decreasing costs did not decrease rotation length. This is due to the sensitivity of the data within the planning periods examined. Ten year planning periods are too long to pick up some management changes. The identification of the sensitivity of data to perturbations is extremely important for management planning. It is likely the sensitivity of results to data perturbations are site specific. Results for each forest will be dependent on interactions between the relativities of costs, prices, current and expected future yields and, the level and type of managerial constraints introduced.

One generalisation, shown in almost all solutions, is that management is almost always sensitive to parameter perturbations, including the 100 year planning horizon. An interesting feature is that many of the solutions are similar (albeit not exact) in the first few planning periods. However, the commonality often disappears in later periods. This raises questions about ultimately determining a management plan in a quantitative manner. In the real world of public forestry, planners following this sort of analytical approach will be faced with a mind-boggling myriad of possible management options. They will be asked to compare a wide variety of strategies. In the end someone or some people will be required to make choices and, for example, forced to decide between plans that have small differences in wood and non-wood outputs in later periods. In such situations uncertainty could be very important to the final decision. In the next chapter some of the implications and difficulties of estimating and forecasting uncertain values are explored.

Another interesting feature of the results relates to the treatment of the oldest forest types. Old growth forest is particularly controversial in Australia because of its importance for some wildlife species. Various FORPLAN results reported in this chapter empirically validated the, perhaps counter-intuitive, fact that the oldest forest types are relatively less valuable for wood production. If these results are generally applicable they suggest that some of the controversy and rhetoric that exists in the public debate over forestry in Australia may be unnecessary. What is needed is a closer examination of current inventories and forest management costs so that more efficient land allocations for wood production can occur.

CHAPTER 6

UNCERTAINTIES IN FORECASTING VALUES AND IMPLICATIONS FOR FOREST PLANNING

6.0 Introduction

Economic theory suggests that public sector managers use prices, or proxies of prices like willingness to pay, to guide their decisions directed at intertemporal efficiency. However, that directive is only of limited usefulness to forest managers if they do not have access to such prices or the expertise to obtain them. There is a further difficulty that many forest goods and services have both uncertain physical and economic values. The purpose of this chapter is to illustrate some of the management implications of uncertainty associated with economic values and investigate how this affects the use of economic principles in forest planning. In particular the path of stumpage prices through time and willingness to pay (WTP) for forest preservation are considered.

Following this introduction the literature on the demand/supply for forest products is examined. The goal is to reveal that much of that literature is only of limited relevance to forest planners and illustrate the fact that very little work has been done addressing the development of long-run stumpage price expectations in forestry. Section 6.2 presents and describes the results of a Monte Carlo simulation model of demand and supply for stumpage and price forecasting. The Monte Carlo problem is set up in the context of minimum uncertainty insofar as the numerical estimates of a demand and supply model are concerned. Monte Carlo techniques are used to generate the required data. In a sense this is an ideal situation for a planner - a demand and supply model known to be true with a long time series of data available. The problem of predicting the future path of exogenous variables is also eliminated by using the actual values as generated by the Monte Carlo model. This approach reduces the uncertainty for forecasting prices to a minimum. Both predicted and actual prices are used in the context of the West Barham FORPLAN model to examine the management implications of differences between the two sets of prices. Section 6.3 covers the WTP material. Some simple calculations are presented and discussed that are relevant to the issue of preserving Australian forests. Also, a Monte Carlo version of a hedonic travel cost problem is presented using the question of preserving the mature/overmature forest type in the West Barham as the context. As with the stumpage model the required data is generated using Monte Carlo simulation methods, thus creating an ideal situation for investigating the application of hedonic pricing techniques. Section 6.4 summarises the chapter and presents some general conclusions.

6.1 Demand for Wood Products and the Derivation of Stumpage Values for Forest Planning

In this discussion stumpage value is defined as the monetary value per unit volume of standing trees (Nautiyal, 1980). Stumpage values are determined by demand and supply forces. Note that actual stumpage prices do not necessarily equate to socially correct stumpage values. This section examines the literature on the supply and demand for wood products to highlight both the micro and macro factors that affect stumpage values and prices.

6.1.1 A Conceptual Overview of Demand for Stumpage

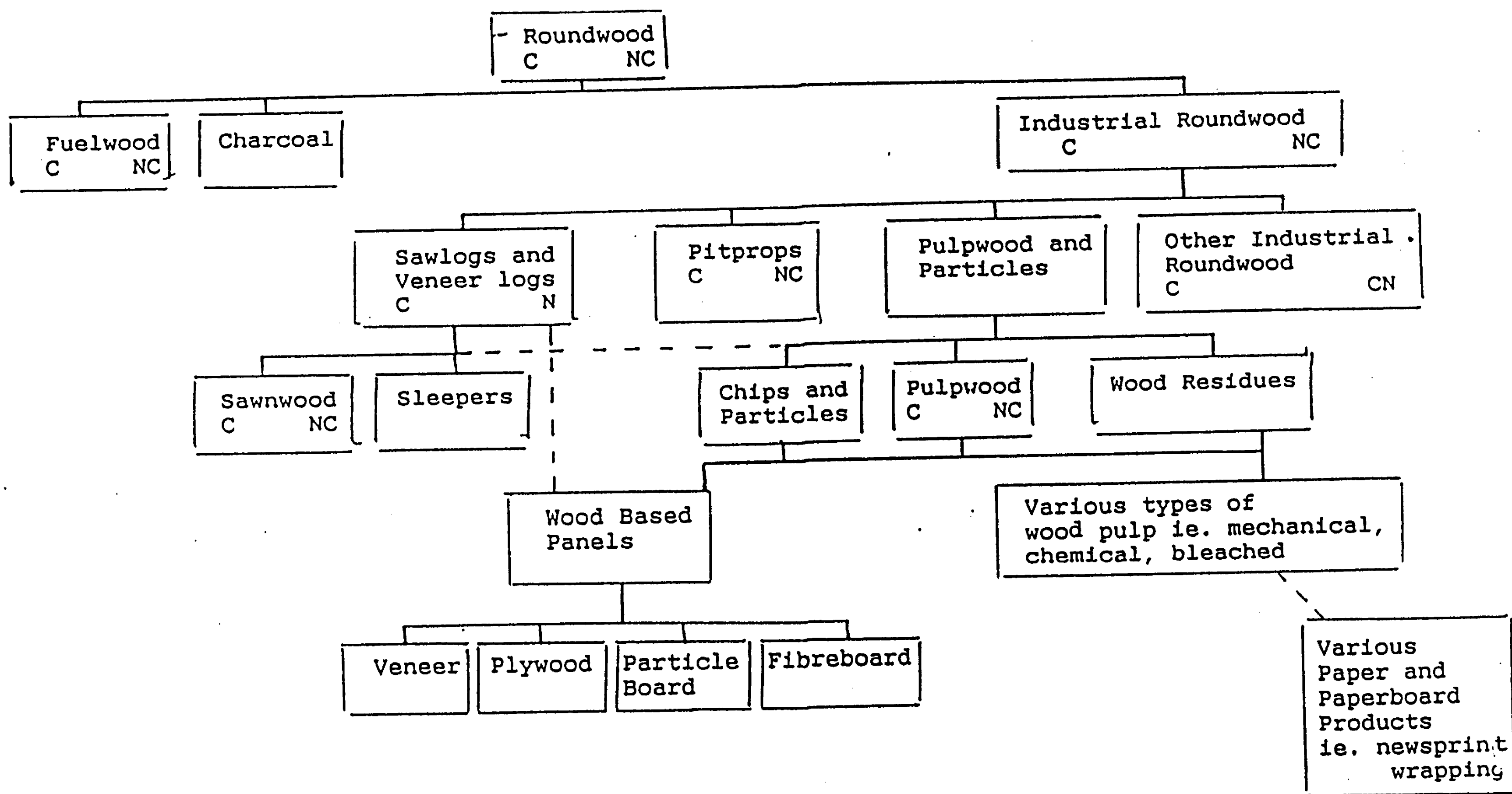
Demand for stumpage is derived from consumer demand for the final products it helps to produce. Figure 6.1 identifies a hierarchy of various wood products. The linkages back to stumpage become increasingly complex the further down the processing chain. The flow chart, Figure 6.2, is a standard economic interpretation of the linkages between final product output and the derived demand for stumpage.

For forest planning concerned with economic efficiency in producing wood the ultimate issue is determining the correct stumpage value. Recall from Chapter 2 the proposition that, excluding external effects and public good considerations, individual forests should, in the long-run, grow and sell as much stumpage as local markets can bear at prices reflecting the marginal costs of production. So in pursuit of intertemporal efficiency socially correct planning would need competitive market stumpage prices, or prices that would reflect competitive conditions. The literature on the demand and supply for forest products is examined with this construct in mind.

6.1.2 Estimating and Forecasting the Demand for Stumpage

There is a large forest economics literature relevant to the demand for stumpage. Kumar (1985) reviewed the techniques that have been used to forecast demand and supply for wood products. His review revealed that forestry production and consumption models have evolved from simple graphical trend projections (Holland, 1960) to much more complex econometric models attempting to identify various market relationships and structures (McKillop, 1967; Adams and Haynes, 1980). This complexity is revealed even more so in the recent forest products literature. Production theory and the concept of duality with the cost function has been used to determine the underlying

Figure 6.1: Schematic Representation Of FAO Forestry Products Hierarchy



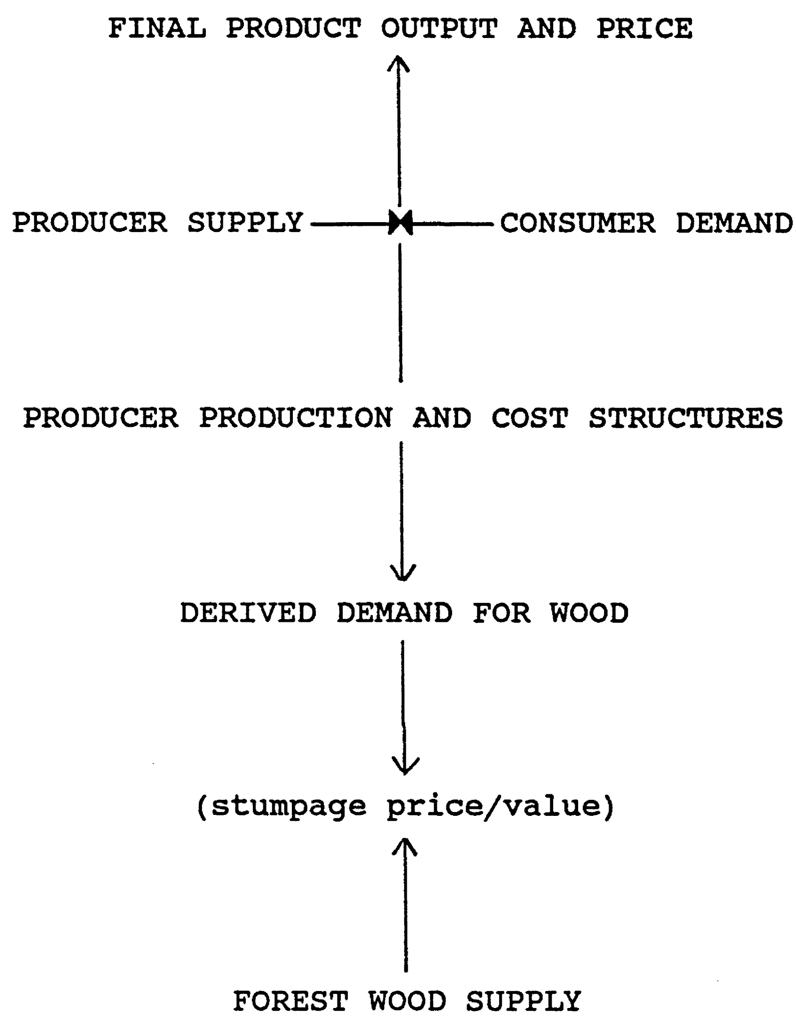
Legend

[box] FAO Product
C Coniferous
NC Non-coniferous

—— direct link or sub-category
---- unclear linkage in FAO classification

Source: Adapted from United Nations Food and Agriculture Yearbook of Forest Products (1983).

Figure 6.2 The Demand for Stumpage



structure of various sectors of the forest industry. Four categories are covered here:

1. consumption forecasts;
2. demand and supply models with respect to wood products;
3. production economics and the cost function approach describing the forest products sector;
4. direct modelling demand for stumpage models.

Consumption Forecasts

Many forecasts of demand for various wood products are actually consumption predictions based on static socio-economic conditions. For example, Buongiourno (1977) developed some long-term forecasts of forest products consumption for both developed and developing countries. He used 10 year lags on both consumption and income levels in the model:

$$C_{ijt} = f_j(CL_{ijt}, Y_{it}, YL_{it}, E_{ijt})$$

where:

C =	per capita consumption (CL - 10 year lag)
f =	the functional form
Y =	per capita income (YL - 10 year lag)
i =	country i
j =	product type j
t =	period or year

Models such as these provide little insight into the underlying structure of demand or supply. This is primarily due to an implicit assumption of no own price or cross price effects. Similar forecasting techniques have been used in Australia (BAE, 1985; Hossain *et al.*, 1989; Forwood, 1975; Eynaud, 1986; Jacobs, 1966). Ferguson

(1973a) reviewed consumption forecasts of sawlogs and pulplogs in Victoria.

According to Byron (1981) forest planning in Australia uses consumption forecasts in the following manner:

1. projections of future consumption levels of various wood products are made based on historical trends and production relationships;
2. the "gaps" between domestic supply and domestic consumption of forest products are calculated;
3. these gaps, which are currently met by imports are determined to be met by increased domestic supply in the future;
4. the volume of logs, and hence plantation area, necessary to provide the increased domestic supply of wood products is estimated;
5. the required plantation area is allocated amongst states or regions based on non-economic criteria.

Determining forestry plantation investment programs in such a manner is not well founded in economic terms. It typically involves the assumption that all plantations are viable and also assumes that self-sufficiency is an important social goal irrespective of the cost.

Demand and Supply Models

There is a voluminous literature on demand and supply models for various wood products. One of the earliest rigorous examinations of the demand and supply for forest products is McKillop's classic study: *Supply and Demand for Forest Products - An Econometric Study* (McKillop, 1967). Supply and demand relationships for lumber, paper, paperboard, plywood, roundwood and stumpage in the US from 1929 to 1960 were examined. Consumption and price levels were forecast to 1975. His model used a system of linear supply and demand relationships to explain price and consumption levels. Stumpage supply was treated superficially due to data and conceptual difficulties. Issues raised in his analysis still generally unresolved involve questions on how to model the heterogeneity of stumpage, and linkages between public and private producers. McKillop modelled stumpage supply as a function of current price and a trend variable. Stumpage demand was defined as a function of current price, the current price of lumber, paper, paperboard, plywood, sawlogs, pulpwood, veneer logs, electric power, and wages in sawmilling and pulp and paper.

Adams and Blackwell (1973) used a 15 equation model to examine the linkages between the lumber, plywood, sawlog, veneer log and stumpage markets in the US over the period from 1949 to 1970. Forecasts of demand and supply for lumber, but not stumpage, were made to 1975. McKillop (1969) developed an econometric model to examine the short-run (month to month) redwood lumber market structure in a region of California. Robinson (1974) used an 8 equation econometric model to examine Douglas-fir and US southern pine stumpage and lumber markets from 1947 to 1967. He suggested public forest harvests be accelerated to keep lumber prices down to help achieve the nation's housing goals. However, these recommendations were not based on empirical estimates of stumpage price expectations through time. The issue of non-wood values affected by public harvests was not addressed. Shim (1982) pooled cross sectional and time series data to estimate sub-regional demand and supply functions for US southern pine lumber between 1968 and 1978. His analysis found southern pine lumber supply to be price inelastic in 3 of 4 regions while demand was highly price elastic in 3 of 4 regions.

Ferguson (1973b) used a two equation model to examine demand and supply for sawntimber in the 5 States of Australia. Bigsby and Ferguson (1989) examined the softwood sawntimber market in Australia with a 5 equation, 2 identity model. In neither of these Australian studies were linkages to the stumpage sector included.

Kumar (1985) suggested a 4 equation model for examining supply and demand of forest products in a small open wood producing economy. He included: 1) a wood product supply equation; 2) an export equation; 3) a domestic demand equation and; 4) an identity where inventories are expressed in terms of the three previous equations and the previous period's inventory of the wood product. Kumar's model is a useful simple conceptualisation of a forest products sector but again lacks the link to forest management. Stumpage supply was exogenous.

Lonnstedt (1986) presents a long-term (15-25 years) demand and supply model of competing domestic and foreign forest products sectors. He called his model a "scenario generator". Each forest sector contained modules for timber management and consumption of various wood products. Exogenous variables included gross domestic production, size of population, price of substitutes, exchange rate, price of inputs, and a measure of technology. The forest management module assumed forest managers adjusted harvesting capacity to industrial capacity. Stumpage price was a function of the negotiating power of both buyers and sellers of stumpage. The potential effects of changes in ownership, inflation, taxes, recreational and environmental considerations were noted but not included in the model. A Swedish case study examined different possible technological developments in the pulp industry and the availability of wood. The Lonnstedt approach is an excellent model for industrial wood processors. It allows processors to generate possible future scenarios based on a number of explicit assumptions about influences on the sector. However, from a grower's perspective it is not as useful. The model does not address the issue of potential profitability of different silvicultural prescriptions, in either the short- or long-run under different price expectation scenarios.

An exhaustive review is not necessary to establish the point that modelling the linkages between stumpage supply and demand and hence stumpage prices through time has generally been ignored in this type of literature. This demand and supply literature focuses on final product consumption and price levels. Where forecasts of stumpage prices do occur they cover time spans too short to be of relevance to long-term planning. A distinction should also be recognised between attempting to forecast actual stumpage prices and determining the path of socially appropriate stumpage values, non-wood considerations aside. Also with respect to either stumpage or wood products, if historical data relates to imperfect markets, then a model estimated using such data cannot be expected to forecast what would happen in perfect markets. It is the prices that would be derived from the latter that public foresters require.

Production Economics

Production economics and the concept of duality between cost and production functions has become widely used in forestry in recent years. The approach originates in the standard theory of production (eg. Fuss and McFadden, 1979). Applications to forestry are reviewed by Sherif (1983). Consider a pulp and paper or lumber producer facing a production function of the general form:

$$Q = f(W,L,K,E,T)$$

where:

Q = gross output

W = wood input

L = labour input

K = capital input

E = energy input

T = level of technology

A production function expresses, *inter alia*, the substitutability between inputs. However, a direct approach to estimating production function parameter values has generally proven difficult. The basic problem is that the required data is difficult to obtain. Duality theory shows that technological characteristics of the production function can be inferred via estimation of the parameters of the cost function:

$$C = g(Q,p,T)$$

where:

C = cost

p = the vector of input prices

Data for cost function estimation tends to be easier to obtain. The approach then provides information about input demands through the use of Shepherd's lemma (Diewert, 1971). Shepherd's lemma states that cost minimising factor demands can be determined by taking the partial derivative of the cost function with respect to the factor price in question. The demand for the i^{th} input is given by:

$$X_i(Q, P_i) = \partial C / \partial Pi$$

where:

X_i = the demand for a particular input as a function of output level and input prices.

Using the cost function enables the analyst to determine elasticities of substitution between inputs, and factor demand own-price and cross-price elasticities. Some functional forms applied to cost functions, like Cobb-

Douglas and the constant elasticity of substitution (CES) place restrictions on these values prior to analysis. The translog (transcendental logarithmic) function (Christensen *et al.*, 1973) does not place any prior restrictions on elasticities and has been the preferred format in many recent forestry studies (Sherif, 1983; Merrifield and Haynes, 1983; Martinello, 1985; Bankskota *et al.*, 1985; Borger and Buongiorno, 1985; Lee 1984; Steir, 1980, 1985; Nautiyal and Singh 1985, 1986). Apostolakis (1988) reviewed the use of the translog production and cost functions in econometric studies generally.

Use of the translog cost function in forestry is typified by Nautiyal and Singh (1986). They used the following 4 input translog cost function to examine short and long run factor demand and productivity in the Canadian pulp and paper industry.

$$\text{InC} = \alpha_0 + \alpha_Q \,\text{InQ} + 1/2\, \alpha_{QQ}(\text{InQ})^2 + \alpha_T \,T + \sum_i \beta_i \,\text{InP}_i$$

$$+ 1/2 \sum_i \sum_j \beta_{ij} \,\text{InP}_i \,\text{InP}_j + \sum_i \beta_{iQ} \,\text{InP}_i \,\text{InQ}$$

where:

Q =	industry output
p =	prices of inputs
T =	trend variable
α, β =	coefficients to be estimated
ij =	Labour (L), Capital (K), Material (M), Energy (E)

The cost function is assumed to be linear homogenous in input prices so the following restrictions are required:

$$\sum_{i=1}^{4} \beta_i = 1, \sum_{i=1}^{4} \beta_{ij} = \sum_{j=1}^{4} \beta_{ji} = 0, \sum_{i=1}^{4} \beta_{iQ} = 0$$

As noted above the derived demand equations are obtainable as:

$$X_i = \partial C \,/\, \partial P_i \qquad i = L, K, M, E$$

The following defines the cost share equations (S_i) with the translog function:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{\partial C P_i}{\partial P_i C} = \frac{X_i P_i}{C} = S_i = \beta_i + \sum_j \beta_{ij} \ln P_j + \beta_{iQ} \ln Q$$

$$j = L, K, M, E$$

Long run elasticities of substitution and price elasticities can be calculated by the following formula:

$$\sigma_{ij} = \left[\beta_{ij} + S_i\, S_j\right] \,/\, S_i\, S_i \qquad i,\ j = L, K, M, E, i \neq j$$

$$\sigma_{ii} = \left[\beta_{ii} + S_i^2 - S_i\right] \,/\, S_i^2 \qquad i = L,\ K, M, E$$

$$\Sigma_{ij} = S_i\, \sigma_{ij} \qquad \Sigma_i = S_i\, \sigma_{ii}$$

where:

S_i, S_j = long run cost shares

Nautiyal and Singh used annual data from 1956 to 1982 for their analysis. Own price elasticities were negative as expected and cross price elasticities were positive, ranging from 0.03 between materials (wood) and energy to 0.45 between energy and labour. All inputs were found to be long run substitutes (from 0.29 to 1.58) although some short run complementarity existed. Even with this brief description of the translog cost function approach it is apparent that such analysis is not trivial. Data requirements and the statistical expertise necessary for estimation and interpretation are great.

Martinello (1985, 1984) reported small degrees of factor substitutability for pulp and paper mills, sawmills and shingle mills, and the logging industry in Canada and British Columbia. Stier (1980) estimated that capital, labour and sawlogs are all substitutes in the US lumber industry. Bankskota *et al.* (1985) examined the Alberta sawmill industry using a translog cost function cross sectional approach (83 Alberta sawmills in 1983). All inputs (energy, labour, capital and wood) were found to be substitutable, however, wood was found to be relatively less substitutable for other inputs. They suggested the ability of the industry to respond to wood shortages is limited and growth in the industry is reliant on wood supplies. Newman (1987) used a production function approach to examine the US southern softwood stumpage markets for pulpwood and sawlogs. Stumpage demand was modelled in the context of a three input (capital, labour, stumpage) production function. Stumpage supply was defined as a function of price and standing inventory. His study found sawlog stumpage supply was more responsive to final product price changes than pulpwood supply.

The literature is not unanimous on the issue of factor substitutability. Merrifield and Singleton (1986) examined the US Pacific northwest lumber and plywood industries and found stumpage demand was closely correlated to industry output and not very responsive to changing capital or technology or stumpage prices. The authors suggest that this implies end use demands can be used to roughly estimate stumpage demand. With reference to the Canadian pulp and paper industry, Sherif (1983) reported complementarity between wood and labour and between capital and energy. Greber and White (1982) reported that labour-saving technical change, not input substitution, was the important factor for productivity change in the US lumber and wood products industry from 1951 to 1973. Merrifield and Haynes (1983) used a system of supply and demand equations to model the U.S Pacific Northwest forest products industry during the period 1950 to 1976. Supply was modelled with a translog production function. While they found capital and stumpage to be substitutes, labour and stumpage were found to be complements in production.

Abt (1987) compared factor demands in three lumber producing regions of the US. His approach was a restricted translog cost function approach with stumpage and labour as variable inputs and capital as a quasi-fixed input. Abt reported statistically significant differences in factor demands between regions although the softwood producing regions were similar. Abt's study is useful in providing some empirical validation of the dangers in applying national input demand structure relationships in different regional contexts. Production structures are likely to differ between regions for a multitude of reasons including the nature of the resource and the final product. Abt's analysis showed the hardwood producing region's factor demand elasticities were markedly different than the softwood regions.

Doran and Williams (1982) examined Australian demand for sawn timber using a cost function approach. However, to this author's knowledge no studies have been done on the derived demand for stumpage in Australia using cost or production function analysis.

Nautiyal and Singh (1983) estimated the demand for roundwood in the lumber, veneer and plywood and, pulp and paper industries of Ontario over a 29 year period. The derived demand for stumpage was found to be inelastic in all 3 industries but less so in the veneer and plywood industry. In one of the more daring statements related to forest policy stemming from this type of analysis Nautiyal and Singh (1983) suggested:

> ... quite reliable estimates of the structure of demand for roundwood can be made if the production functions of the wood using industries are precisely known, and better knowledge of the demand functions for the products are available. Then it should be possible to project future demands for roundwood on the basis of the projections of the constituent variables from macroeconomic models. (However)... projections of demand into the future on the basis of the extrapolation of future trends for constituent variables are clearly full of grave risks.

Besides the problems of forecasting exogenous variables such as returns to capital and relative wage levels, forecasting economically accessible wood supplies can be difficult simply because of biological uncertainties and limited inventory data. In regions where forest growth is slow the cost of growing future forests may require increases in stumpage fees that could result in industrial restructuring if the growing sector is to be efficient. The point raises a major problem associated with extrapolating current stumpage demands into the future. Regions which rely on old growth forests for wood supplies may undergo industrial restructuring as the resource is depleted and the nature of the raw fibre changes (Sedjo and Lyon, 1983). In that situation forest planners should be cautious about inferring future demands from current factor demand structures.

Lyon (1981) provides important theoretical insights on the price path of timber. He examined the question of the path of timber prices through time as forests are mined, to a stationary state. One conclusion was that mining of the forest could result in a growth rate of the net price of timber that is greater than, equal to, or less than the interest rate depending on a mix of factors such as distance to markets, current growth rates, and the regenerative capacity of the forest. Transportation costs can play an important role in both the absolute level of the price of timber and the growth rate of prices. Lyon's study raises questions about appropriate regional price levels to use in planning. The more distant forests that are mined have lower stumpage values to wood processors. Ironically perhaps, willingness to pay required to preserve them from harvesting would be less.

Although the techniques of production economics have provided insights on stumpage demand few authors have discussed their results in the context of forest planning. Most results are more relevant to short run forest policy, not longer run investment questions. The production economics approach to understanding regional stumpage demand would be difficult to operationalise. Few forest agencies have either the expertise or the data. There is also a sense in which the approach is simply a sophisticated version of the residual pricing technique mentioned in Chapter 2. It infers nothing about the appropriate stumpage price unless one assumes current local prices are correct (competitively determined). As identified in Chapter 2 such an assumption may be dubious in some jurisdictions.

Directly Modelling Stumpage Markets

The previous two sub-sections showed that modellers have generally a) restricted their analyses to the wood products sectors; b) only cursorily related their analyses to forest planning either in the short or long term and; c) implicitly assumed actual stumpage prices are socially correct. There is another growing body of literature, particularly in the US, attempting to grapple more specifically with understanding stumpage markets and the ramifications for forest planning. This is perhaps predicated by some combination of legislative, academic, conservation and US Forest Service pressures.

The development of the Timber Assessment Market Model (TAMM) (Adams and Haynes, 1980) is one example. TAMM is a spatial model (6 demand and 9 supply regions) of the North American softwood lumber, plywood and stumpage markets. Supply regions consist of forests with a wide variety of tenure and jurisdictional control. The model makes long range (50 year) projections of price, consumption levels and production trends in both the processing and growing sectors. Stumpage demands are defined as:

$$d_{jt} = K^{L}_{jt}\, S^{L}_{jt} + K^{P}_{j} + S^{P}_{jt} + K_{j} + P_{jt} + MP_{jt} + F_{jt} + LE_{jt}$$

where:

d_{jt} = total stumpage demand region j, period t

K^{L}_{jt}, K^{P}_{jt} = product recovery factors for lumber and plywood

S^{L}_{jt}, S^{P}_{jt} = lumber and plywood output region j, period t

$K_{jt}(P_{jt})$ = roundwood requirement for regional pulp output

MP_{jt}, F_{jt}, LE_{jt} = miscellaneous products, fuelwood and log exports output

Aggregate derived demand for stumpage, and supply equilibrate to determine the level of harvest by different ownerships and stumpage price. Stumpage supply comes from both public and private forests. In the public sector supply evolves around proposed annual allowable harvest levels. Private sector supply has both short and long-run components. Short run supply was related to price and inventory levels. Alternative runs of the TAMM model simulate different long run responses to changing prices. The TAMM model has been and is still being used extensively by the US Forest Service to estimate regional stumpage demands for input into forest planning problems (Haynes *et al.*, 1980, 1981; Haynes, 1989). The Canadian Forestry

Service is also adapting TAMM for use in Canada (Merckel, *pers comm.*). The original TAMM was clearly an improvement on regional forest demand/supply models but it failed to separate pulpwood and sawlog stumpage prices. The authors also suggested the influence of non-wood considerations and those effects on wood supplies should be incorporated into TAMM.

Other studies have also taken regional perspectives. Adams (1974) developed a quarterly econometric model of the US Douglas-fir region forest products market including a stumpage sector that contained the US Forest Service, Bureau of Land Management, and other government and private land-holders. That study focussed on short-term market responses to changes in Forest Service wood supplies. More recently, Adams and Haynes (1989) developed a short run regional model of stumpage markets in the western US which separates public and private ownerships. Clements *et al.* (1988) considered demand and supply in two sectors - the primary wood products (sawlogs and pulplogs) market and the stumpage market. Stumpage demand was derived using residual valuation where the bid price for a particular unit volume equalled the harvest revenue less harvesting costs, hauling costs and a profit margin. Stumpage supply was a function of reservation price where reservation price is the opportunity cost of holding the standing timber one more period. The model was used to examine these 2 sectors and identify possible future market trends in Virginia, US to the year 2000.

Moving from aggregate regional demand for stumpage to demand for stumpage from an individual forest area presents a number of problems. Subregional analyses are complicated by (Haynes *et al.*, 1981): 1) species differentiation, 2) the impact of alternative sources of stumpage on local demand (eg. private holdings and roundwood imports), and 3) local market imperfections.

In the longer run the potential for structural change in the industry should also be considered. However, an important practical concern for such analysis is the lack of data.

Jackson (1983) provided a useful insight on sub-regional demand analysis derived from regional demand curves. Consider the following relationship (from Jackson, 1983):

$$q_D = Q_D - (1-K)Q_S$$

where:

q_D = the demand estimate for stumpage from an individual forest

Q_D = the demand estimate for stumpage for the region

Q_S = the supply estimate of stumpage for the region

As K approaches 1 the individual forest's demand curve matches the regional demand curve. Jackson showed that if Q_D and Q_S are independent the variance of q_D depends on the level of K. The variance of q_D increases as the regional market share, K, of the individual forest decreases. This suggests very little confidence be placed in demand estimates of forest regions with small market shares.

Majerus, Jackson and Connaughton (1989) presented an empirical analysis of demand for stumpage from 10 US National forests. Percent standard error of the demand estimates ranged from 34% to 2640%, the largest being the forest with the smallest proportion of regional harvest. If data were available one would expect a similar exercise for the Otways to produce large standard errors since the region comprises a small proportion (approximately 2%) of the State's harvest. It should also be noted that stumpage prices in the US are, roughly speaking, determined through a competitive bidding system. Therefore price levels could be assumed to be close to socially "correct" prices, non-wood values aside. This is not the case in Australia.

6.1.3 Summary of Factors Affecting Stumpage Values and Problems with Predicting Values in Australia

Ultimately stumpage values are a result of the interaction of both supply and demand forces. Both microeconomic and macroeconomic factors influence stumpage values in the long and short run. Microfactors can include the following (not necessarily in any particular order):

- tree diameter affects harvesting and milling costs and potential final product use and price. Generally, larger diameter trees have higher potential end product values;
- species and wood quality characteristics;
- physical site attributes of the logging area such as slope and nature of the terrain;
- logging methods;
- different silvicultural objectives which influence cost of harvesting operations;
- other environmental related constraints on harvesting operations;
- average volume per hectare harvested;
- haul distance to mill and market centres;
- prevailing market conditions including local mill capacities and price expectations in both the stumpage and end product markets;
- the influence of non-financial objectives of forest owners.

Macrofactors which can affect stumpage values both directly and indirectly include:

- degree of market power exercised by both buyers and sellers of stumpage;

- population and income levels;
- technological changes in the growing and processing sectors;
- government stumpage pricing policies and tax incentives and disincentives on both growers and processors;
- other institutional structures and constraints such as laws which influence land use and, domestic and international trade;
- capital, labour and energy costs;
- general forest inventory levels can influence price expectations;
- consumer preference shifts;
- end product and substitute product price level changes.

These lists are not meant to be exhaustive but serve to illustrate the point that stumpage values have many influences. A complete understanding of stumpage value for an individual forest is difficult. From a policy perspective the question of interest is how might forest managers judge the results of research into the demand and supply of forest products insofar as it relates to planning.

To begin with it should be noted that distinctly Australian theoretical and empirical contributions to the forest economics literature are, relatively speaking, lacking. The literature is predominantly North American and European. This is not meant to be an indictment of forest economists in Australia - there simply are not many of them. The relationships between Australian stumpage pricing policies and forest product market structures is poorly understood. Extrapolating results to Australia from the overseas literature without some empirical evidence should be done cautiously. Much more theoretical and applied forest economics research on a variety of topics is required in Australia.

There are numerous implicit assumptions present in the overseas literature that may not be applicable in Australia. The more important of these include: competitive input and output markets; forest owners are profit maximisers; and wood as the only socially valuable output from forests. While final product output markets can probably be considered to operate in competitive situations, even a casual glance at stumpage markets in Australia suggest this is not likely the case with stumpage. State governments are the primary sellers, there are often only a few buyers and stumpage is generally sold by royalty formula rather than competitive bidding. Numerous authors have raised doubts about efficiency aspects of Australian stumpage price policies (Byron and Douglas, 1981; SSCTC, 1981). Log pricing is the subject of a current inquiry at the Australian Bureau of Agricultural and Resource Economics and will also be investigated by the federal government's new Resource Assessment Commission.

Even in the US, where competitive bidding for publicly owned wood resources is widely practiced, the issue of below cost timber sales has raised questions about subsidy levels for the processing sector. Shuster and Jones (1985) discuss the issue of below-cost timber sales in the US. The issue is complex and serves to illustrate another dimension to the determination of prices that forest managers should consider when planning.

With respect to forest owners acting as profit maximisers, it is widely accepted that neither public nor private owners appear to act in such a manner. While it is reasonable to assume that owners maximise their own notion of utility it, is accepted that on forests, non-financial objectives can enter utility functions in a significant way. Measurement of these objectives is extremely difficult and has for obvious reasons been omitted from most theoretical and empirical analyses of forest owner behaviour.

Byron (1981) has identified a number of other, often implicit, assumptions made by policy-makers with respect to forest planning and development. They include:

- that trends in macro-economic variables affecting both growers and processors will not change (i.e. interest rates, population and income levels);
- that all plantations are economically viable;
- that the elimination of forest products imports is in the country's best interest. Carron (1980) gives a historical discussion of this issue in Australia;
- that production relationships in the processing sectors are static and unresponsive to changing relative factor prices. Economic theory suggests that firms will adjust to changing factor prices and the empirical literature cited above confirms this;
- that public supply of wood is costless even excluding external effects, where external effects are the negative effects of harvesting operations on non-wood resources. Administrative overheads, silviculture, fire protection, roads and capital costs are important determinants of the net economic benefits of forestry;
- that employment in the wood products sector is relatively more important than employment in other sectors;
- that macro-economic government incentive structures have little impact on forest management. Actually Government tax, tariff and royalty policies influence both public and private growers and wood processors. Repetto and

> Gillis (1988) provides case study examples of the negative effects of various well-intended public policies on forest developments.

It should be obvious that the determination of the socially "correct" price to use for intertemporal efficiency analysis in forest planning is complicated even in the absence of external effects.

6.2 A Simulation Approach to Developing Price Expectations and Implications for Forest Planning

6.2.1 Introduction and Background

Clearly, one of the more intractable economic problems in forest planning is the derivation of the time path of stumpage prices (see also Berck, 1979). Estimation of this price path, although perhaps conceptually more straightforward than non-wood values, presents a number of practical difficulties including the development of a suitable forecasting model and dataset. However, if intertemporal efficiency is considered to be an important objective of forest management, then prices must be made explicit in a planning model. The previous section identified that most of the demand and supply for forest products literature fails to link results to the problem of long-range forest planning.

What is suggested in this section is a Monte Carlo approach to developing stumpage price expectations over time. Results can be used in linear programming (LP) models like FORPLAN to gauge some implications of stumpage price uncertainty on forest plans. Perhaps one of the most important policy questions concerning uncertainty relates to the robustness of forest plans. Robustness here means the sensitivity of silvicultural prescriptions and harvest schedules over time to changing price expectations. The approach suggested enables an analyst to empirically interrogate that question. At a more general level the simulation approach can be used on any valuation forecasting problem.

The following briefly summarises the framework and methodology given in more detail later. A simple world supply and demand model for stumpage is presented. This assumes, in effect, that forest planners have rational expectations, and realise that in the long run they act as price takers. This is a reasonable assumption in a small open economy like Australia, and for any individual forest region in the long run. The dataset required for the model, including prices, is generated using Monte Carlo techniques. The parameter estimates for the forecasting equation are calculated using ordinary least squares (OLS) on a portion of the dataset. The OLS parameter estimates and the "true" (simulated) exogenous variable values are used to forecast prices on the portion of the dataset not included in the OLS estimation. Forecast prices can then be compared to the "true" prices. Finally to gauge the implications of the divergence between actual and predicted prices some results are used in the West Barham FORPLAN model.

Generally speaking Monte Carlo analyses involve the specification of a probability distribution for the additive error terms and/or the estimated coefficients in simulation models. Economists, among others, have found the technique useful for examining the implications of uncertainty in a wide range of contexts (Smith, 1973).

Stochastic simulation is not uncommon in forestry. Caulfield (1988) used a stochastic approach to examine the optimal rotation for a risk-averse forest owner with changes in annual probability of fire. Routledge (1980) examined the optimal forest rotation with a stochastic probability of mortality due to fire or insect plagues. His analysis assumed risk neutrality. Both Routledge and

Caulfield found rotation lengths to generally decrease under conditions of increasing risk. Norstrom (1975), Brazee and Mendelsohn (1988) and, Johansson and Lofgren (1985) and Lohmander (1987) also examined the effects of price uncertainty on the rotation problem.

Campbell (1975) used a stochastic model to examine growth and harvesting of mountain ash in Victoria. His study included the development of probability distributions on growth and yields of mountain ash. Probability distributions were also placed on establishment costs, fire occurrence, interest rate and initial stocking levels in the timber stand. Optimal rotation was found to be relatively insensitive to all uncertainties except interest rate. Initial stocking and fire probabilities were the most important variables within managerial control that affected expected net present value.

6.2.2 A Monte Carlo Investigation of the Implications of Uncertainty About Future Stumpage Values

The logic of the Monte Carlo approach sidesteps a number of problems inherent in forest planning to attempt to gain some insights on the robustness of the whole exercise. One common problem inherent to almost all modellers is a lack of data. That problem is overcome here by generating the required dataset. Also, the model is explicitly assumed to be the true representation of world supply and demand for stumpage. This is the best possible scenario a planner could ever expect - a model known to be true and a long time series to obtain the model coefficients for forecasting. However, uncertainties are still involved in the forecasting process. By using both actual and predicted prices in the LP optimisation phase, insights on the effects of these uncertainties on forest plans can be made. For example, how important is the uncertainty with respect to expected net present values, management activities and prescriptions? Although the approach could be used in any context the particular results are of course relevant only to the West Barham.

Australia has the characteristics of a small open economy. As such it generally acts as a price taker and should therefore, after consideration of transportation costs, use the world stumpage price as a guide for investment analysis on wood production. There is not a world market for stumpage *per se* but there are markets for various types of roundwood. Assume the following 3 equation model represents the true demand and supply of stumpage (in a world where all stumpage is substitutable):

$$Q_t^D = \alpha_1 Y_t^{\alpha_2} Pw_t^{\alpha_3} Ps_t^{\alpha_4} e^{\epsilon_t^D} \qquad 6.2.1$$

$$Q_t^S = \alpha_5 Pw_t^{\alpha_6} Plag1_t^{\alpha_7} Plag2_t^{\alpha_8} e^{\epsilon_t^S} \qquad 6.2.2$$

$$Q_t^S = Q_t^D \qquad 6.2.3$$

where:

$Q^D{}_t$	=	the demand for stumpage at time t
$Q^S{}_t$	=	the supply of stumpage at time t
Y_t	=	a measure of world income per capita at time t
P_w	=	the price of Otway-like stumpage
P_s	=	a measure of the price of substitutes
Plag1	=	a 10 year lag of P_w
Plag2	=	a 30 year lag of P_w
$\epsilon_t^D, \epsilon_t^S$	=	independent error terms
e	=	natural logarithm

Equation 6.2.1 is a standard economic interpretation of demand. Demand is a function of income, own price, and price of substitutes. A more complicated demand structure

could include a transportation component and linkages to final product demands and population levels. Equation 6.2.2 addresses the somewhat more problematic issue of stumpage supply but for the sake of simplicity, supply is a function of current price and, due to the intertemporal nature of growing and harvesting trees, a 10 and 30 year price lag. More complex representation of supply could include some proxy for non-wood objectives, growing stock inventories (both virgin and plantation stocks), and/or forest land availability. This simple demand and supply representation is adequate to illustrate some of the problems with price forecasting and the resultant ramifications for planning.

The linear form of the model is as follows:

$$\ell n\, q_d = \alpha_1 + \alpha_2\, \ell n\, Y_t + \alpha_3\, \ell n\, Pw_t + \alpha_4\, \ell n\, Ps_t + \epsilon_t^D \qquad 6.2.4$$

$$\ell n\, q_s = \alpha_5 + \alpha_6\, \ell n\, Pw_t + \alpha_7\, Plag1_t + \alpha_8\, Plag2_t + \epsilon_t^S \qquad 6.2.5$$

$$q_s = q_d \qquad 6.2.6$$

Solving for the reduced from for Pw gives:

$$\ell n\, Pw_t = \left[\alpha_5 - \alpha_1 - \alpha_2\, \ell n\, Y_t - \alpha_4\, \ell n\, Ps_t + \alpha_7\, \ell n\, Plag1_t + \alpha_8\, \ell n\, Plag2_t\right]$$

$$\left[\alpha_3 - \alpha_6\right]^{-1} + \left[\epsilon_t^S - \epsilon_t^D\right]\left[\alpha_3 - \alpha_6\right]^{-1} \qquad 6.2.7$$

or

$$\ell n\, Pw_t = \beta_0 - \beta_1\, \ell n\, Y_t - \beta_2\, \ell n\, Ps_t + \beta_3\, \ell n\, Plag1_t + \beta_4\, Plag2_t + \beta_5\, \epsilon_t \qquad 6.2.7'$$

where:

$$\beta_0 = \frac{\alpha_5 - \alpha_1}{\alpha_3 - \alpha_6},\ \beta_1 = \frac{\alpha_2}{\alpha_3 - \alpha_6},\ \beta_2 = \frac{\alpha_4}{\alpha_3 - \alpha_6},\ \beta_3 = \frac{\alpha_7}{\alpha_3 - \alpha_6},\ \beta_4 = \frac{\alpha_8}{\alpha_3 - \alpha_6},\ \beta_5 = \frac{1}{\alpha_3 - \alpha_6}$$

$$\epsilon_t = \epsilon_t^S - \epsilon_t^D$$

With forecasts of Y and Ps, the reduced form equation (6.2.7′) can be used to predict Pw. For very long-term forecasts (eg. 50-100 years) the forecast values themselves become the lagged price terms.

The problem addressed here is the issue of developing price expectations for forest planning and the implications of imperfect expectations. There are two distinct phases associated with the following analysis:

1. data simulation and price forecasting using Monte Carlo techniques and;
2. LP analysis with true and forecast prices.

This analysis extends previous published studies in two ways. Firstly, Monte Carlo simulation methods provide a useful framework for value prediction and policy development problems in forestry. This does not appear to be well recognised in the literature. Secondly the LP facet of this study quantitatively examines the effect of uncertainties in forecasts of wood values on management. It should be noted that analytical results are not sufficient to understanding the dimensions of this uncertainty. There are two important reasons for this:

1. the reduced form equation 6.2.7 involves lagged dependent variables. This means that OLS estimation is only asymptotically unbiased. In "small" samples the size and direction of bias is unknown;
2. the numerical values are of interest themselves and required for actual policy development. With this Monte Carlo approach a specific forecast over 100 years can be directly compared to a corresponding "true" value.

The data generation and OLS estimation were performed using a BASIC program. A copy of the BASIC program is given in Appendix 6.1. A summary of the steps involved is as follows:

1. The income stream was assumed to grow at a specified rate with a stochastic error term as follows:

$$Y_t = Y_0 (1 + g1)^t e^{v_t}$$

where:

gl =	a specified growth rate, varied in the analyses,
e =	natural logarithm,
v_t =	value at time t of a normally distributed random variable with 0 mean and a specified variance of 0.5,
Y_t =	income at time t
Y_o =	starting income level.

2. The price of substitutes stream was assumed to grow at specified rate with a stochastic error term as follows:

$$Ps_t = Ps_0 (1 + g2)^t e^{u_t}$$

g^2 =	a specified growth rate varied in the analyses
e =	natural logarithm
u_t =	value at time t of a normally distributed random variable with 0 mean and a specified variance of 0.5,
Ps_t =	price of substitutes at time t
Ps_o =	starting level of the price of substitutes.

3. The elasticity and intercept values were based on intuitive estimates from reading the relevant literature. They were chosen to produce a reasonably sensible model.

Note the alphas could, in principle, take on any value desired.

i) $\alpha_2 = .8$ income elasticity

This is primarily based on Buongiourno (1977) estimates of income elasticities for various forest products. The range in his analysis was 2.730 to 0.808 for developing countries and 1.453 to 0.382 for developed countries

ii) $\alpha_3 = -5.0$ stumpage price demand elasticity

There is a wide range of own-price elasticity estimates in the literature for stumpage demand. Adams (1983) summarised some of the difficulties associated with empirical estimates of the elasticity of demand for US National Forest stumpage. Many studies produce results contrary to theoretical expectations. Adams reported a range of -1.6 to -333.3 so the value -5.0 was chosen as a conservative estimate.

iii) $\alpha_4 = 1.5$ elasticity on the price of substitutes

The initial assumption on the cross price elasticity of the price of substitutes was more problematic. McKillop (1967) reported a cross price elasticity of 1.247 for steel with respect to softwood lumber demand. Berck (1979) reported a cross price elasticity of 1.389 for steel with respect to Douglas-fir stumpage. The value of 1.5 was chosen as a conservative long run estimate.

iv) $\alpha_6 = 1.25$ stumpage price supply elasticity

Supply responses to changes in stumpage price vary considerably between ownerships. Strictly regulated public supplies may be unresponsive while profit maximising private owners may respond more readily to price changes. In this study world stumpage supply was assumed to be elastic.

v) $\alpha_7 = -.2,\ \alpha_8 = .3$ lag price elasticities in supply

These values were primarily intuitive estimates - an increase in price 10 years ago decreases supply while the 30 year response is slightly positive

vi) $\alpha_1 = 24.6694$ intercept in demand equation

This value was calculated based on other elasticities assumed above, long run assumed starting values of Y=100, Pw=20 and Ps=50, and a world output of 1,435,112,000m^3 (1980 world industrial roundwood production, FAO, 1983)

vii) $\alpha_5 = 17.0407$ intercept in supply equation

This value was calculated in a similar fashion to the intercept value in the demand equation.

4. Stumpage price observations were calculated from equation (6.2.7) using the values of the alphas as specified and the simulated values for Y and Ps. The supply and demand error terms were stochastic variables of mean 0 and a specified variance of 1. The first 30 observations assumed a constant historic price for the lags. After the first 30 observations the lagged values assumed the appropriate lagged computer generated price. The BASIC program generates 400 observation points. This can be interpreted as 400 years of data.

5. An OLS estimation of the coefficients of (6.2.7′) was performed using observations 200 to 300. Using this portion of the dataset should eliminate any influence of the assumption of constant historic prices in the first 30 observations.

6. A forecast of 100 years of Pw was calculated using equation (6.2.7′) and the OLS estimates for the parameters. The 100 forecast values of Pw therefore correspond to observations 301 to 400 in the dataset. Forecast values for income (Y) and the price of substitutes (Ps) were required. In the analysis presented here the actual or true values of Y and Ps were used (observations 301 to 400). When forecasting Pw the lagged dependent variables, Plag 1 and Plag 2, used the actual values of Pw until the forecast values themselves became the lagged value. This occurs at observation 311 and 331 for the 10 year lag (Plag1) and 30 year lag (Plag2) respectively. Predicting Pw on observations 301 to 400 allows for comparison of actual and predicted values over a time span of 100 years. This is the length of the planning horizon in the West Barham model.

7. The OLS estimators, predicted and actual values for Pw on observations 301 to 400 (100 observations in total) were saved so that the results of numerous simulations can be averaged. The data simulation, estimation and forecasting were replicated 50 times for each set of model assumptions. Summary statistics of the replicated forecast were calculated (ie. mean, standard deviation, of actual and predicted stumpage values (Pw)).

Replicating the simulation and forecasting a large number of times gives an indication of the range of values that could be expected under particular sets of assumptions. The prices used in the West Barham FORPLAN model arose from a single replication. It was considered that this would more closely emulate a real world scenario;

that is, a single long run data set on which to perform the OLS estimation and forecast.

Some results of the replicated model runs are shown in figures 6.3 - 6.6. The figures show, over a 100 year time frame, the mean across 50 replications of the actual prices, the mean across 50 replications of the predicted prices, and plus and minus 2 standard deviations of the predicted mean. The figures illustrate the results of variations in model assumptions with respect to the per annum growth rate in income (Y) and the growth rate on the price of substitutes. The results presented are intended to be indicative rather than report all model variations performed. As would be expected, in all cases the further into the forecasting horizon the wider the 95% (plus/minus 2 standard deviations) confidence limits on the predicted prices. In all figures the mean of actual prices exhibits fluctuations not picked up by the forecasts. The variance in the error terms, the stochastic elements of the income and price of substitutes variables and the lagged price terms are the cause of this fluctuation in actual prices.

Figure 6.3 presents the results of a simulation across 50 replications in which income was assumed to increase 2% per annum and the price of substitutes decrease at .2% per annum. In this scenario, predicted prices ranged from about $37 per cubic metre at the beginning of the planning horizon to $47 at the end of 100 years. In the results shown in Figure 6.4 income increased 3% per annum and the price of substitutes decreased 1% per annum. Predicted prices steadily increased, ranging from about $30 to $36 per cubic metre across the time horizon. The results reported in Figure 6.5 had per annum income growth set at 3% and the annual price of substitutes decreasing at 2% per annum. In this scenario prices declined from about $15 to $13 per cubic metre across the time horizon. Figure 6.6 shows the results of a simulation in which income increased

Figure 6.3 Monte Carlo Price Expectations

where g1 = 2%, g2 = .2%

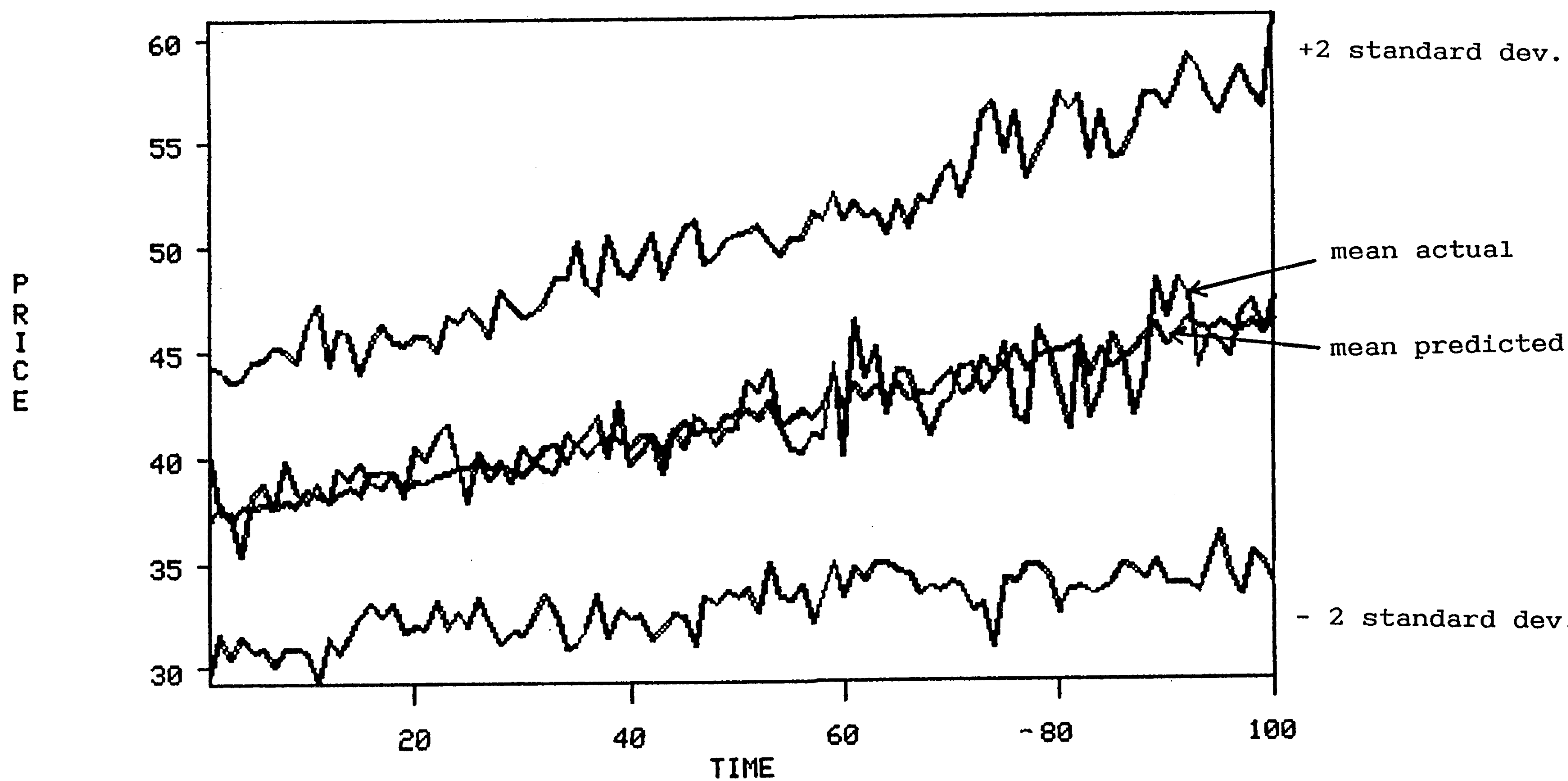


Figure 6.4 Monte Carlo Price Expectations

where g1 = 3%, g2 = -1%

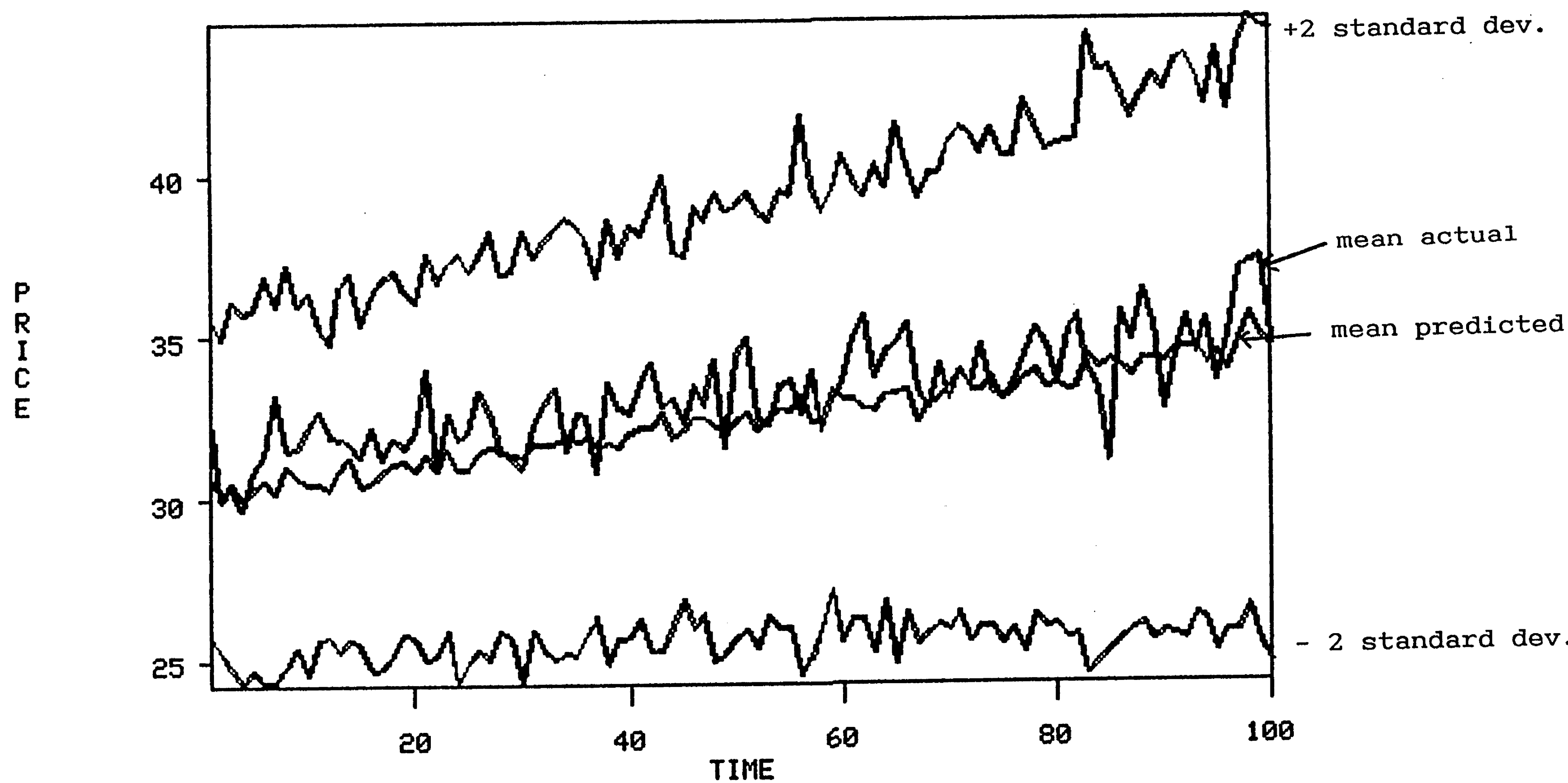


Figure 6.5 Monte Carlo Price Expectations
where g1 = 3%, g2 = -2%

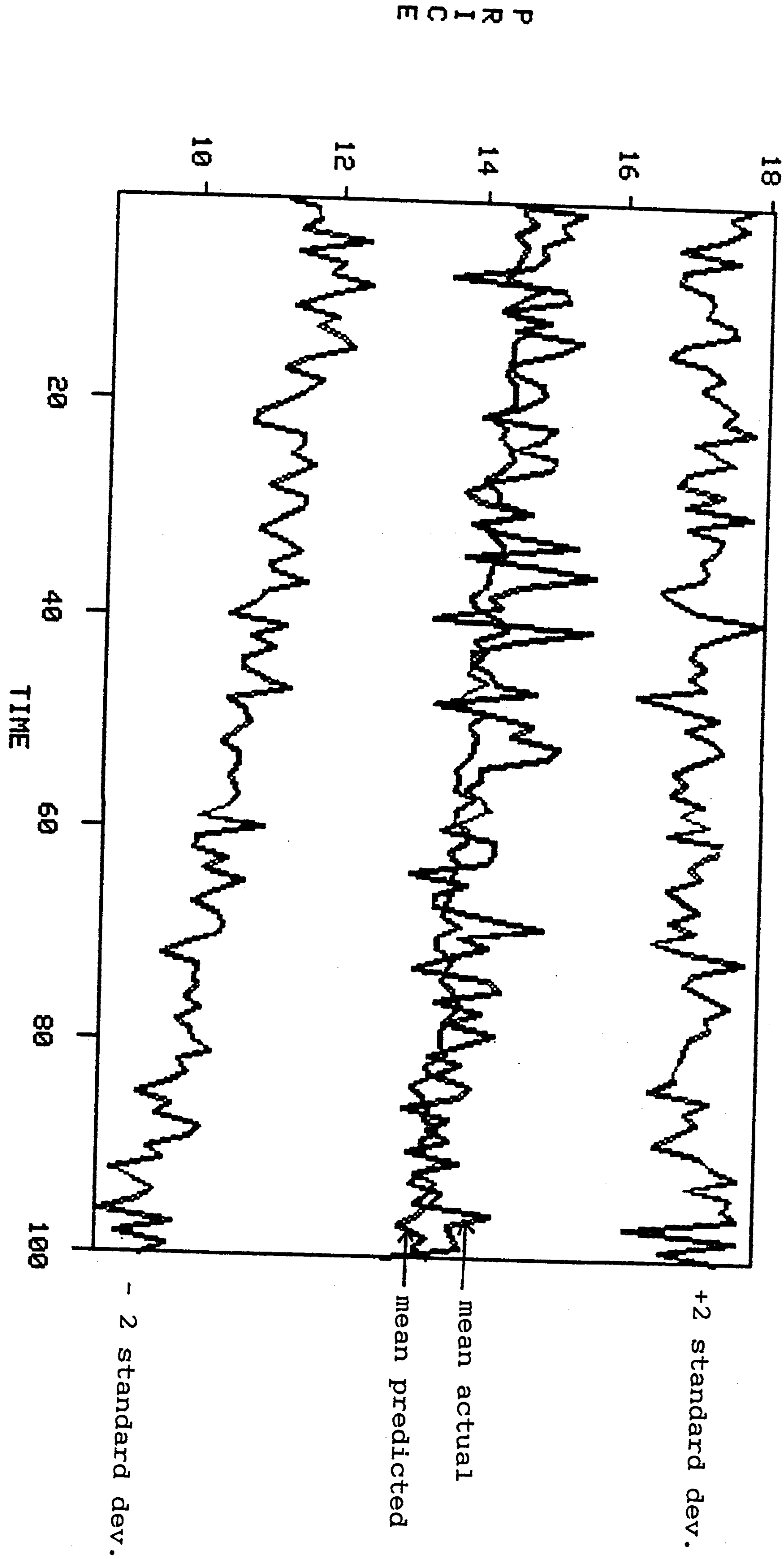
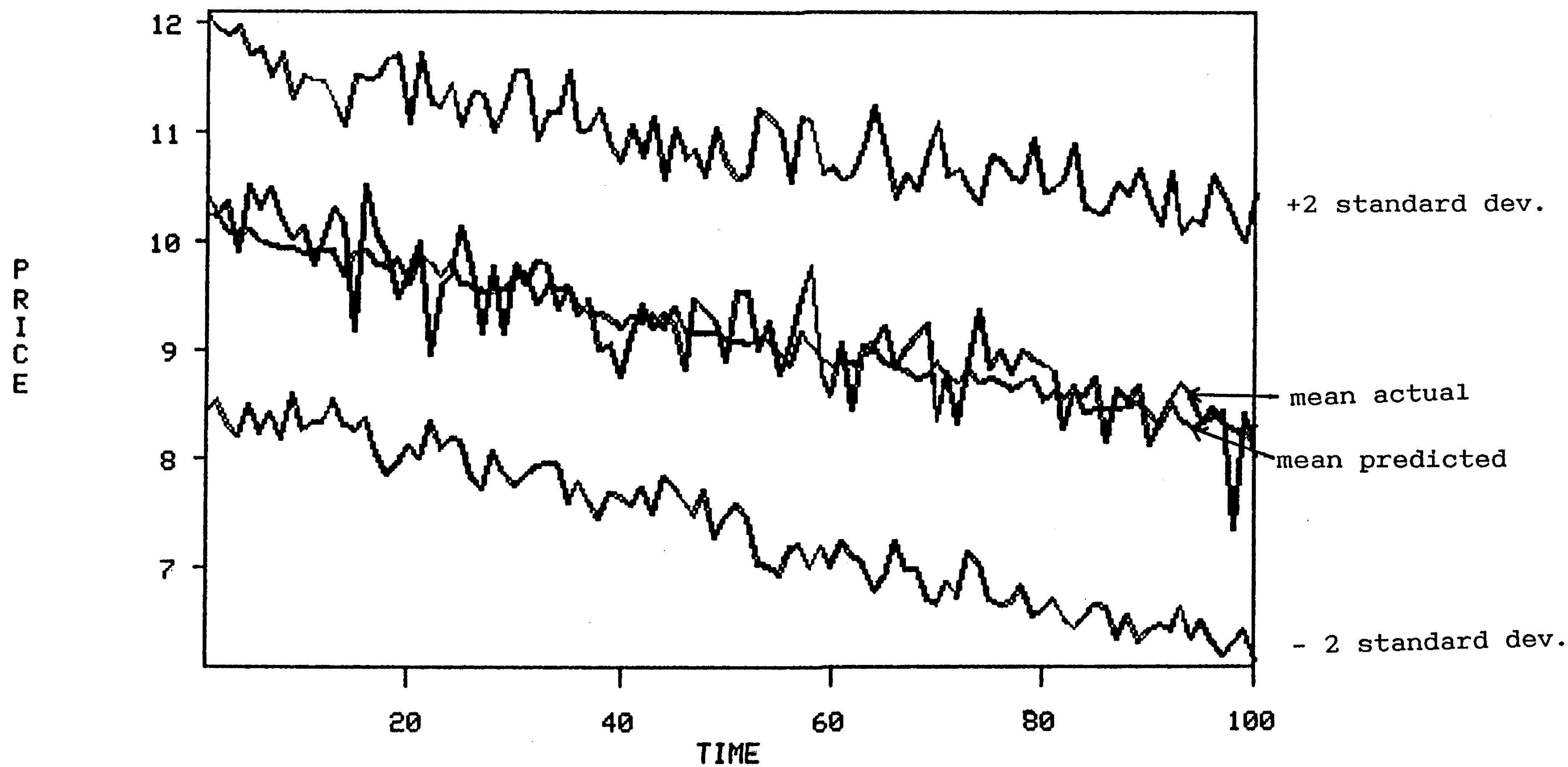


Figure 6.6 Monte Carlo Price Expectations

where g1 = 2%, g2 = -2%



2% per annum and the price of substitutes decreased 2% per annum. As in the previous scenario prices declined over time but in this case from about $10 to $8.5 per cubic metre. The difference between the cases reported in Figures 6.5 and 6.6 was a 1% greater per annum increase in income. Given the elasticity assumptions it is clear from the results reported in Figures 6.3 to 6.6 that stumpage prices will increase or decrease over time depending on the relative growth rates between income and the price of substitutes.

The results of the replicated simulations are as expected. Pindyck and Rubinfeld (1976, p.360) identify five sources of error that can occur in forecasts from multi-equation models:

1. equation(s) may contain an implicit additive error term;
2. estimated values of the coefficients are random variables and may therefore differ from the true values;
3. exogenous variables need to be forecast and these forecasts may have errors;
4. individual equation(s) may be mis-specified;
5. the structure of the model as a whole may be mis-specified.

Also, in multi-equation models any errors can be magnified across equations. In the model used here the presence of lagged price variables in the forecasting equation increases the error band. This is because the lagged price values eventually take on the numerical estimates of predicted prices. The other possible sources of error are not relevant in this model because the actual values of exogenous variables (Y, Ps) are used in the forecast and the model is, for the purposes of this exercise, considered to be the true representation of the world market for stumpage.

A detailed discussion of these results is not itself germaine to the policy questions of interest here. Clearly actual and predicted prices and the 95% confidence limits of the predicted prices will vary according to the elasticity assumptions, variances in the error terms and growth rates assumed in the income and the price of substitutes determinations. What is important is the methodology of identifying a relevant price range. From a policy perspective the problem is whether or not the actual and predicted prices suggest different forest management strategies. In other words are the forest plans robust between actual and predicted prices?

To investigate this question a single replication of the Monte Carlo model was used to determine actual and predicted prices. A single replication reflects the more realistic real world situation in which a long time series is available for the OLS estimation and price forecast. Uncertainty in the exogenous variable values is assumed away by using their actual values in forecast. This reduces the uncertainty in the exercise to a minimum.

Tables 6.1 to 6.4 present the results of FORPLAN analysis of the West Barham using both actual and predicted prices from single replications of the Monte Carlo model. The FORPLAN results are reported in a similar fashion to those reported in Chapter 5 except that age classes are omitted. The area of timber harvest, the method of regeneration, the water yield and cumulative present net worth are provided. The simulated prices were used only on the sawlog class B and C. This was to simplify the interpretation of the results. Prices for sawlog class A and the D and residual class were the same as the original base case. All other FORPLAN model specifications were as defined in Chapter 5; that is, the base case runs were unconstrained NPV maximisation with a 4% discount rate, a

100 year time horizon and the CFL (current policy) case runs had the following constraints:

1. no timber harvests below age 60;
2. no more than 250 hectares to be harvested in any one planning period;
3. no natural regeneration and;
4. no pulpwood harvests.

As expected, the objective function values are always different under different assumptions about prices. Objective function value differences are not necessarily a problem unless management strategies differ since actual prices, not predicted prices, would be realised in each planning period. What is of relevance to policy is whether actual management strategies differ under the two sets of prices (eg. silvicultural prescriptions and harvest schedules). Note also that initial model runs often influence the development of both wood and non-wood constraints. These constraints may exacerbate the deviation from the "optimal" plan when they arise from predicted, not actual, prices.

Table 6.1 reports the results of an unconstrained FORPLAN run in which the price simulation assumed a 2% per annum increase in income (Y) and a 0.2% annual decline in the price of substitutes. (See Figure 6.5 for this price time path with 50 replications of the Monte Carlo model). Predicted prices ranged from about $37 to $45 per cubic metre across the planning horizon. Table 6.1 reports results using both actual and predicted prices in FORPLAN. Recall that FORPLAN only requires prices for the middle of each planning period. The actual and predicted values occurring at the middle of the planning were used. It was felt this would maintain consistency with the long-run planning nature of the thesis. Short run price fluctuations would influence harvest schedules within planning periods but that issue is not addressed here. All

Table 6.1 Base Case for Actual and Predicted Prices*

Output/ activity		1	2	3	4	5	6	7	8	9	10
					Planning Period						
Timber harvest	A	730	42	-	661	-	-	772	-	-	661
(ha)	B	730	42	-	661	-	-	772	-	-	661
Prescription	A	P/N	P	-	P	-	-	P/N	-	-	P
	B	P/N	P	-	P	-	-	P/N	-	-	P
Water yield	A	8754	7185	6223	7335	7022	6219	7613	7164	6168	7327
(0's ML)	B	8754	7185	6223	7335	7022	6219	7613	7164	6168	7327
Cumulative	A	2622	2651	2651	3613	3613	3613	4004	4004	4004	4095
present net worth ($000s)	B	2125	2154	2154	2922	2922	2922	3200	3200	3200	3277

A - actual prices, B - predicted prices
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period.

* price simulation with income growth at +2% pa, price of substitutes at -0.2% pa.

Table 6.2 CFL Case for Actual and Predicted Prices*

Output/ activity		1	2	3	4	5	6	7	8	9	10
					Planning Period						
Timber harvest	A	250	227	-	123	-	103	250	100	-	250
(ha)	B	250	250	100	-	-	103	250	250	100	-
Prescription	A	P	P/S	-	P	-	S	P	P	-	P/S
	B	P	P	P	-	-	S	P	P	P	-
Water yield	A	8799	8281	7399	7134	6932	7169	7603	7465	7134	7372
(0's ML)	B	8782	8313	7411	6826	6769	7153	7655	7733	7273	6815
Cumulative	A	1553	1609	1609	1904	1904	1963	2287	2331	2331	2420
present net worth ($000s)	B	1157	1535	1550	1550	1550	1612	1817	1953	1990	1990

A - actual prices, B - predicted prices
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period.

* price simulation with income growth at+2% pa, price of substitutes at -0.2% pa.

aspects of the management strategies reported in Table 6.1 are identical except the cumulative present net worth. The price differential between actual and predicted was not sufficient to change the optimal strategy. Thirty year rotation periods and planting are the preferred silvicultural regime on land that is harvested. An exception to this is the scrub forest (69 hectares) which is harvested in the first period and left to regenerate naturally. It is harvested again in the seventh period.

Table 6.2 presents the results of the same price series with current policy constraints included in the FORPLAN model. The inclusion of constraints caused the optimal strategies between actual and predicted prices to differ. In this instance the price differential was sufficient to delay the harvest of some of the West Barham in the second and third planning periods to the fourth period. The important thing to note about predicted prices in this scenario was their relative consistency through time compared to actual prices. Actual prices exhibit much more volatility, not unlike the real world. Clearly having perfect information about price volatility induces changes in optimal management but perfect information is impossible. The difference in actual and predicted prices was in the order of \$10 to \$15 per cubic metre in some periods, roughly 25% of the total value. The difference in the harvest schedule decreases the magnitude of the change in water flow. This is because harvesting occurs over a longer period of time and as flows decline on some areas harvests increase flows in other areas. Silvicultural prescriptions were similar in both cases except for a seeding regime that occurs on some land in the second period. Cumulative net present value is higher in the actual price case than in the predicted price case.

Tables 6.3 and 6.4 present unconstrained and constrained FORPLAN runs with different assumptions on the

Table 6.3 Base Case for Actual and Predicted Prices*

Output/ activity		1	2	3	4	5	6	7	8	9	10
		Planning Period									
Timber harvest	A	227	484	288	415	288	415	288	415	288	415
(ha)	BP	600	111	661	42	661	42	661	42	661	42
Prescription	A	S	S/N	S	S	S	S	S	S	S	S
	B	S	S/N	S	S	S	S	S	S	S	S
Water yield	A	8579	8152	7328	7320	7232	7329	7291	7405	7367	7472
(0's ML)	B	8866	7451	7548	7100	7452	7109	7511	7185	7587	7252
Cumulative	A	87	812	950	1084	1147	1208	1237	1265	1278	1291
present net worth ($000s)	B	646	684	1001	1015	1159	1165	1231	1234	1264	1265

A - actual prices, B - predicted prices.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period.

* price simulation with income growth at +2% pa, price of substitutes at -2% pa.

Table 6.4 CFL Case for Actual and Predicted Prices*

Output/ activity		1	2	3	4	5	6	7	8	9	10
		Planning Period									
Timber harvest	A	-	250	-	123	-	-	42	250	61	123
(ha)	B	250	-	-	123	-	-	42	250	61	123
Prescription	A	-	S	-	S	-	-	S	S	S	S
	B	S	-	-	S	-	-	S	S	S	S
Water yield	A	8576	8722	8276	8028	7742	7721	7921	8359	8139	7945
(0's ML)	B	8799	8277	7953	7981	7822	7853	8063	8443	8154	7945
Cumulative	A	0	310	310	335	335	335	339	349	351	351
present net worth ($000s)	B	144	144	144	164	164	164	167	174	175	175

A - actual prices, B - predicted prices.
P = planting, N = natural regeneration, S = seeding, P/S = both planting and seeding.
Notes: the planning periods are 10 years long; harvests occur in middle of period.

* price simulation with income growth at +2% pa, price of substitutes at -2% pa.

price simulation model. In these cases income was assumed to grow at 2% per annum and the price of substitutes decline at 2% per annum. This could reflect a situation in which technological change was having a larger impact on the price of substitutes than assumed in Tables 6.1 and 6.2. Figure 6.6 shows the magnitude of this price range over 50 replications. Predicted prices decline over time from roughly \$10 to \$8.50 per cubic metre. Actual prices fluctuate around these values ranging from roughly \$14/m^3 to \$6.50/m^3. Table 6.3 shows the unconstrained scenario using actual and predicted prices. With low prices, seeding and short (20 years) rotations become the generally preferred management option on most land. The timing of the harvest varies between actual and predicted prices. In the actual price scenario, prices rise sufficiently in the second period to justify delaying the harvest (\$14.30/m^3 actual compared to \$8.85/m^3 predicted). Water flows fluctuate more in the predicted price scenario. This is due to the harvest level fluctuating more between periods. As expected cumulative net present value differed only marginally (\$26,000) between the two cases, the reasons being the small differential between actual and predicted prices and the aggregate harvest level being the same.

Table 6.4 presents the same price scenario as Table 6.3 inclusive of current policy (CFL) constraints. Again the timing of the management activities varies slightly between actual and predicted prices. The increase in prices in the second period with actual prices was sufficient to delay the 250 hectare harvest that occurs in the first period with predicted prices. The total net present value of the actual price case was twice that of the predicted prices. It should be noted that, relative to the CFL case presented in Table 6.2, the prices used to get the results in Table 6.4 were sufficiently low to make the harvest of some forest areas uneconomic. While the NPV of the predicted price case was less than half that of the actual CFL price case it was only 86% less than the unconstrained actual price case. Consider the issue of forest preservation under these stumpage price expectations. The perceived NPV loss would be very small with the CFL constraints as compared to the unconstrained setting. This re-emphasises the fact that unconstrained analysis should be the point of departure for considering forest policy. Otherwise the opportunity costs of policy will not be calculated correctly.

The results have only been briefly discussed but are sufficient to highlight a number of key points. The determination of numerical values for prices is critical for management strategies. It has been shown that small changes in relative prices can affect management. The absolute price levels affect the type of management prescribed (ie. seeding or planting and rotation lengths) while price volatility can affect the timing of harvests.

In this situation a simple model existed to describe the time path of prices, a long time series of data was available to estimate the parameter values for the forecasting equation, and perfect information was available on the time path of the exogenous variables. Even in this ideal situation the differences between actual and predicted prices were sufficient to cause departures from socially optimal management strategies. This serves to highlight Berck's (1979) point about the path of stumpage prices being one of the most worrisome economic aspects of forest planning.

This dilemma could be seen as a condemnation of the preoccupation with sophisticated demand estimation and forecasting in forestry economics, at least with respect to long-term forest planning. Even if econometricians get to the stage of having good forecasting models and long time series of data available to get parameter estimates to forecast stumpage prices, optimal management strategies are likely to vary within a small range of values. In fact, the dimensions of uncertainty of these stumpage price expectations are small compared to that likely in the real world. LP planning results should, therefore, only be used as a strategic guide, and not for a penultimate resolution of the planning problem. It is conceivable that if economic estimates, predictions, and the uncertainties therein, of non-wood values were included in planning models then an even wider range of plausible management strategies would eventuate.

6.3 WTP Estimates for Forest Preservation

6.3.1 An Overview

Some of the uncertainties associated with WTP estimates for forest preservation are discussed in this section. Chapter 2 included a discussion of the derivation of economic values for non-wood outputs of forests. Well-known techniques, although not commonly used in Australia, include the contingent valuation, travel cost and hedonic travel cost methodologies. Very little of that literature actually discusses the practical implications on forest policy development due to uncertainty in non-market welfare estimates.

Table 5.18 in Chapter 5 listed some net present value costs associated with preserving different forest types. The values listed in that table represent the opportunity costs, in terms of NPV foregone, for disallowing harvesting on different forest types. Those values are approximations of what conservationists would have to be willing to pay to compensate forest owners for not logging those forest types. Table 5.18 shows that the required willingness to pay varies between forest type and according to different price expectations and discount rates.

At the most basic level the contingent valuation approach requires a survey asking what Australians would be willing to pay to preserve forests. Individual WTP can be aggregated across the relevant population to determine total WTP. This total WTP can be directly compared to opportunity cost of preserving the forest. However, there are three difficult, and somewhat problematic issues that can arise in such an exercise.[13] Firstly, what is the relevant population to survey? Some forests will have higher existence values than recreational use values and vice versa.[14] There are likely to be more difficulties in identifying the interested population when existence values are in question. Estimating current users of a specific site should be more straight forward, because foresters can actually observe visitors or set up traffic counters to do so. Secondly, the selection of a social discount rate will have a significant effect on the WTP required to preserve a forest since this affects the value of wood production from the land. Another interesting problem facing conservationists from an Australia-wide perspective is the determination of the forest area to be preserved. Which forests need to be preserved to maintain what non-wood values? If WTP values are calculated as dollars per hectare of forest type as in Table 5.18, then the size of forest area to be preserved must be divided by the aggregate WTP. This provides a WTP per hectare that is comparable to the opportunity costs of not harvesting.

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13. A forthcoming article by Kahneman and Knetsch (1990) reveals a potentially fatal problem with applications of contingent valuation techniques. Through an empirical study they suggest that contingent valuation responses may only be reflecting WTP for the moral satisfaction of contributing to public goods, not the economic value of these goods (Knetsch *pers comm.*).

14. Existence, option and use values were discussed in Chapter 2.

To summarise, three important issues have been identified here that should be addressed by those interested in WTP surveys for forest preservation:

1. determining the relevant population;
2. identifying a social discount rate;
3. identifying the total forest area to be preserved.

To investigate the orders of magnitudes involved some simple calculations based on variations of the above mentioned factors and different assumed individual annual WTP values are presented in Tables 6.5 and 6.6. Using annual WTP estimations makes the results directly comparable to the annuity values in Table 5.18. For example it is conceivable that conservationists could be asked ..."how much would you be willing to increase your annual tax burden to preserve a forest?" The values were calculated according to the following formula:

AWTP = (WTP*Pop)/Area

where:

AWTP = annual WTP per hectare of forest
WTP = individual WTP
Pop = relevant population
Area = forest area to be preserved (hectares)

Basically two scenarios are presented. In both tables the relevant population ranges from 1000 to 5,000,000 and the individual annual WTP ranges from $10 to $500. Tables 6.5 and 6.6 list annual WTP values when the relevant forest area is 5000 hectares and 400,000 hectares respectively.

Five thousand hectares is intended to represent the preservation of a modest forest area, for example, the area of mature/overmature forest type in the entire Otways is about 12,000 hectares. The population level 1000 could represent the annual number of recreational visitors to a small forest area such as the West Barham (there is no information available on the actual number of visitors to the West Barham). If a small forest area had unique features that could have significant existence values a greater number of people may be interested in preserving the area. The population level 5,000,000 roughly approximates the number of households in Australia. If $100/ha is assumed to be roughly the cost of preserving a forest (eg. the mature/overmature forest type in the West Barham - see the unconstrained results in Table 5.18), then Table 6.5 shows 1000 people would be required to pay $500 each to justify preserving 5000 hectares while 50,000 people would require just $10 each.

Table 6.6 presents similar calculations for a forest area of 400,000 hectares. 400,000 hectares is roughly the amount of "old-growth" forest remaining in Australia (Norton, *pers comm.*). As mentioned in Chapter 5 the management of that forest type is one of the more controversial aspects of forestry in Australia. Again assuming $100/ha opportunity costs, results presented in Table 6.6 show 50,000 people would be required to pay more than $500 each to justify the preservation of that forest type on economic efficiency grounds. With 2,000,000 people the required WTP is $20 each and for 5,000,000 the required individual WTP drops to less than $10 each. Such numerical results should be interpreted cautiously. Some old-growth forests are likely to have higher opportunity costs than others. The purpose of Tables 6.5 and 6.6 is only to illustrate, to a first approximation, the orders of magnitude involved in this sort of problem in particular the importance of identifying the relevant population. This sort of approach to estimating WTP would require surveys. Another approach, the hedonic travel cost method, more directly estimates use benefits by observing the pattern of visitors across sites and inferring value of

Table 6.5

Forest Preservation Willingness To Pay Scenarios*

	Population 1000	5000	50000	2000000	5000000
Annual WTP per person	Annual WTP per ha				
10	2.0	10.0	100.0	4000.0	10000.0
20	4.0	20.0	200.0	8000.0	20000.0
30	6.0	30.0	300.0	12000.0	30000.0
40	8.0	40.0	400.0	16000.0	40000.0
50	10.0	50.0	500.0	20000.0	50000.0
60	12.0	60.0	600.0	24000.0	60000.0
70	14.0	70.0	700.0	28000.0	70000.0
80	16.0	80.0	800.0	32000.0	80000.0
90	18.0	90.0	900.0	36000.0	90000.0
100	20.0	100.0	1000.0	40000.0	100000.0
200	40.0	200.0	2000.0	80000.0	200000.0
300	60.0	300.0	3000.0	120000.0	300000.0
400	80.0	400.0	4000.0	160000.0	400000.0
500	100.0	500.0	5000.0	200000.0	500000.0

*Hectares of forest 5000

Table 6.6

Forest Preservation Willingness To Pay Scenarios*

	Population 1000	5000	50000	2000000	5000000
Annual WTP per person	Annual WTP per ha				
10	0.0	0.1	1.3	50.0	125.0
20	0.1	0.3	2.5	100.0	250.0
30	0.1	0.4	3.8	150.0	375.0
40	0.1	0.5	5.0	200.0	500.0
50	0.1	0.6	6.3	250.0	625.0
60	0.2	0.8	7.5	300.0	750.0
70	0.2	0.9	8.8	350.0	875.0
80	0.2	1.0	10.0	400.0	1000.0
90	0.2	1.1	11.3	450.0	1125.0
100	0.3	1.3	12.5	500.0	1250.0
200	0.5	2.5	25.0	1000.0	2500.0
300	0.8	3.8	37.5	1500.0	3750.0
400	1.0	5.0	50.0	2000.0	5000.0
500	1.3	6.3	62.5	2500.0	6250.0

*Hectares of forest 400000

site characteristics from differences in visitation rates. The following section presents a simple approach to consider some of the uncertainty involved in hedonic travel cost problems.

6.3.2 A Monte Carlo Investigation of Willingness to Pay for Forest Preservation

The purpose of this section is to illustrate the uncertainty involved in estimating willingness to pay (WTP) for forest preservation with a simple hedonic travel cost in a situation of good data availability. As with the stumpage price expectation model presented in section 6.2, the required data is generated using Monte Carlo techniques. The approach enables an analyst to compare actual WTP to estimated WTP.

Kling (1988) developed a similar approach to compare actual welfare measures of environmental quality to estimated welfare values. The problem of interest in her study was the reliability of multiple-site recreation demand models. Kling worked within the hedonic travel cost framework and using a common data set showed that both pooled and logit models of recreation demand tended to underestimate the true WTP for water quality improvements. Of course the results refer only her experiment and they arise, in part, because of the assumptions on the utility function and error terms. Caulkins *et al.* (1985) also used Monte Carlo techniques to examine the actual effect (bias) of omitted variables in travel cost models. The direction of bias was shown to be dependent on the true economic relationship of the site in question with the alternative site; that is, whether the 2 sites are complements or substitutes and the degree of correlation between their travel costs.

Although some work has been done comparing the results of different methods of welfare estimation (see for example

Brookshire *et al.*, 1982, who compares hedonic techniques with survey techniques, and Duffield, 1984, who compares travel cost with contingent valuation), very little work has been done determining the relative accuracy of the methods. The point is that although two methods give similar answers this does not necessarily mean both are correct.

The problem addressed here is the reliability of WTP for forest preservation estimates. To the best of this author's knowledge this sort of question has not been formally addressed in the forestry literature. The issue of forest preservation is controversial not only in Australia but also in many other parts of the world. The theory reviewed in Chapter 2 showed that if aggregate individual WTP is greater then the present value of current and future stumpage receipt net of costs, then forest preservation (ie. not allowing timber harvests) is justified on economic grounds. To investigate this issue a simple hedonic travel cost model is formulated using the West Barham catchment as a context. The hedonic travel cost method was selected for two major reasons. Firstly, the hedonic approach is capable of inferring value due to variations in site quality or characteristics. Secondly, the hedonic travel cost model may be the most readily available and practical framework for foresters to estimate non-marketed welfare benefits of site characteristics in an operational setting. This assumes foresters do have some information on visitation rates and site(s) characteristics of different recreation areas. Contingent valuation techniques require surveys and the simple travel cost method does not infer value on site characteristics.[15]

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15. It is worth noting that the US Forest Service has developed travel cost software for personal computers that is public domain and available by writing to the Forest Service (Rosenthal *et al.*, 1986). It could be used for simple hedonic cost models of the type described here. To this author's knowledge there is

To begin, consider that the demand for recreational trips to a site per annum is given by:

$$V_i = \alpha - \beta\left[T_i + P\right] + \epsilon_i \qquad 6.3.1$$

where:

V_i	=	trips per annum by a visitor from the i^{th} location to the site
α, β	=	coefficients to be estimated
T_i	=	true travel costs from the i^{th} location
P	=	price of admission
ϵ_i	=	error term assumed to be distributed normally with 0 mean and a specified variance.

Given ϵ_i with a zero mean the expectation of V_i is:

$$V_i' = \alpha - \beta P - \beta T_i$$

When P, the admission price is zero the expectation of V_i is:

$$V_i' = \alpha - \beta T_i$$

The price that would drive visits to the area to zero is known as the "kill" price and is:

$$0 = \alpha - \beta P_i^* - \beta T_i$$

$$P_i^* = \alpha/\beta - T_i$$

An individual's consumer surplus for visits is given by the area under their demand curve for the site (see Figure 6.7).

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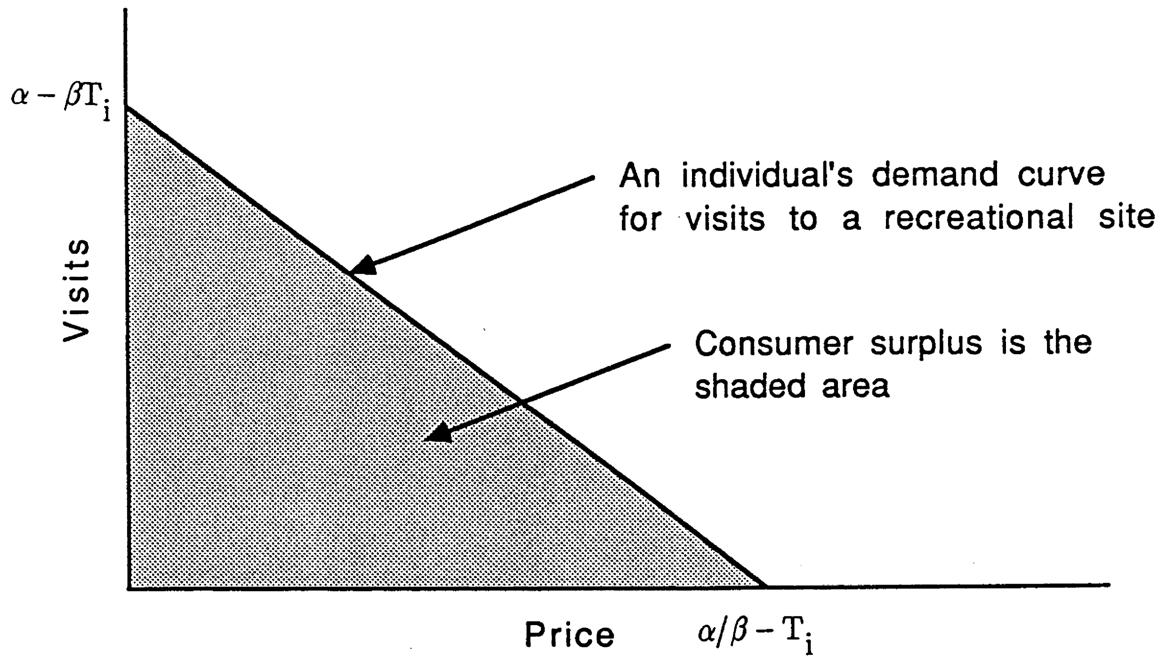
no widely available software for the contingent valuation approach or more complicated hedonic pricing applications.

Figure 6.7 Consumer Surplus for Recreational Visits to a Site



Following Bockstael and Strand (1987) the "true" individual expected consumer surplus is:

$$CS_i = \frac{1}{2} \left[\alpha - \beta T_i\right]\left[\alpha/\beta - T_i\right]$$
$$= \frac{1}{2} \left[\alpha - \beta T_i\right]^2$$
$$= \left[V_i'\right]^2 / 2\beta$$

The estimated individual consumer surplus is

$$\hat{CS}_i = 1/2\, \hat{\beta} \left[\hat{\alpha} - \hat{\beta} T_i\right]^2$$

The total aggregate consumer surplus across all individuals is:

$$CS = \sum_i N_i \, 1/2 \, \beta\left[\alpha - \beta T_i\right]^2 = 1/2 \, \beta \sum_i N_i \left[\alpha^2 + \beta^2 T_i - 2\alpha\beta T_i\right]$$

6.3.2

$$CS = \alpha^2/2\beta \sum N_i + \beta/2 \sum N_i T_i^2 - \alpha \sum N_i T_i$$

and

$$\hat{CS} = \sum_i \hat{N}_i \, 1/2 \, \hat{\beta}\left[\hat{\alpha} - \hat{\beta} T_i\right]^2 = 1/2 \, \hat{\beta} \sum_i N_i \left[\hat{\alpha} + \hat{\beta}^2 T_i^2 - 2\hat{\alpha}\hat{\beta} T_i\right]$$

$$\hat{CS} = \hat{\alpha}^2/2\hat{\beta} \sum \hat{N}_i + \hat{\beta}/2 \sum \hat{N}_i T_i^2 - \hat{\alpha} \sum \hat{N}_i T_i$$

where:

$\hat{N}_i$ = the assumed number of visitors from i locations

N_i = the actual number of visitors from i locations

Note that typically the total number of visitors to a site is not known. The number of visitors must be estimated and, as shown later, this estimate can have a profound impact on the results.

An interesting algebraic result arises if errors in visitor estimates are assumed to be a proportion of true numbers (ie. $N_{1i} = eN_{1i}$). So given no estimation errors in parameters $\alpha_1 = \hat{\alpha}_1 \quad \beta_1 = \hat{\beta}_1$ etc. then the consumer surplus error (CSERR) for a site is:

$$\begin{aligned} \text{CSERR} &= \alpha^2/2\beta_1 \ (1-e) \sum N_i + \beta/2 \ (1-e) \sum N_i T_i^2 - (1-e) \sum N_i T_i \\ &= \text{CS} \ (1-e) \end{aligned}$$

To develop this simulation experiment suppose there is visitor data on the West Barham catchment (WB) and on another site that is identical in all respects except for the absence of the 227 hectares mature/overmature forest type. Further assume that the sites are sufficiently far apart such that there is no prospect for cross visits, and that individuals in recreation catchments for the forests are identical in all relevant socio-economic aspects. Also the only determinant of visits for both forests is the cost of the visit. Given this ideal scenario the difference between the consumer surplus for visits to the WB and the consumer surplus at the second site is a measure of the WTP to preserve the mature/overmature forest in the WB. This assumes only visitors are relevant to the estimate of WTP and there are no relevant existence, bequest or option values.

The error in the difference between consumer surpluses of the 2 sites where $N_{1i} = eN_{1i}$ and $N_{2i} = eN_{2i}$ is given by:

$$\text{WTPERR} = \text{CS}_1 \ (1-e_1) - \text{CS}_2 \ (1-e_2)$$

This result is used to illustrate the implications of incorrect N estimates in the WTP estimations that follow.

To set up the Monte Carlo experiment it is necessary to assume parameter values so that the true or actual value of WTP is known. It is assumed that:

$T_{1i} = T_{2i} = i$ for $i = 1, 2, \ldots, 50$

Also assume $N1_i = N2_i = 5$ all i so that

$$\sum N_i = 250, \sum N_i T_i^2 = 214625, \sum N_i T_i = 6375$$

Assume the following are the true alpha and beta values:

$$\alpha_1 = 50, \beta_1 = .5,$$

$$\alpha_2 = 45, \beta_2 = .44$$

By inserting the above values into 6.3.2 the following consumer surpluses are derived for each site:

$CS_{WB} = 359906.25$

$CS_2 = 335626.6$

Subtracting the consumer surplus of visits to the West Barham from the second site gives the WTP to preserve the mature/overmature forest type.

$WTP = CS_{WB} - CS_2 = 24279.65$

The above numerical assumptions were adopted so as to generate a true WTP for preservation which exceeds that required by a margin of more than 10%. So with ϵ_{1i} and ϵ_{2i} $\sim N(0, \sigma^2)$ the expected value or WTP to preserve the mature/overmature forest in the West Barham is \$24279. The value, \$24729, is actually 18% greater than the required

WTP to preserve the West Barham mature/overmature forest type and is the point of departure for comparison with the results presented later. Recall from Chapter 5 that in the base case the opportunity cost of preserving the mature/overmature forest type was $89 per hectare per year. So to preserve all 227 hectares of this forest type in the West Barham the total WTP would have to be at least 89*227 = $20203 per year.

In an actual exercise to determine WTP the parameters of the equations V_{1i} and V_{2i} would have to be estimated as would N_1 and N_2. The question to be investigated regards the decision on whether or not to preserve, based on estimated values of this WTP. Three major cases are presented to examine this question, from assuming no estimation problems to heteroscedastic assumptions about measurement errors in the travel costs.

No Estimation Problems

First consider a situation in which there are no estimation problems with respect to alphas and betas. In a situation like this, OLS is known to be consistent and unbiased. The approach here is to generate a single data set using actual parameter values and T_{1i} = 1, 2, ..., 50 and T_{2i} = 1, 2, ..., 50 and, the error terms ϵ_{1i} and ϵ_{2i} have a zero mean and a specified variance as in equation 6.3.1. The OLS regressions for V_1 and V_2 are computed from the simulated data set hence CS_{WB}, CS_2 and WTP can be calculated. The results presented here assume both correct and erroneous values for N_1 and N_2 (ie. varying e_1 and e_2). The econometric package SHAZAM was used to both generate the required data and perform the OLS estimation. A copy of the program is given in Appendix 6.2.

Table 6.7 shows the results of 3 single data set simulations of the program in which the standard deviation of the error terms ϵ_{1i} and ϵ_{2i} was 1. The WTP estimates from using incorrect N estimates are also reported. Numbers in parentheses are the percentage difference from the true WTP of $24729 and range from -329% to +64%. The asterisks in the Table indicate whether the estimated WTP would lead to a correct decision. In the reported results only 7 of the 27 cells have a WTP large enough to lead to a correct policy decision. When e_1 and e_2 are both 1 corresponds to the situation when both $\hat{N}_1$ and $\hat{N}_2$ are correct. In the case of $e_1 = e_2 = 1$, the 3 simulations yielded one WTP slightly greater (24512) than the expected (24279) and two WTP (17116, 20044) less than the expected. When e_1 is less than e_2 negative WTP are generally reported. When e_2 is greater than e_1 a negative WTP also arises. In situations where e_1 and e_2 are the same but not equal to 1, WTP is lower than the expected value. When e_1 is greater than e_2 the WTP is greater than the expected value. An interpretation of the negative WTP is that the mature/overmature forest detracts value from the West Barham. Recreationalists would actually prefer those trees not to be there.

Table 6.7 Willingness to Pay Estimates with No Estimation Problems

e_1	e_2	Simulation 1	Simulation 2	Simulation 3
1.0	1.0	17116 (-30)	24512 (+1)*	20044 (-17)
.5	1.0	-55672 (-329)	-54043 (-323)	-53745 (-321)
.9	1.0	-11134 (-146)	-10808 (-145)	-10749 (-144)
1.3	1.0	33403 (+38)*	32426 (+34)*	32247 (+33)*
1.0	.7	38538 (+59)*	39780 (+64)*	38260 (+58)*
1.0	1.1	-12846 (-153)	-13260 (-155)	-12753 (-153)
.5	.5	8558 (-65)	12256 (-50)	10022 (-59)
.9	.9	1711 (-93)	2451 (-90)	2004 (-92)
1.3	1.3	-5134 (-121)	-7353 (-130)	-6013 (-125)

- numbers in parentheses are the percentage difference from the true WTP (24279); * indicates that a correct policy decision would be made if based on the WTP estimate.

Shown in Table 6.8 are WTPU and WTPL, the upper and lower limits of WTP respectively when the standard deviation on ϵ_{1i} and ϵ_{2i} varied between 1 and 3. Again each row of results arise from a single replication of the SHAZAM model. The limits were calculated by taking plus/minus 1.96 times the standard errors on each of the coefficients, $\hat{\alpha}_1$, $\hat{\alpha}_2$, $\hat{\beta}_1$, $\hat{\beta}_2$, and determining the upper and lower limits of the consumer surplus estimates for each site. To calculate the upper bound of WTP, the upper value for the consumer surplus on the West Barham was subtracted from the lower bound of the consumer surplus from site 2. The lower limit of WTP was calculated in a similar way. The arithmetic is shown in the computer program reproduced in Appendix 6.2. These upper and lower limits provide the, roughly, 95% confidence limits on WTP.

Table 6.8 95% Limits of Willingness to Pay with No Estimation Problems and Correct N's

Std Dev on ϵ_{1i} ϵ_{2i}	WTP	WTPU	WTPL
1	17116	31455	2746
1	24512	40943	8134
1	20044	36649	3412
2	29344	62395	-3390
2	2036	33786	-29974
3	22659	67120	-21553
3	-399	45794	-47272

Notes: WTP - the point estimate of WTP. WTPU and WTPL represent the 95% confidence limits on WTP.

The values reported in Table 6.8 give an indication of the 95% bounds of expected results from an exercise in which the number of visitors to both sites is correctly known. Negative WTP are reported as the lower limit when the standard deviation on ϵ_{1i} and ϵ_{2i} increased to 2 and 3.

In fact the point estimate of WTP was -399 for one simulation in which the standard deviation of ϵ_{1i} and ϵ_{2i} was 3. In all the simulations reported in Table 6.8 the 95% bounds encompass values that would tell decision-makers to both cut the trees down and preserve them. As expected the greater the standard deviation on ϵ_{1i} and ϵ_{2i}, the greater the upper and lower limits.

Errors In Variables Case

The second major scenario is an example of a situation where the "errors in variables" problem attends parameter estimation (see Johnston, 1984, p.428). Travel costs are generally considered to be subject to some measurement error. Consider the case where the reported travel costs, R, include an error term:

$$R_{1i} = T_{1i} + W_{1i}$$

$$R_{2i} = T_{2i} + W_{2i}$$

where W_{1i} and W_{2i} are assumed to be normally distributed with a mean of 0 and specified variance. In such a case the parameter estimates of alphas and betas will be biased and inconsistent (Johnston, 1984, p.430). Since actual numerical values are important for policy analysis the model was modified to include W_{1i} and W_{2i} in the data simulation phase.[16]

Table 6.9 reports the point estimates of 3 single data set simulations of this formulation. The standard deviation of ϵ_{1i}, ϵ_{2i}, W_{1i} and W_{2i} was 1 for all reported results. The three point estimates with correct N's were all less than the true or actual WTP. As with the results in Table 6.7, e_1 and e_2 were varied. In the reported results WTP varied between 39560 and -57620. Table 6.9

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16. Note also that the values for $\sum N_i T_i$ and $\sum N_i T_i^2$ will change in this situation.

includes the notation of A and R, representing A - accept preservation and R - reject preservation. Only 7 of the 27 cells would in this case suggest the correct policy. Clearly estimates of N_1 and N_2 are critically important to WTP calculations. In these simulations only when e_1 was greater than e_2 was the WTP estimate generally greater than the amount required to preserve the forest. e_1 greater than e_2 incorrectly infers more users of the West Barham relative to the second site than is actually the case hence a greater value associated with the mature/overmature forest type. It is possible to algebraically derive the asymptotic error of the alphas and betas estimates for these sorts of problems (Johnston, 1984, p. 428-430). There does not appear to be any analytical results in the literature regarding the impact of travel cost measurement error on welfare measure estimation. However, it is the numerical error in terms of WTP that is of interest here. To determine the direction of bias on WTP this model formulation was replicated 100 times with correct N estimates. The resultant mean WTP was 19467 (about 20% less than the true WTP), indicating a bias downwards that would lead to an incorrect policy decision, even when the estimates of N are perfect.

Table 6.9 Willingness to Pay with Errors in Variables

		Simulation		
e_1	e_2	1	2	3
1.0	1.0	16626R	16818R	22557A
.5	1.0	-57620R	-54866R	-51532R
.9	1.0	-11524R	-10973R	-10306R
1.3	1.0	34572A	32920A	30919A
1.0	.7	39560A	37965A	37686A
1.0	1.1	-13186R	-12655R	-12562R
.5	.5	8313R	8409R	11278R
.9	.9	1662R	1681R	2255R
1.3	1.3	-4987R	-5045R	-6767R

- A stands for accept preservation, R for reject preservation

Heteroscedasticity and Errors in Variables

Another plausible situation in travel cost models is that the errors in reported costs vary with true costs. This can be represented as:

$$R_{1i} = T_{1i} + T_{1i} W_{1i}$$

$$R_{2i} = T_{2i} + T_{2i} W_{2i}$$

This scenario will give heteroscedastic as well as errors in variables problems. There is no standard well known result for the asymptotic errors on alphas and betas in this case.

Table 6.10 Willingness to Pay Estimates with Heteroscedasticity and Errors in Variables

		Simulation		
e_1	e_2	1	2	3
1.0	1.0	20225A	21073A	21523A
.5	1.0	-53720R	-54148R	-53074R
.9	1.0	-10744R	-10829R	-10614R
1.3	1.0	32232A	32489A	31844A
1.0	.7	38299A	38811A	38302A
1.0	1.1	-12766R	-12937R	-12767R
.5	.5	10112R	10536R	10761R
.9	.9	2022R	2107R	2152R
1.3	1.3	-6067R	-6321R	-6457R

- A stands for accept preservation, R for reject preservation

Results of three single data set simulations of this model are given in Table 6.10 for correct and incorrect $\hat{N}_1$ and $\hat{N}_2$. The standard deviation for ϵ_{1i}, ϵ_{2i}, W_{1i} and W_{2i} was 1 for all reported cases. The accept and reject notation is also included in this table (nine A - accept preservation, and eighteen R - reject preservation). As in previous cases WTP encompassed negative values depending on the value of e_1 and e_2. Where e_1 was greater than e_2 the estimated WTP was greater than the actual WTP. The point estimates of WTP were less than the actual value when e_1 and $e_2 = 1$ but greater than the amount required to justify preservation. One hundred replications of this model with correct N estimates yielded a mean WTP of 19597 (19% less than the actual), again indicating a bias downwards. As with the errors in variables case, these results suggest an incorrect decision would generally be made even if the number of visitors to both sites are correctly estimated.

Conclusions

The purpose of the reported results was to illustrate some of the implications of various sorts of uncertainty in an exercise of this nature. In many of the simulations the 95% limits encompassed negative values even when the numbers of visitors to both sites were correctly identified. The point estimates ranged from well below to well above the expected (actual) value of WTP which itself was almost 20% greater than the amount required to justify preserving the forest type in question. This identifies a fundamental dilemma on the use of non-market welfare estimation techniques when 0, 1 type decisions are involved. Even in this ideal situation of good data availability and a simple model, the results can be flawed or imperfect; in fact, imperfect to the degree that reasonable interpretations will lead to incorrect policy decisions. In both the "errors in variables" cases and "heteroscedasticity and errors in variables" cases the 100 replication results suggest the rejection of preservation.

This outcome should not be interpreted as a condemnation of techniques like the hedonic travel cost model but rather as a sobering realisation of the potential fallibility of such techniques for policy development. Clearly a realistic perspective must be maintained when using results for policy. The 95% limits of models may suggest radically different management strategies. Also the results indicate that the pursuit of more data is not necessarily going to improve decisions. Much depends on what sort of data is being pursued. For example when comparing sites, correctly identifying visitor numbers was shown to be very important to the consumer surplus estimates of particular attributes (in this case mature/overmature forest). This point seems to be ignored in much of the literature but is critical for policy development. In fact, estimating visitors could be one of the most difficult and expensive operational considerations for widespread proper application of hedonic pricing techniques.

6.4 Summary and Conclusions

This chapter first examined the extent to which the existing analysis in the literature of the demand/supply for forest products and stumpage provides useful linkages to the problem of long-term forest planning. Much of this literature makes normative statements about forest policy that often implicitly disregards efficiency aspects in the growing sector and ignores non-wood values. Stumpage values are, in fact, a result of a complex variety of supply and demand factors. Many of these were identified in section 6.1. Important factors include non-wood objectives of forest suppliers, various macro-economic conditions and government policies that affect both growers and processors.

Despite the difficulties in estimating stumpage values in imperfect market conditions forest planners require a time stream of expected or forecast prices if they are to be concerned with intertemporal efficiency. To that end, a

Monte Carlo simulation approach to developing stumpage price expectations was considered. The results of a number of simulations, which give so-called true and predicted prices, were incorporated into the West Barham FORPLAN model to examine the robustness of forest plans. The approach emulated an ideal situation in which there is a good price forecasting model and a long time series available to estimate the coefficients. In the forecasting model situation perfect knowledge of the time path of the exogenous variables for the forecasting model was also assumed to reduce uncertainty to a minimum.

Even in the ideal situation of a good model and data to forecast prices, both the unconstrained and constrained forest plans were shown to be not very robust over the long-run. In the light of this lack of robustness the legitimacy of the whole analytical approach to long-term planning could be questioned. Presumably what forest planners would like is an analytical approach that can incorporate efficiency considerations in a relatively robust manner but also permits managerial flexibility when more knowledge is gained on physical and social values. One interesting feature is that the plans discussed in both this chapter and Chapter 5 were often similar for the first few planning periods. Clearly, over time, forest managers could adjust their planned rotation lengths as more information becomes available. However, it was shown that harvest schedules for particular forest types are more dependent on the path of stumpage prices in the first few planning periods. This is more likely how inefficiencies will arise (eg. non-wood values aside, some forests could be harvested before they should be on efficiency criterion).

In cases where CFL constraints were used in FORPLAN some forest types were not harvested. This reinforces the view that in the presence of management constraints affecting the viability of forest harvesting, critical assessment of both the plans and the reasoning behind the constraints should be ongoing. In the case of the Victorian Conservation, Forests and Lands Department, plans are to be reviewed every five years. However, it is not clear that the Department's basic forest policies will be reviewed with such regularity.

The Monte Carlo approach could be applied to any problem of forecasting or inferring valuations. The approach to using Monte Carlo simulation techniques developed in this chapter could be applied to any problems of forecasting on inferring valuations. The quantitative dimensions of various types of uncertainty can be manipulated and policy implications derived. A simple hedonic travel cost model was presented in section 6.3 that also used Monte Carlo techniques to generate the required data. The results illustrated some of the potential limitations of applying sophisticated economic techniques to identifying social values for policy making. Even in situations of good data availability results can easily lead to incorrect decisions. It is important to recognise this possibility when using non-market techniques of welfare estimation. Clearly the ability of these techniques to answer policy questions with any degree of certainty will depend on what sorts of questions are being asked. An interesting research problem would be to develop a time stream of values for some non-wood resources and investigate the implications of a range of values on management strategies. What are the relativities involved between wood and non-wood values that would suggest radically different management regimes in both the short and long-run?

CHAPTER 7

CONCLUSIONS

7.0 Introduction

This thesis has dealt with the juxtaposition of the economic principles of allocative efficiency on the practical problem of long-term public forest planning. Public forestry attempts to account for un-priced values as well as the management of priced commodities such as wood. The fact that forests exist through long periods of time complicates the management problem. Current practices affect not only the immediate value of forest outputs but also the value of future flows of goods and services from the forest. Even if the biological production functions of most of these goods and services were known with certainty, current and future social valuations are required if forest planning is to be intertemporally efficient. Clearly this is an heroic task. It may be impossible to achieve with a high degree of certainty. Nevertheless, it is generally understood that intertemporal efficiency is the economic standard for considering public policy on allocation issues.

If used properly, techniques common to economic analysis such as linear programming, for example, can help clarify the trade-offs involved between priced and un-priced values. Depending on the accountability of decision-makers, this may force clearer articulation and justification of public forest management and objectives.

However, operationalising economic principles for forest planning is not a simple or costless exercise.

The thesis was divided into 4 major parts. The first part, Chapter 2, dealt with the relevant economic theory. Chapter 3 discussed what some public forestry agencies do in practice with respect to planning. Chapter 3 also identified some of the major impediments to the use of economic analysis in public forestry. The third part of the thesis, Chapters 4 and 5, presented a case study on public forestry planning in Australia using economic principles as a guide for the exercise. Chapter 6 explored the issue of uncertainty with respect to economic valuations in forestry at greater length. Section 7.1 briefly reviews the major points of each chapter. Section 7.2 presents some general conclusions and some final remarks are given in section 7.3.

7.1 Summary

Chapter 2 presented the economic theory of relevance to long-term public forest planning. The notion of allocative efficiency was reviewed to identify the relevance of cost-benefit analysis to forestry. Three methods of deriving economic values on unpriced forest goods and services were discussed: contingent valuation, travel cost and hedonic travel cost. These techniques, although well-known to economists, have not been widely used in Australia. The value of wood from forests (stumpage value) was also discussed. Stumpage value is often misunderstood by non-economists. One reason for this is that the demand for stumpage is derived from the demand for the final products it helps to produce. The value of the final product is sometimes associated with stumpage values, however, this approach to stumpage valuation ignores the opportunity costs of other inputs to the final product, like labour, energy and capital. For long run forest planning, stumpage values are the appropriate point of departure for determining the correct economic value of wood resources in a forest. Some difficulties in identifying socially correct stumpage values were also discussed in Chapter 2.

Chapter 2 included a presentation of the capital analysis associated with the rotation problem in forestry; that is, the optimal time (rotation age) to harvest an even-aged single stand of trees. When wood is the only socially valuable forest output the solution to this problem has been named after the German forester, Martin Faustmann, who first identified the analytical approach in 1848. The Faustmann rotation length is generally shorter than the rotation period which maximises the physical output of wood from a forest. When non-wood values enter the decision calculus the optimal solution has been called the Hartman rotation age after Hartman (1976). Depending on the non-wood benefit functions(s) included in the problem formulation, the Hartman rotation age can sometimes be shorter than the Faustmann rotation period. In fact the rotation age can be shorter than, greater than, or equal to the Faustmann age. There are also conceivable situations where it would be optimal to never harvest a stand to realise the wood values. However, unambiguous generalisations from the Hartman formulation are difficult to obtain, the problem is essentially an empirical one.

Another complication arises when stand interdependencies are considered. Both the Hartman and the Faustmann approaches implicitly assume, by looking at a single stand, that there are no stand interdependencies; that is, the value of forest goods and services are unaffected by the condition of the stock of adjacent land. In fact, both wood and non-wood values can be affected by the condition of adjacent land. However the empirical analysis of such problems is difficult even if data are available (see the discussion in section 2.4).

Chapter 2 presented linear programming (LP) as an operational approach to incorporating economic considerations into forest planning problems. Linear programming has a long history as an aid to decision-making. While LP has been used for some forestry problems in Australia, until recently it has not been used for multiple-use planning of native forests.

Chapter 3 described planning practices for a number of public forest agencies in both North America and Australia. Most agencies have broadly defined multiple-use objectives. However, quantitative analytical approaches to the multiple-use planning problem are few. The USFS has expended a lot of effort on the development of FORPLAN - a linear programming based approach to planning that can explicitly include non-wood outputs and prescriptions within a timber harvest scheduling model. The USFS appears to be one of the few public forestry agencies to develop such a system on an operational scale. Some of the possible impediments to quantitative economic analysis in forest planning were identified in Chapter 3. Impediments range from a lack of expertise and legislative direction to high costs, lack of data and an apparent distrust of economic analysis as a paradigm to assist decision-making in forestry.

The State of Victoria has recently developed a Timber Industry Strategy that, among other things, provides direction to the public agency responsible for forest planning. Quantitative multiple-use planning and consideration of economic efficiency are included in the Strategy. A discussion of forest management and planning in Victoria was given in Chapter 4. Chapter 4 also presented the background for the LP based case study of multiple-use planning. The West Barham catchment of the Otway Ranges was chosen as the case study area. The selection of that catchment arose out of a larger planning project for the Otways, although the case study was not itself a part of that project. Given the data constraints, a single catchment analysis was deemed most appropriate. The FORPLAN software, the tool of analysis for the case study, was also described in Chapter 4.

Results were given in Chapter 5. An unconstrained model formulation was used to represent the view of wood as the only socially valuable output of the forest. This management plan is the benchmark for comparing the output from other model formulations. For example, the essential aspects of current policy were easily represented in a separate formulation. Sensitivity analysis on these cases had varying results. In some instances the resultant management strategies were different from the original scenarios and sometimes they were not. Other FORPLAN model formulations were presented to identify the consequences of other objectives (eg. greater water flows, logging bans on some forest types, restricted annual harvests). Some outputs and constraints in FORPLAN can be used as proxies for values and objectives that would otherwise be difficult to include. For example, age classes can be used as a proxy for wildlife habitat suitability. Restricted annual harvests can be used to indirectly proxy water quality or other conservation objectives since management for those objectives often affects harvest levels. The opportunity costs of management for those services, in terms of NPV foregone, can be estimated by putting constraints on the proxy outputs or timber harvest levels.

The problem of uncertainty in deriving forest values and implications on forest plans was explored in Chapter 6. Firstly the difficulties of forecasting stumpage values were addressed. There is very little literature relevant to the development of stumpage price expectations for long-run planning. A Monte Carlo model to develop price expectations was presented. The approach also allows an investigation of the implications of using incorrect prices in FORPLAN. Results showed that even in the best conceivable circumstances of data availability, standard econometric forecasting techniques will yield differences in stumpage price expectations as compared to actual prices that can lead to non-optimal management plans. This result seems to suggest that a preoccupation with sophisticated demand and supply models to determine price levels for long-run forest planning may be mis-placed. Small differences in price levels through time can lead to different strategies. It is inconceivable that sophisticated models could improve the forecasts to the degree required for robust plans.

An investigation of the uncertainties involved estimating non-wood values was also presented in Chapter 6. A Monte Carlo approach for a simple hedonic travel cost problem was used to estimate willingness to pay for forest preservation in the context of the West Barham management problem. It was shown that wrong answers are easily derived from such exercises and in fact, in the context of that specific problem, highly likely. This highlights the need for careful consideration of the application of non-market welfare estimation techniques.

7.2 Some General Conclusions

In this section I will summarise the most relevant aspects of the thesis for policy, and comment on some implications. In particular I consider the problem of operationalising economic principles for long-range public forest planning.

In its most basic form the multiple-use planning problem was first formally given by Hartman (1976) (Section 2.3):

$$NPV = \underset{T}{Max}\left\{\left[\left[PV(T)e^{-rT} + \int_0^T \left[a(n)e^{-rn}\right] dn - C\right] / \left[1 - e^{-rT}\right]\right\}\right. \qquad 2.3.7$$

The data requirements for applying and using this relatively simple problem formulation are as follows:

1. wood growth and yield (V(t));
2. stumpage price (P);
3. the costs for silvicultural prescriptions (C);
4. the amenity value benefit function for various amenity services over time (a(n));
5. an appropriate discount rate (r).

This formulation refers to a single stand. With multiple stands there are many forest types for yields, quality and size classes of trees for prices, and different management prescriptions to consider. Ideally stand interactions would also be considered. In reality numerical estimates of (1), (2) and (3) are of dubious quality, at least in Victoria. This situation is unlikely to differ in other jurisdictions. The amenity value functions are, generally, even more difficult to obtain. This holds true not only for social valuations but also for the biophysical production functions that underlie the amenity value estimates. There are also serious difficulties associated with the determination of an appropriate discount rate. However, the discount rate problem applies to all cost-benefit analyses not just forestry. Despite the difficulties associated with quantitative exercises of the type described above, insights can sometimes be gained with limited information. These insights might not be immediately obvious without at least attempts at quantitative analysis (eg. the relative costs of logging bans as presented in Chapter 5). The fact is that current forest management decisions are being made without the aid of quantitative tools. The question is whether quantitative exercises to improve the decisions are worth the cost. Foresters have implicit, sometimes explicit, assumptions about the effects of current activities on future flows of goods and services.

Quantitative exercises can, if properly formulated, identify or test many of these assumptions.

Although this thesis is not about FORPLAN *per se* it is about the use of such tools in an operational setting. Even if all the required data were easily available, using FORPLAN is a time-consuming and costly exercise. The primary difficulty is getting the data to set up the planning problem. Once this is done adding constraints and doing sensitivity analysis is relatively costless. However modifying the initial problem could be costly. It should be noted that including economic values for non-wood outputs in the case study model would have been simple if such values were available. It should also be noted that the case study FORPLAN model was not set up to consider spatial relationships for either wood or non-wood values. To do so would have required a significantly different FORPLAN set up for the West Barham problem[17]

These problems suggest a few implications for quantitative forest planning. Firstly, if public forest agencies are required to do quantitative planning, society will have to recognise how costly the exercise is. However, it is possible to envisage a single generic FORPLAN model that could be used for the general planning problem in different regional contexts within an agency's jurisdiction. By generic FORPLAN model, I mean a model that is relatively transportable between regions that can be used to roughly estimate the cost and benefits of different timber harvest schedules. Proxy non-wood outputs like age classes could be easily included in the model. Such a model would be relatively transparent and easy to use in different regional contexts provided estimates of wood growth and yields, costs of prescriptions and areas of the various forest types were available. In fact, except

17. Bowes and Krutilla (1987) comment on this problem of spatial definition in USFS FORPLAN models.

for water flows, the West Barham FORPLAN model as developed in this thesis, with some minor modifications, could be a generic model for Victoria. The generic model approach may be a method for eliminating some of the costs of quantitative planning. This approach could be used to both test and identify rules of thumb management principles for different regions.

Another problem revealed in the case study and with Monte Carlo experiments is the sensitivity of the FORPLAN solution to modifications in the data input. Empirical analysis is necessary for quantitative multiple-use forestry planning because small changes in the actual numbers will influence the solution. Purely analytical approaches do not provide unambiguous management solutions without restrictive assumptions. Using the Monte Carlo experiment results in FORPLAN showed the solution was sensitive to differences in prices even when the best conceivable circumstances with respect to the determination of future values were emulated. The second major implication for quantitative forest planning is that not only will planning be costly, it will also be imperfect even when data is not a problem. This revelation adds merit to rules of thumb management approaches. This also suggests that the reversibility of decisions should be a major consideration in planning. Where errors in management are irreversible for long periods of time a conservative strategy may be preferable if costs are not too high. For example consider the issue of logging the mature/overmature old growth forest type in the West Barham. Harvesting this forest type would be an irreversible decision for 150 years. Not harvesting is obviously a reversible decision. FORPLAN can cost such constraints easily, and in this instance showed the cost of preservation to be small relative to other forest types in the catchment under a wide range of assumptions.

7.3 Final Remarks

Quantitative multiple-use planning incorporating economics is not an easy task. It involves interdisciplinary teamwork that can be both time-consuming and costly. It will also be imperfect even in the best conceivable circumstances of data availability. Nevertheless the process of approaching the problem quantitatively is likely to lead to insights that may otherwise have been overlooked. This includes the spillover benefit of identifying research topics that would be relevant to improving management decisions. The approach could also help decrease conflict and improve the level of community debate over land allocation issues in forestry. For example, results from Chapter 5 suggest the wood resources of some old-growth forests in Australia may be less valuable than previously thought. The opportunity costs of instituting logging bans on younger forests was higher than bans on old growth.

The difficulties with quantitative planning suggest public forest agencies develop a philosophy on planning. The philosophy should identify the agency's expectations of the planning exercise. The expectations should be reasonable, based on an understanding of the underlying theory and data problems. The ultimate result should be plans that are viewed as strategic goals or guidelines by both foresters and the public, rather than uncompromising covenants.

It would appear that an important planning research topic is the development of methods of analysis that are less demanding in data and effort. Planning models should presumably be relatively transparent, cheap to use, incorporate notions of allocative efficiency, include wood and important non-wood outputs, and identify strategies that are both robust and flexible to changing circumstances. Whether all this is achievable remains to be seen. Nevertheless, this thesis has helped clarify the application of economic theory to forest planning and illustrated, by way of examples, a novel way to use Monte Carlo techniques for investigating the implications of uncertainty.

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Appendix 4.1a: The Basic FORPLAN Model for the Case Study

```
PRINT OUT DATA AND GENERATE MATRIX
TITLE
  DATA SET FOR DAN'S OTWAY MODEL WEST BARHAM CATCHMENT
TIME
*YEARS1988 10 10 10 10 10 10 10 10 10 10
*YEAR GROUP 10
IDENTIFIERS
*LEVEL1       NOT IN USE
*LEVEL2       WATER SUPPLY CATCHMENTS (FCATCH) X WATER YIELD TYPES
  BA    WSBASH   WEST BARHAM RIVER; ASH
  BM    WSBMIX   WEST BARHAM RIVER; MIX
  BO    WSBOTH   WEST BARHAM RIVER; OTHER
*AGGREGATE  LEVEL2
  WB    WESBAR   WEST BARHAM RIVER
        BA BM BO
*LEVEL3       NOT IN USE
*LEVEL4       TIMBER  STAND TYPE (L4)
  V7    1890     1890                          Y.T. 7
  1A    1919S    1919/26 SINGLE AGE            Y.T. 1 & 3
  V2    1919M    1919/26 MIXED AGE             Y.T. 2, 8 & 14
  V9    1939     1939                          Y.T. 9
  1B    1939    POST 1939                     Y.T. 4
  1C    1970-O   REGEN 1970'S NO OVERWOOD      Y.T. 4
  1D    1980-O   REGEN 1980'S NO OVERWOOD      Y.T. 4
  3C    1970+O   REGEN 1970'S    OVERWOOD      Y.T. 67% 4
  3D    1980+O   REGEN 1980'S    OVERWOOD      Y.T. 67% 4
  OM    MAT/OM   OM/M                          Y.T. 10 & 11
  O1    M/OWES   OM/M WESTERN OTWAYS (20%)     Y.T. 11A
  RS    RESRVE   NON EUCALYPT - 'RESERVE' NO YIELDS
  SC    SCRUB    NON EUCALYPT - 'SCRUB'        Y.T. 6
*AGGREGATE LEVEL4
  MH    MTNHWD   ALL MOUNTAIN HARDWOOD TYPES
        V7 1A V2 V9 1B 1C 1D 3C 3D OM
        O1
  AO    OVERMA   ALL MATURE/OVERM TYPES
        OM O1
  R7    1970'S   ALL 1970'S REGEN
        1C 3C
  R8    1980'S   ALL 1980'S REGEN
        1D 3D
  EX    SCRRES   SCRUB AND RESERVE VEGETATION
        RS SC
  NT    19/26    ALL 1919/26
        1A V2
  AT    ALLTYP   ALL FOREST TYPES
        V7 1A V2 V9 1B 1C 1D 3C 3D OM
        O1 RS SC
*LEVEL5       NOT IN USE
*LEVEL6       NOT IN USE
*LEVEL7       MGMT  TYPE
  NL    NOLOG    NO LOGGING
  HS    HARSAW   HARDWOOD SAWLOG HARVESTING ONLY NON SCRUB
  HI    HARINT   HARDWOOD INTEGRATED HARVESTING NON SCRUB
  SR    SRCSAW   SCRUB CONVERSION-SAWLOG ONLY
  SI    SCRINT   SCRUB CONVERSION-INTEGRATED OP
*AGGREGATE LEVEL7
  SA    SAWALL   ALL HARDWOOD SAW HARVESTING
        HS SR
  IA    INTALL   ALL HARDWOOD INTEGRATED HARVESTING
        HI SI
  HW    ALLHWD   ALL HWD NON-SCRUB HARVESTING
        HS HI NL
  AH    ALLHAR   ALL HARVESTING EX SOFTWOOD
        HS HI SR SI NL
  AS    ALLSCR   ALL SCRUB HARVESTING
        SR SI NL
  AM    ALLMGM   ALL MANAGEMENT TYPES
        NL HS HI SR SI
*LEVEL8       MGMT  INTENS
```

```
  NL     NOLOG     NO LOGGING
  C1     CLEFEL    HARDWOOD CLEARFELL, NAT REGEN
  C2     CLBUSE    HARDWOOD CLEARFELL, SEED
  C3     CLBUPL    HARDWOOD CLEARFELL, PLANT
*AGGREGATE LEVEL 8
  CA     CLALL     ALL HARDWOOD REGIMES
         NL C1 C2 C3
  C4     CLINT     INTENSIVE, SEED OR PLANT REGIMES
         C2 C3
TREATMENT TYPES
  C     HWD CFL(EX)              Y Y Y N Y Y N Y Y  Y  N
  D     HWD CFL(RG)              Y Y Y N Y Y N Y Y  N  N
  B     BEFORE                   N N N N N N N N N  N  B
  A     AFTER                    N N N N N N N N N  N  A
  =     BEFORE-AFTER             N N N N N N N N N  N  L
  W     WATER                    N N Y N Y N N N N  Y  N
  G     AGES                     Y Y Y N Y N N N N  Y  N
AT AGGREGATE TREATMENT TYPES
  X     ALL HWD CFL        C D
ACTIVITIES
  PLAI  INT PLANTING REGIME          HA       N C P      Y N N
  PLAS  SAWLOG ONLY PLANTING         HA       N C P      Y N N
  SPR2  SCRUB SEEDING REFOR          HA       N C P      Y N N
  SPR3  SCRUB PLANTING  REFOR        HA       N C P      Y N N
  SEEI  INT SEEDING REGIME           HA       N C P      Y N N
  SEES  SAWLOG ONLY SEED REGIME      HA       N C P      Y N N
  NATR  NATURAL REGEN                HA       N C P      Y N N
  VRC1  HARVESTING SUPERVISION      M 3       N C P      Y N N
  VRC2  ROADWORKS (UTILISATION)     M 3       N C P      Y N N
  VRC3  DEPARTMENTAL (UTILISATN)    M 3       N C P      Y N N
*COMMON COSTS FOR ACTIVITIES
  SE1                 HSC2  SEES
*                                    515.
  SE2           V7    HSC2  SEES
*                                    540.
  SE3           AO    HSC2  SEES
*                                    550.
  SE4                 HIC2  SEEI
*                                    430.
  SE2           V7    HIC2  SEEI
*                                    405.
  SE2           AO    HIC2  SEEI
*                                    365.
  SP1                 HIC3  PLAI
*                                    690.
  SP2           V7    HIC3  PLAI
*                                    665.
  SP3           AO    HIC3  PLAI
*                                    625.
  SP4                 HSC3  PLAS
*                                    785.
  SP5           V7    HSC3  PLAS
*                                    810.
  S10           AO    HSC3  PLAS
*                                    820.
  SC1                 ASC2  SPR2
*                                   1230.
  S11                 ASC3  SPR3
*                                   1445.
  NA1                 SAC1  NATR
*                                     80.
  NA2                 IAC1  NATR
*                                     80.
  VC1                 HS    VRC1
*                                      0.70
  VC2                 HI    VRC1
*                                      0.40
  VC3           AO    HS    VRC1
*                                      0.90
  VC4           AO    HI    VRC1
*                                      0.55
  VC8           MH    HS    VRC2
*                                      2.85
```

```
  VC9          MH    HI    VRC2
*                                        1.60
  V13                AS    VRC3
*                                       45.00
OUTPUTS AND ENVIRONMENTAL EFFECTS
  SAW1  SAWLOG CLASS A             M 3        N C P      N Y
  SAW2  SAWLOG CLASS B&C           M 3        N C P      N Y
  PULP  SAWLOG D & RESIDUAL        M 3        N C P      N Y
  FHAR  FINAL HARVEST HA          HA          N C P      N N
  WATR  WATER QUANTITY           MEGAL        N C Y      N Y
  AGE1  AGE CLASS 0-20            HA          N C P      N Y
  AGE2  AGE CLASS 21-40           HA          N C P      N Y
  AGE3  AGE CLASS 41-80           HA          N C P      N Y
  AGE4  AGE CLASS 81-100          HA          N C P      N Y
  AGE5  AGE CLASS 101-150         HA          N C P      N Y
  AGE6  AGE CLASS  150           HA          N C P      N Y
*AGGREGATE NAMES FOR OUTPUTS
  HARD  ALL HARDWOOD LOGS          M 3        C          SAW1 SAW2 PULP
*COMMON RETURNS ON OUTPUTS
  SA1                        SAW1
*                                       50.0
  SA2                        SAW2
*                                       27.0
  RES                        PULP
*                                        7.00
  AG1                        AGE1
*                                        0.00
  AG2                        AGE2
*                                        0.00
  AG3                        AGE3
*                                        0.00
  AG4                        AGE4
*                                        0.00
  AG5                        AGE5
*                                        0.00
  AG6                        AGE6
*                                        0.00
  W01                        WATR
*                                        0.00
YIELD COMPOSITE NAMES FOR OUTPUTS/ACTIVITIES
#1TIMHY TIMBER HARDWOODS
#2     C HARD
#2FHAR W HARD X TI C   1.0
#2SEEI W HARD   AG
#2SEES W HARD   AG
#2PLAI W HARD   AG
#2PLAS W HARD   AG
#2SPR2 W HARD   AG
#2SPR3 W HARD   AG
#2NATR W HARD   AG
#2VRC1 W HARD   AG
#2VRC2 W HARD   AG
#2VRC3 W HARD   AG
#2WATR W HARD   AG G
#2AGE1 W HARD   AG
#2AGE2 W HARD   AG
#2AGE3 W HARD   AG
#2AGE4 W HARD   AG
#2AGE5 W HARD   AG
#2AGE6 W HARD   AG
TIME DEPENDENT RELATIONS AMONG ACTIVITIES/OUTPUTS
#1LOG SAW1
#2W A HARD
#3                AH
#4
#5  1 10       1.
#1LO2 SAW2
#2W A HARD
#3                AH
#4
#5  1 10       1.
#1PUL PULP
#2W A HARD
```

```
#3                 IA
#4
#5  1 10       1.
AGE DEPENDENT RELATIONS AMONG ACTIVITIES/OUTPUTS
#1SES SEES
#2W C HARD
#3                 HSC2
#4
#5         0  0 1.
#1SEI SEEI
#2W C HARD
#3                 HIC2
#4
#5         0  0 1.
#1PLS PLAS
#2W C HARD
#3                 HSC3
#4
#5         0  0 1.
#1PLI PLAI
#2W C HARD
#3                 HIC3
#4
#5         0  0 1.
#1SCS SPR2
#2W C HARD
#3                 ASC2
#4
#5         0  0 1.
#1SPT SPR3
#2W C HARD
#3                 ASC3
#4
#5         0  0 1.
#1NAT NATR
#2W C HARD
#3                 AHC1
#4
#5         0  0 1.
#1VC1 VRC1
#2W A HARD
#3                 HWCA
#4
#5         0  0 1.
#1VC2 VRC2
#2W A HARD
#3                 HWCA
#4
#5         0  0 1.
#1VC3 VRC3
#2W A HARD
#3                 AS
#4
#5         0  0 1.
#1AG1 AGE1
#2W C HARD
#3
#4
#5  0  2       1.
#1AG2 AGE2
#2W C HARD
#3
#4
#5  3  4       1.
#1AG3 AGE3
#2W C HARD
#3
#4
#5  5  8       1.
#1AG4 AGE4
#2W C HARD
#3
#4
```

```
#5  9 10       1.
#1AG5 AGE5
#2W C HARD
#3
#4
#5 11 14       1.
#1AG6 AGE6
#2W C HARD
#3
#4
#5 15 30       1.
OBJECTIVE   PNW  10 Y .04  N Y
PRINT DETAIL  104326
                                                        .00001
AP PRESCRIPTION SOURCE INFORMATION
#1RX3          EX
#2                   NLNL    N2
#2                   SRC1    S4
#2                   SRC2    S5
#2                   SRC3    S6
#2                   SIC1    S7
#2                   SIC2    S8
#2                   SIC3    S9
#1RX4          MH
#2                   NLNL    N1
#2                   HSC1    M1
#2                   HSC2    M2
#2                   HSC3    M3
#2                   HIC1    M6
#2                   HIC2    M7
#2                   HIC3    M8
SOURCE OF ACTIVITY/OUTPUTS
#1TIMH
#2                   HS
#2                   HI
#2                   SR
#2                   SI
HARVEST SOURCE
#1HARD
*EXIST
#2             NT    HWCA             7 18
#2             1B    HWCA             4 15
#2             3C    HWCA             2 13
#2             3D    HWCA             1 14
#2             V9    HWCA             5 16
#2             1C    HWCA             2 13
#2             1D    HWCA             1 12
#2             OM    HWCA            15 26
#2             O1    HWCA            15 26
#2             SC    ASCA            10 21
#2             V7    HWCA            10 21
#2             RS    ASCA            15 26
*REGEN
#2                   AM                           2 10
YIELDS
AA 001   BM  OM       192.
AA 002   BM  O1        35.
AA 003   BM  3D        15.
AA 004   BM  1D        46.
AA 005   BM  1C        42.
AA 006   BA  V2        35.
AA 007   BM  V2         8.
AA 008   BM  1A       117.
AA 009   BO  1A        35.
AA 010   BM  V7       178.
AA 011   BO  SC        69.
AA 012   BO  RS       261.
END OF DATA
```

Appendix 4.1b: The Basic FORPLAN Yield File for the Case Study

```
ANALYSIS AREA INFORMATION
CODE HARD
*I      BM  1A     HI
*A EXIST    07      SEEDED REGEN VOL TABLE FOR 1919/26  ASH REG (STRATUM 1)
  SAW1CA07   2.     3.     4.     5.     5.     6.     7.     7.     8.     8.
  SAW2CA07 244.   324.   393.   467.   534.   594.   645.   700.   745.   784.
  PULPCA07 218.   273.   327.   362.   391.   415.   435.   457.   480.   515.
*I          1B     HI
*A EXIST    04      SEEDED REGEN VOL TABLE FOR R/R POST 1939  (STRATUM 1B)
  SAW1CA04   0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA04  36.    89.   165.   241.   317.   368.   395.   419.   448.   475.
  PULPCA04 393.   329.   218.   152.   135.   143.   136.   134.   141.   128.
*I          1C     HI
*A EXIST    02      SEEDED REGEN VOL TABLE FOR R/R 1970'S (STRATUM 4)
  SAW1CA02   0.     0.     0.     1.     2.     2.     3.     4.     4.     4.
  SAW2CA02   0.     2.    15.    50.   127.   199.   276.   346.   378.   402.
  PULPCA02   0.   376.   402.   377.   304.   162.   152.   138.   136.   143.
*I          1D     HI
*A EXIST    01      SEEDED REGEN VOL TABLE FOR R/R 1980'S (STRATUM 4)
  SAW1CA01   0.     0.     0.     0.     1.     2.     2.     3.     4.     4.
  SAW2CA01   0.     0.     2.    15.    50.   127.   199.   276.   346.   378.
  PULPCA01   0.     0.   376.   402.   377.   304.   162.   152.   138.   136.
*I      BO  1A     HI
*A EXIST    07        VOL TABLE FOR 1919/26 OTHER SP  (STRATUM 3)
  SAW1CA07   2.     2.     3.     3.     4.     4.     4.     5.     5.     5.
  SAW2CA07 163.   217.   263.   313.   357.   398.   433.   469.   500.   526.
  PULPCA07 146.   183.   219.   242.   262.   278.   291.   306.   322.   345.
*I          3C     HI
*A EXIST    02      67%*SEEDED REGEN VOL TABLE FOR REGEN+O'WD 1970'S (STR 3C)
  SAW1CA02   0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA02   0.     1.    10.    34.    86.   135.   187.   234.   256.   272.
  PULPCA02 100.   252.   269.   253.   204.   109.   102.    92.    91.    96.
*I          3D     HI
*A EXIST    01      67%*SEEDED REGEN VOL TABLE FOR REGEN+O'WD 1980'S (ST 4A)
  SAW1CA01   0.     0.     0.     0.     1.     1.     1.     2.     3.     3.
  SAW2CA01   0.     0.     1.    10.    34.    85.   134.   185.   232.   253.
  PULPCA01   0.     0.   252.   269.   253.   204.   109.   102.    92.    91.
*I      BA  V2     HI
*A EXIST    07      1919/26 WITH M & OM, 1919/26/39, ASH VOL TABLE (STR 2)
  SAW1CA07   2.     2.     2.     3.     3.     3.     4.     4.     4.     4.
  SAW2CA07 169.   204.   237.   265.   293.   320.   347.   371.   397.   424.
  PULPCA07 318.   335.   353.   358.   348.   340.   330.   329.   320.   313.
*I          V9     HI
*A EXIST    05      1939 WITH M & OM VOL TABLE (STRATUM 9)
  SAW1CA05   0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA05 112.   146.   180.   214.   242.   262.   288.   315.   332.   355.
  PULPCA05 345.   396.   431.   456.   481.   484.   475.   485.   469.   477.
*I      BO  V2     HI
*A EXIST    07      1919/26 WITH M & OM, 1919/26/39 MIXED SPP (STR 14)
  SAW1CA07   0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA07 108.   135.   159.   182.   203.   222.   239.   256.   273.   292.
  PULPCA07 216.   235.   260.   279.   290.   298.   303.   308.   318.   321.
*I          V7     HI
*A EXIST    10      1890'S VOL TABLE (STRATUM 7)
  SAW1CA10   1.     1.     2.     2.     2.     2.     3.     3.     3.     4.
  SAW2CA10 110.   137.   162.   195.   221.   244.   272.   301.   324.   370.
  PULPCA10 129.   154.   191.   218.   237.   253.   269.   279.   293.   304.
*I      BM  V2     HI
*A EXIST    07      1919/26 WITH M & OM, 1919/26/39 ASH-MIXED (STR 8)
  SAW1CA07   2.     2.     2.     3.     3.     3.     3.     4.     4.     4.
  SAW2CA07 154.   189.   222.   254.   283.   305.   330.   351.   376.   401.
  PULPCA07 274.   292.   308.   317.   310.   321.   323.   323.   322.   335.
*I      BM  1A     HS
*A EXIST    07      SEEDED REGEN VOL TABLE FOR 1919/26  ASH/MIX (STRATUM 1A)
  SAW1CA07   2.     3.     4.     5.     5.     6.     7.     7.     8.     8.
  SAW2CA07 244.   324.   393.   467.   534.   594.   645.   700.   745.   784.
  PULPCA07   0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          1B     HS
*A EXIST    04      SEEDED REGEN VOL TABLE FOR R/R POST 1939    (STRATUM 1B)
```

```
  SAW1CA04  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA04 36.    89.   165.   241.   317.   368.   395.   419.   448.   475.
  PULPCA04  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          1C    HS
*A EXIST    02     SEEDED REGEN VOL TABLE FOR R/R 1970'S (STRATUM 1C) NO PULP
  SAW1CA02  0.     0.     0.     1.     2.     2.     3.     4.     4.     4.
  SAW2CA02  0.     2.    15.    50.   127.   199.   276.   346.   378.   402.
  PULPCA02  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          1D    HS
*A EXIST    01     SEEDED REGEN VOL TABLE FOR R/R 1980'S (STRATUM 1D) NO PULP
  SAW1CA01  0.     0.     0.     0.     1.     2.     2.     3.     4.     4.
  SAW2CA01  0.     0.     2.    15.    50.   127.   199.   276.   346.   378.
  PULPCA01  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I       BO 1A    HS
*A EXIST    07    67%*SEEDED REGEN VOL TABLE FOR 1919/26 OTHER SP(STRATUM 3A)
  SAW1CA07  2.     2.     3.     3.     4.     4.     4.     5.     5.     5.
  SAW2CA07 163.  217.   263.   313.   357.   398.   433.   469.   500.   526.
  PULPCA07  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          3C    HS
*A EXIST    02    67%*SEEDED REGEN VOL TABLE FOR REGEN+O'WD 1970'S (STRATUM 3C)
  SAW1CA02  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA02  0.     1.    10.    34.    86.   135.   187.   234.   256.   272.
  PULPCA02  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          3D    HS
*A EXIST    01    67%*SEEDED REGEN VOL TABLE FOR REGEN+O'WD 1980'S (ST 4A)
  SAW1CA01  0.     0.     0.     0.     1.     1.     1.     2.     3.     3.
  SAW2CA01  0.     0.     1.    10.    34.    85.   134.   185.   232.   253.
  PULPCA01  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I       BA V2    HS
*A EXIST    07     1919/26 WITH M & OM, 1919/26/39 ASH VOL TABLE (STRATUM 2)
  SAW1CA07  2.     2.     2.     3.     3.     3.     4.     4.     4.     4.
  SAW2CA07 169.  204.   237.   265.   293.   320.   347.   371.   397.   424.
  PULPCA07  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          V9    HS
*A EXIST    05     1939 WITH M & OM VOL TABLE (STRATUM 9)
  SAW1CA05  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA05 112.  146.   180.   214.   242.   262.   288.   315.   332.   355.
  PULPCA05  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I       BO V2    HS
*A EXIST    07     1919/26 WITH M & OM, 1919/26/39 MIXED SPP VOL TABLE (STR 14)
  SAW1CA07  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA07 108.  135.   159.   182.   203.   222.   239.   256.   273.   292.
  PULPCA07  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          V7    HS
*A EXIST    10     1890'S VOL TABLE (STRATUM 7)
  SAW1CA10  1.     1.     2.     2.     2.     2.     3.     3.     3.     4.
  SAW2CA10 110.  137.   162.   195.   221.   244.   272.   301.   324.   370.
  PULPCA10  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I       BM V2    HS
*A EXIST    07     1919/26 WITH M & OM, 1919/26/39 ASH-MIXED VOL TABLE (STR 8)
  SAW1CA07  2.     2.     2.     3.     3.     3.     3.     4.     4.     4.
  SAW2CA07 154.  189.   222.   254.   283.   305.   330.   351.   376.   401.
  PULPCA07  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          OM    HI
*A EXIST    15     M/OM VOL TABLE FOR WESTERN OTWAYS (20%) (STRATUM 11)
  SAW1CA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA15 40.    40.    40.    40.    40.    40.    40.    40.    40.    40.
  PULPCA15 150.  150.   150.   150.   150.   150.   150.   150.   150.   150.
*I          O1    HI
*A EXIST    15     M/OM VOL TABLE FOR WESTERN OTWAYS (80%) STRATUM 11A
  SAW1CA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA15 15.    15.    15.    15.    15.    15.    15.    15.    15.    15.
  PULPCA15 100.  100.   100.   100.   100.   100.   100.   100.   100.   100.
*I          OM    HS
*A EXIST    15    M/OM VOL TABLE FOR WESTERN OTWAYS (20%) (STRATUM 11)
  SAW1CA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA15 40.    40.    40.    40.    40.    40.    40.    40.    40.    40.
  PULPCA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          O1    HS
*A EXIST    15     M/OM VOL TABLE FOR WESTERN OTWAYS (80%) STRATUM 11A
  SAW1CA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA15 15.    15.    15.    15.    15.    15.    15.    15.    15.    15.
  PULPCA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
```

```
*I          RS    SR
*A EXIST    15      VOLUMES FOR RESERVE VEG -- NONE
  SAW1CA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  PULPCA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          RS    SI
*A EXIST    15      VOLUMES FOR RESERVE VEG -- NONE
  SAW1CA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2CA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  PULPCA15  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          SC    SR
*A EXIST    10      NATURAL REGEN VOL TABLE (STRATUM 6) FOR SCRUB
  SAW1CA10  30.    40.    50.    60.    60.    60.    60.    60.    60.    60.
  SAW2CA10  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  PULPCA10  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I          SC    SI
*A EXIST    10      NATURAL REGEN VOL TABLE (STRATUM 6) FOR SCRUB
  SAW1CA10  30.    40.    50.    60.    60.    60.    60.    60.    60.    60.
  SAW2CA10  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  PULPCA10  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I                IAC2
*A REGEN           SEEDED MTN ASH REGEN VOL TABLE (STRATUM 4)
  SAW1DA00  0.     0.     0.     0.     0.     1.     2.     2.     3.     4.
  SAW2DA00  0.     0.     0.     6.     36.    88.    163.   239.   314.   364.
  PULPDA00  0.     0.     341.   390.   393.   329.   218.   152.   135.   143.
*I                IAC3
*A REGEN           PLANTED MTN ASH REGEN VOL TABLE (STRATUM 4A)
  SAW1DA00  0.     0.     0.     1.     2.     2.     3.     3.     3.     3.
  SAW2DA00  0.     0.     13.    82.    159.   227.   283.   303.   323.   341.
  PULPDA00  0.     0.     286.   399.   453.   453.   423.   389.   323.   286.
*I                IAC1
*A REGEN           NATURAL REGEN VOL TABLE (STRATUM 6)
  SAW1DA00  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2DA00  0.     0.     0.     0.     5.     30.    40.    50.    60.    70.
  PULPDA00  0.     0.     30.    35.    40.    45.    50.    55.    60.    65.
*I                SAC2
*A REGEN           SEEDED MTN ASH REGEN VOL TABLE (STRATUM 4)
  SAW1DA00  0.     0.     0.     0.     0.     1.     2.     2.     3.     4.
  SAW2DA00  0.     0.     0.     6.     36.    88.    163.   239.   314.   364.
  PULPDA00  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I                SAC3
*A REGEN           PLANTED MTN ASH REGEN VOL TABLE (STRATUM 4A)
  SAW1DA00  0.     0.     0.     1.     2.     2.     3.     3.     3.     3.
  SAW2DA00  0.     0.     13.    82.    159.   227.   283.   303.   323.   341.
  PULPDA00  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
*I                SAC1
*A REGEN           NATURAL REGEN VOL TABLE (STRATUM 6)
  SAW1DA00  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  SAW2DA00  0.     0.     0.     0.     5.     30.    40.    50.    60.    70.
  PULPDA00  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
CODE WATR
*I          V2
*A EXIST    07
      WA07  5.71   6.15   6.52   6.82   7.05   7.22   7.35   7.45   7.52   7.57
            7.61   7.64   7.66   7.68
*I          1A
*A EXIST    07
      WA07  5.71   6.15   6.52   6.82   7.05   7.22   7.35   7.45   7.52   7.57
            7.61   7.64   7.66   7.68
*I          V7
*A EXIST    07
      WA10  6.68   6.94   7.14   7.29   7.40   7.48   7.55   7.59   7.63   7.65
            7.66   7.68
*I          1C
*A EXIST    02
      WA02  4.41   3.76   4.08   4.34   4.90   5.45   5.94   6.35   6.68   6.94
            7.14   7.29   7.40   7.48   7.55   7.59   7.63   7.65
*I          3C
*A EXIST    02
      WA02  4.41   3.76   4.08   4.34   4.90   5.45   5.94   6.35   6.68   6.94
            7.14   7.29   7.40   7.48   7.55   7.59   7.63   7.65
*I          1D
*A EXIST    01
```

```
      WA01  6.58  4.41   3.76   4.08   4.34   4.90   5.45   5.94   6.35   6.68
            6.94  7.14   7.29   7.40   7.48   7.55   7.59   7.63   7.65
*I          3D
*A EXIST    01
      WA01  6.58  4.41   3.76   4.08   4.34   4.90   5.45   5.94   6.35   6.68
            6.94  7.14   7.29   7.40   7.48   7.55   7.59   7.63   7.65
*I          OM
*A EXIST    15
      WA15  7.68  7.68   7.68   7.68   7.68   7.68   7.68   7.68   7.68   7.68
*I          01
*A EXIST    15
      WA15  7.68  7.68   7.68   7.68   7.68   7.68   7.68   7.68   7.68   7.68
*I          SC
*A EXIST    10
      WA10 11.95  11.95 11.95  11.95  11.95  11.95  11.95  11.95  11.95  11.95
*I          RS
*A EXIST    10
      WA10 11.95  11.95 11.95  11.95  11.95  11.95  11.95  11.95  11.95  11.95
*I
*A REGEN
      CA00 7.71   5.24   3.95   3.76   4.08   4.61   5.18   5.71   6.15   6.52
           6.82   7.05   7.22   7.35   7.45   7.52   7.57   7.61   7.64
END OF DATA
```

Appendix 6.1 The Monte Carlo Stumpage Price Expectation Model

```
10 randomize
100 rem this version does 50 replications
101 rem and only ouputs summary statistics
200 dim z1(800), z2(800), z(800)
201 dim e1(400), e2(400), ed(400), es(400), v(400)
202 dim ly(400), lps(400), lp(400), p(400)
203 dim xx(400,5), yy(400,1), x(100,5), xt(5,100)
204 dim xtx(5,5), q(5,5), qq(5,100), coeff(5,1)
205 dim ys(100,1)
210 dim flp(400), fp(400)
211 dim devp(400), devfp(400)
212 dim a(50,5), sum(50), mean(5)
213 dim mp(50), mfp(50), vp(50), vfp(50)
214 DIM AAP(50,100), AFP(50,100), SAAP(100), SAFP(100)
215 DIM AVSAAP(100), AVSAFP(100)
216 DIM DVFP(50), SDFP(100), SDPT(100), SDMT(100)
300 for k=1 to 50
400 rem the normal generator comes from basic book
410 rem by groeneveld p 138
500 for i=1 to 800
510 z1(I)=sqr(-2*log(rnd))
520 z2(I)=6.2831853*rnd
530 z(I)=z1(I)*cos(z2(I))
540 next i
550 rem z is standard normal so need to fix vars for inc and sub price?
560 rem do this with adj as sq root of required variance
570 adj1=0.2236
580 adj2=0.2236
590 for i=1 to 400
600 e1(I)=adj1*z(I)
610 next i
620 for i=401 to 800
630 e2(I-400)=adj2*z(I)
640 next i
650 rem g1 and g2 are growth rates for inc and sub price
660 rem k1 and k2 are lns of inc and sub price starts
670 g1=0.02
680 g2=-0.01
690 k1=log(1000)
700 k2=log(50)
710 for i=1 to 400
720 LY(I)=k1+(i*log(1+g1))+e1(I)
730 LPS(I)=k2+(I*LOG(1+g2))+e2(I)
740 next i
800 a1=24.6694
810 a2=0.8
820 a3=-5.0
830 a4=1.5
840 a5=17.0407
850 a6=1.25
860 a7=-0.2
870 a8=0.3
900 a9=(a3-a6)
910 b0=(a5-a1)/a9
920 b1=a2/a9
```

```
930 b2=a4/a9
940 b3=a7/a9
950 b4=a8/a9
960 rem "start" is lr eq for ln of p given other starts
965 rem and so needs calctng for any new pars or starts
970 start=3.3
1000 rem this bit generates error terms for sttcl and rf eqtns
1010 for i=1 to 800
1020 z1(I)=sqr(-2*log(rnd))
1030 z2(I)=6.2831853*rnd
1040 z(I)=z1(I)*cos(z2(I))
1050 next i
1060 rem now set adjs on sttcl errors as above for gowth terms
1070 adj3=1
1080 adj4=1
1090 for i=1 to 400
1100 ed(I)=adj3*z(I)
1110 next i
1120 for i=401 to 800
1130 es(i-400)=adj4*z(I)
1140 next i
1150 for i=1 to 400
1160 v(I)=(ed(I)-es(I))/a9
1170 next i
2000 rem this bit generates data using reduced form eqtn
2010 for i=1 to 30
2020 lp(I)=b0-(b1*ly(I))-(b2*lps(I))+(b3*start)+(b4*start)+v(I)
2025 p(I)=exp(lp(I))
2030 next i
2040 for i=31 to 400
2050 lp(I)=b0-(b1*ly(i))-(b2*lps(i))+(b3*lp(i-10)) +(b4*lp(i-30))+V(I)
2055 P(I)=EXP(LP(I))
2060 next i
3000 rem this bit does rf estmtn by ols
3010 rem first step is to read in data
3020 for i=200 to 300
3030 xx(i,1)=1
3040 xx(i,2)=ly(i)
3050 xx(i,3)=lps(i)
3060 xx(i,4)=lp(i-10)
3070 xx(i,5)=lp(i-30)
3080 yy(i,1)=lp(I)
3090 next i
3100 for j=1 to 5
3110 for i=1 to 100
3120 x(i,j)=xx(i+200,j)
3125 ys(i,1)=yy(i+200,1)
3130 next i
3140 next j
3150 mat xt=trn(x)
3160 mat xtx=xt*x
3170 mat q=inv(xtx)
3180 mat qq=q*xt
3190 mat coeff=qq*ys
3200 for i=301 to 310
3210 flp(I)=coeff(1,1)+(coeff(2,1)*ly(I))+(coeff(3,1)*lps(I))
3220 flp(I)=flp(I)+(coeff(4,1)*lp(i-10))+(coeff(5,1)*lp(i-30))
```

```
3230 fp(I)=exp(flp(I))
3240 next i
3250 for i=311 to 330
3260 flp(I)=coeff(1,1)+(coeff(2,1)*ly(I))+(coeff(3,1)*lps(I))
3270 flp(I)=flp(I)+(coeff(4,1)*flp(i-10))+(coeff(5,1)*lp(i-30))
3280 fp(I)=exp(flp(I))
3290 next i
3300 for i=331 to 400
3310 flp(I)=coeff(1,1)+(coeff(2,1)*ly(I))+(coeff(3,1)*lps(I))
3320 flp(I)=FLP(I)+(coeff(4,1)*flp(i-10))+(coeff(5,1)*flp(i-30))
3330 fp(I)=exp(flp(I))
3340 next i
3341 FOR I=301 TO 400
3342 AAP(K,I-300)=P(I)
3343 AFP(K,I-300)=FP(I)
3344 NEXT I
3350 sump=0
3360 sumpf=0
3370 for i=301 to 400
3380 sump=sump+p(I)
3390 sumpf=sumpf+fp(I)
3400 next i
3410 meanp=sump/100
3420 meanfp=sumpf/100
3430 sumpv=0
3440 sumpfv=0
3450 for i= 301 to 400
3460 devp(I)=p(I)-meanp
3470 devp(I)=devp(I)^2
3480 sumpv=sumpv+devp(I)
3490 devfp(I)=fp(I)-meanfp
3500 devfp(I)=devfp(I)^2
3510 sumpfv=sumpfv+devfp(I)
3520 next i
3530 varp=sumpv/100
3540 varpf=sumpfv/100
5000 for j=1 to 5
5010 a(K,J)=coeff(j,1)
5020 next j
5030 mp(K)=meanp
5040 mfp(K)=meanfp
5050 vp(K)=varp
5060 vfp(K)=varpf
5070 next k
5071 FOR I=1 TO 100
5072 FOR J=1 TO 50
5073 SAAP(I)=SAAP(I)+AAP(J,I)
5074 SAFP(I)=SAFP(I)+AFP(J,I)
5075 NEXT J
5076 AVSAAP(I)=SAAP(I)/50
5077 AVSAFP(I)=SAFP(I)/50
5078 NEXT I
5079 OPEN "ACTUAL.DAT" FOR OUTPUT AS #23
5080 OPEN "FCAST.DAT" FOR OUTPUT AS #24
5081 FOR I=1 TO 100
5082 PRINT #23, AVSAAP(I)
5084 PRINT #24, AVSAFP(I)
```

```
5085 NEXT I
5089 for j=1 to 5
5090 for k=1 to 50
5100 sum(J)=SUM(J)+A(k,j)
5110 next k
5120 next j
5130 for j=1 to 5
5140 mean(J)=sum(j)/50
5150 print "average of coefficient estimates"
5160 print mean(j)
5170 next j
5171 FOR I=1 TO 100
5172 SMFP=0
5173 FOR J=1 TO 50
5174 DVFP(J)=AFP(J,I)-AVSAFP(I)
5175 DVFP(J)=DVFP(J)^2
5176 SMFP=SMFP+DVFP(J)
5177 NEXT J
5178 SDFP(I)=SQR(SMFP/50)
5179 NEXT I
5180 FOR I=1 TO 100
5181 SDPT(I)=AVSAFP(I)+(2*SDFP(I))
5182 SDMT(I)=AVSAFP(I)-(2*SDFP(I))
5183 NEXT I
5184 OPEN "SDPT.DAT" FOR OUTPUT AS #25
5185 OPEN "SDMT.DAT" FOR OUTPUT AS #26
5186 FOR I=1 TO 100
5187 PRINT #25, SDPT(I)
5188 PRINT #26, SDMT(I)
5189 NEXT I
5190 summp=0
5191 summfp=0
5200 sumvp=0
5210 sumvfp=0
5220 for k=1 to 50
5230 summp=summp+mp(K)
5240 summfp=summfp+mfp(K)
5250 sumvp=sumvp+vp(K)
5260 sumvfp=sumvfp+vfp(K)
5270 next k
5280 avmp=summp/50
5290 avmfp=summfp/50
5300 avvp=sumvp/50
5310 avvfp=sumvfp/50
5320 print "actual data - average mean over forecast period"
5330 print avmp
5340 print " forecast data - avergage mean over forecast period"
5350 print avmfp
5360 print "actual data - average varioance over forecast period"
5370 print avvp
5380 print "forecast data - average variance over forecast period"
5390 print avvfp
```

Appendix 6.2 The Hedonoc Travel Cost SHAZAM Model

```
SET NODOECHO
PAR 100
DIM T1(50) T2(50) V1(50) V2(50) E1(50) E2(50)
DIM EST1(2) EST2(2) SE1(2) SE2(2) ET1(2) ET2(2)
DIM NE1(15) NE2(15) CSERR(15) DCSM(15)
DO #=1,50
SMPL 1 1
GENR E1(#)=NOR(3)
GENR E2(#)=NOR(3)
GENR T1(#)=#
GENR T2(#)=#
GENR V1(#)=50-(.5*T1(#))+E1(#)
GENR V2(#)=45-(.44*T2(#))+E2(#)
ENDO
SET ECHO
SMPL 1 50
OLS V1 T1 / COEF=EST1 STDERR=SE1
OLS V2 T2 / COEF=EST2 STDERR=SE2
PRINT EST1 EST2
SMPL 1 1
GENR SN=250
GENR SNTS=214625
GENR SNT=6375
GENR ET1(1)=ABS(EST1(1))
GENR ET1(2)=ABS(EST1(2))
GENR ET2(1)=ABS(EST2(1))
GENR ET2(2)=ABS(EST2(2))
GENR CS1=((ET1(2)**2/2*ET1(1))*SN)+((ET1(1)/2)*SNTS)-(ET1(2)*SNT)
GENR CS2=((ET2(2)**2/2*ET2(1))*SN)+((ET2(1)/2)*SNTS)-(ET2(2)*SNT)
GENR DCS=CS1-CS2
* THESE ARE THE ERRORS FOR THE N ESTIMATES
GENR START=.5
DO #=1,5
GENR NE1(#)=START
GENR NE2(#)=1
GENR CSERR(#)=CS1*(1-NE1(#))-CS2*(1-NE2(#))
GENR START=START+.2
ENDO
GENR START=.5
DO #=6,10
GENR NE2(#)=START
GENR NE1(#)=1
GENR CSERR(#)=CS1*(1-NE1(#))-CS2*(1-NE2(#))
GENR START=START+.2
ENDO
GENR START=.5
DO #=11,15
GENR NE1(#)=START
GENR NE2(#)=START
GENR CSERR(#)=CS1*(1-NE1(#))-CS2*(1-NE2(#))
GENR START=START+.2
ENDO
GENR PE1=(1.96*SE1(1))+ET1(1)
GENR PE2=(1.96*SE2(1))+ET2(1)
GENR ME1=ET1(1)-(1.96*SE1(1))
```

```
GENR ME2=ET2(1)-(1.96*SE2(1))
GENR PI1=(1.96*SE1(2))+ET1(2)
GENR PI2=(1.96*SE2(2))+ET2(2)
GENR MI1=ET1(2)-(1.96*SE1(2))
GENR MI2=ET2(2)-(1.96*SE2(2))
GENR CS1U=((MI1**2/2*PE1)*SN)+((PE1/2)*SNTS)-(MI1*SNT)
GENR CS2U=((MI2**2/2*PE2)*SN)+((PE2/2)*SNTS)-(MI2*SNT)
GENR CS1L=((PI1**2/2*ME1)*SN)+((ME1/2)*SNTS)-(PI1*SNT)
GENR CS2L=((PI2**2/2*ME2)*SN)+((ME2/2)*SNTS)-(PI2*SNT)
GENR DCSU=CS1U-CS2L
GENR DCSL=CS1L-CS2U
PRINT DCS DCSU DCSL
DO #=1,15
GENR DCSM(#)=DCS
ENDO
SMPL 1 15
FORMAT(4F12.3)
WRITE(22) DCSM NE1 NE2 CSERR / NAMES FORMAT
STOP
```