University of Alberta

FOREST REGENERATION STANDARDS AND TENURE: A PRINCIPAL-AGENT ANALYSIS

by

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ABSTRACT

A principal-agent model specifies a penalty function for delayed reforestation on crown lands in the Canadian prairie provinces:

$$\frac{[(\text{Foregone timber benefits} + \text{foregone non-timber benefits}) + \text{2nd attempt regen. costs}] + \text{monitoring costs}}{\text{Probability of detection}}$$

Using a timber supply model (MUNCHER), Annual Allowable Cut (AAC) is calculated using various reforestation delays for an Alberta case. Reduction in AAC due to these delays is multiplied by estimates of economic rent and discounted to estimate lost timber values. The model suggests penalties of approximately $92.25/ha/year delayed. These results imply that current penalties ($30/ha/year) may be too low. Suggested penalties are high due to the Allowable Cut Effect, which immediately decreases AAC in response to expected decrease in future timber yields. The sensitivity of the model to changes in stumpage prices suggests that penalties should be linked to stumpage prices.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Canada includes within its borders some of the most abundant and far-reaching forest and wilderness areas in the world. Since Europeans arrived in North America several centuries ago, the northern boreal forest has provided fuel, building materials, wood products, recreation, wilderness experiences, and other goods which have assisted in the economic growth and wellbeing of the nation. For much of this time, Canada's forests seemed limitless and inexhaustible; there was little motivation to replant trees after harvesting. However, in recent years concern about the state of Canada's forests has mounted. While the forest products industries stress the need for a dependable flow of timber from Canada's forests, increasing environmental consciousness has pointed out the importance of maintaining forested areas for diverse reasons, in addition to timber harvesting. The international community faces concerns about decreasing global forest cover, global warming, and loss of biodiversity. These concerns are underlined in the increasing media coverage given to the global impact of forest management activities. As the global population continues to expand, there is increasing concern that the world's supply of timber and wilderness areas will not be able to meet the escalating demands of this ever-increasing population (Natural Resources Canada, Canadian Forest Service, 1993).

Society receives a diverse flow of benefits from the forest, and many people and groups believe that this flow should be maintained for future generations. To make sure that forests will continue to provide these benefits, it has become widely accepted that harvested forests must be replaced, whether naturally or by replanting. As a result, reforestation has become one of the most important natural resource policy issues facing Canadians today.

Across Canada, as well as much of the rest of the world, there is a growing perception that the future health and supply of forest and wilderness areas must be ensured. However, at present, macroeconomic factors such as increasing government deficits and debt place constraints on achieving "ideal" forest management. Because of these constraints, provincial governments in the Canadian prairies are determined to exercise fiscal restraint. As part of fiscal restraint strategy, many provinces are considering the delegation of more responsibility to the forest industry for reforestation. As responsibilities are transferred, an incentive system is needed to encourage forest industry efforts toward forest regeneration. This thesis explores one possible incentive system and demonstrates its use for reforestation regulations in Alberta.

In Canada, provincial governments are presently responsible for setting and enforcing regeneration standards. While methods vary across the country, all provinces have forest renewal guidelines in place, and silviculturists and other forest managers continue to refine standards. This paper outlines the current regeneration standards in the prairie provinces, and develops a principal-agent model which can inform government policy-makers, by helping to ensure that reforestation standards are efficiently enforced and fulfilled.

1.2 Thesis objectives

The suitability of principal-agent theory for understanding and designing interactions between a regulatory agency and firms with managerial knowledge and responsibility has been investigated in a number of areas, such as pollution control, employer-employee relations, and landowner-tenant agreements. However, this theory has not been applied to the specific issue of forest renewal incentives. This thesis examines reforestation standards in the Canadian prairies using principal-agent theory to understand the relationships between government and the forest industry, and suggests some applications for the province of Alberta.

The primary objective of this study is to provide insight into the potential of principal-agent theory for interpreting and informing natural resource regulatory issues where there is a principal, or owner of a resource, and an agent (or agents) with managerial responsibilities. Most research done using principal-agent theory assumes either a 'command and control' arrangement, where government regulations compel private agents to comply with imposed standards of behaviour or results, or a sharecropping arrangement, where an agent's perception of future equity gains induces compliance with standards. This thesis explores these command and control measures and sharecropping incentives, but also enables an investigation of a combination of the two methods. These principal-agent arrangements are discussed as to their effectiveness for influencing forest companies' compliance with reforestation standards, and a principal-agent model is developed which may inform the development of forest management policy incentives.

A further objective of this study is to apply the principal-agent model to a specific case in order to examine what controls provincial governments could put in place to enforce the command that reforestation be undertaken according to provincial standards. To explore these controls, existing forest renewal standards in Alberta, Saskatchewan, and Manitoba are examined, and the social cost of failure or delay in reforestation operations undertaken by forest tenure holders in Alberta is investigated.

In the thesis, the effectiveness of current regulations and enforcement is evaluated, and changes to the current incentive system are suggested. This research may provide information about the construction of more efficient incentive systems which could persuade forest companies to act in the best interests of society. The results of the principal-agent model will be considered, with their implications for reforestation regulations in the Canadian prairie provinces.

1.3 Study Plan

This thesis is composed of six chapters. The second chapter provides an overview of principal-agent theory. A literature review describes the theoretical components of principal-agent models, and summarizes relevant natural resource applications of principal-agent theory. The third chapter outlines the institutional framework of regeneration standards in the prairie provinces. This includes a description of forest companies, Forest Management Areas, reforestation standards, and enforcement strategies in the three provinces. While similar in some respects, policies vary among provinces, and these variations are contrasted. This chapter gives some indication of the status quo of reforestation standards and possible future trends for regeneration policies.

Chapter four proposes a principal-agent model for evaluating forest regeneration in the Canadian prairies. Drawing on previous literature and theoretical models, combined with the relevant parameters set out in chapter three, this section develops an optimal penalty function which may be used to calculate a charge for forest companies who fail to comply with regeneration standards.

Chapter five adjusts the model to conform to existing standards and practices in Alberta. In this study, the government is assumed to be maximizing social welfare from the perspective of Potential Pareto Improvement (PPI). Because social welfare is diminished when reforestation is not adequate, losses to society from delayed reforestation are relevant to devise appropriate penalties to prevent damages. To approximate social welfare losses, chapter five calculates estimates of the social costs resulting from reforestation delay. Social costs are assumed to be composed of timber and non-timber costs, with emphasis placed on calculating lost fibre values. The timber costs are estimated using a Cut/Grow Timber Supply model called MUNCHER[1], where several harvest scenarios are modelled to predict the loss in Annual Allowable Cut resulting from delayed regeneration. Using these figures, and a range of economic rents (stumpage fees) for timber, the present value of the foregone stream of future timber benefits from the forest area[2] is estimated. The resulting numbers give rise to suggestions for policy directions which could be used to inform both government and industry as to the losses incurred when tenure holders fail or delay in meeting standards.

The concluding chapter summarizes the development of the research and the conclusions drawn from applying the principal-agent model to Alberta regeneration standards. This chapter also outlines conclusions and insights provided by the study of reforestation arrangements in the Canadian prairies. Finally, suggestions are proposed for further research into the area of optimal forest renewal regulations.

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[1]Beck, Barbara H. and James A. Beck, Jr., 1995.

[2]A detailed study of a management unit in the Weldwood FMA near Hinton, Alberta is conducted using actual forest data from the company's own silvicultural reports.

CHAPTER II

LITERATURE BACKGROUND

2.1. Introduction

This chapter contains a review of economics literature employing principal-agent theory. This theory seeks to understand those interactions which are observed but not fully explained by more standard economic theory, and provides guidance for the construction of contracts to influence principal-agent relations (Besanko and Sappington, 1987). The evaluation will begin by outlining the simplest scenario and assumptions, and then discuss and modify these situations to construct them as they might occur in typical forestry situations.

2.2. The principal-agent relationship

The basic framework for principal-agent relationships is the presence of two individuals or groups. The principal "owns" a resource, while the agent "manages" the resource, possessing superior management information and/or expertise to the principal. When the principal-agent relationship is applied to reforestation in Canada, the government is the principal and the forest companies are each agents.

The agent must choose an action from among different alternatives, and this action affects the principal as well as the agent. For example, a forest company may decide to exert a certain amount of effort towards reforestation operations. The resulting success or failure of their efforts can affect the company's profits from future timber, as well as social benefits under the jurisdiction of the principal, both of which are obtained from the forested area. This forestry example is similar to a sharecropping arrangement, where a tenant farmer's cropping decisions affect the revenue received by a landowner as well as the payment received by the farmer. The principal, at least in the most elementary cases, sets up payoff rules before an action happens which assign an amount to pay or to collect based on observations of the action's outcome (Arrow, 1986). For example, a landlord may rent to a tenant according to a prearranged share of the crop revenues or a fixed rent. In another example of principal-agent interactions, the production decisions and equipment selection of a firm which emits pollution as a product of its production process affect not only the firm's own profits but social welfare as well. The principal, which is a government regulatory agency acting on behalf of the public, sets up rules to encourage pollution abatement effort. These rules could assign the polluting company a penalty based on their efforts to control pollution or on the outcome of their efforts, measured by the amounts of pollution emitted (Cohen, 1987).

The assignment of a penalty or a bonus ideally approximates to the agent, in monetary form, the same costs or benefits of the action taken that are perceived by the principal. If the agent experiences these monetary costs or benefits, the agent's incentives will be exactly aligned with the principal's objectives, and the agent will choose the efficient level of effort as evaluated by the principal, who as a government is assumed to be looking out for social welfare. In this way, the agent behaves as the principal would if the principal possessed the agent's superior information and expertise.

2.3 Assumptions of the basic principal-agent relationship

The theoretical assumptions of the basic principal-agent case are: 1) both parties share the same initial beliefs about critical random variables; 2) both parties are risk neutral; 3) the agent's performance is publicly observable and the agent can be costlessly bound to carry out the terms of the agreement without the principal increasing monitoring or enforcement costs; and 4) there is one period, one principal, and one agent. In principal-agent theory, both principal and agent are assumed to be making their decisions optimally with respect to their constraints, and intended transactions are accomplished (Sappington, 1991). These assumptions will each be briefly discussed.

If both principal and agent share the same initial understanding of important variables affecting reforestation, they will agree among other things on the value of timber and other forest benefits, the costs of reforestation, and the probability of success of regeneration efforts. This assumption implies that both the principal and agent have equal information about any possible eventualities that might occur over the course of the tenure agreement.

If both parties are assumed to be risk-neutral, the agent is usually charged a fixed amount regardless of their behaviour. This means that the agent bears all the risk associated with random variables affecting the outcome. In forestry, under this assumption a penalty for reforestation failure would be based only on the outcome -- the area failing to meet regeneration standards. The agent would have to pay this penalty regardless of their effort toward regeneration. When the agent is risk-averse, the optimal contract will usually involve some risk sharing, where the agent might be charged a portion of the outcome based on their efforts. To illustrate, under this type of arrangement a risk-averse agent would not necessarily be forced to shoulder the entire burden of poor regeneration in a drought year.

If the agent's performance is publicly observable, the need for monitoring effort is not great, and the penalty or payment can be based on the observed outcome, assuming that all relationships among variables and the outcome are known. If the agent's effort must be discovered, the agreement can likewise be enforced if the agent's effort is costlessly confirmed by the agent and the principal (or some impartial arbitrator). However, in reality it is often difficult to precisely measure compliance. For example, while the prescribed areas may have been replanted, the trees may not be healthy, they may not grow at initially predicted levels, they may be susceptible to poor growing conditions, or necessary silviculture operations (thinning, for example) might be insufficient. This random element[3] is often not clearly understood, and the outcome is usually not a simple function of the agent's effort. Therefore it is much more difficult to construct contracts which take all variables into account and can costlessly measure the agent's performance.

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[3]Forestry examples of random variables may include quality of planting stock, suitability of standards to the particular microclimate in the area, diligence of planting crews, conditions in planting crew camps, weather variables, and soil types (Personal communication, Lorne Brace, Silviculture Consultant, May 1994).

The basic case assumes that the agent can be compelled to fulfil their part of the agreement without the principal increasing monitoring or enforcement costs. This assumption means that even though the agent might realize that their net returns may be much lower due to unforseen events (for example, low rainfall affecting seedling mortality), they cannot renegotiate or terminate the agreement reached with the principal, and no costs are incurred by the principal to prevent contract changes. Also, the payment or penalty arranged cannot be altered after the outcome is observed. However, in reality the agent may not be perfectly bound to the agreement. Firms could declare bankruptcy and renege on their contracts. Changes in the price of timber or in the cost of regeneration operations affect the forest company's net revenues and hence the feasibility of meeting costly regeneration requirements. The principal is also limited in their ability to commit to a contract. In fact, the agreements signed by forest tenure holders may not be considered contracts because of the right of the crown to alter some terms of tenure arrangements without compensation (Luckert, 1991). Although some of the clauses resemble contractual obligations, many changes to tenures do not entail "takings"[4], so no compensation is required if the government changes the regulations. Sometimes, but not always, the crown can be bound to pay compensation to forest companies. Changes to tenure agreements by provincial governments could result in altered reforestation regulations, as changing public opinion could urge

[4]"Takings" refers to situations where property is taken from an individual or group by the government or a third party, and where compensation is then due to the injured party. Because of regulatory power, the government may have the power to direct the use of property, including land, without paying compensation to the property owner, as in the case of changes to forest tenure agreements (Ackermann, 1988).

governments to make standards more rigorous, as seen in much of Canada in recent years. Therefore, monitoring costs may have to be altered after the initial agreement to ensure that the agent complies with any revisions to reforestation regulations.

The above assumptions of the basic principal-agent relationship create issues which will be examined in the following section in the context of forest renewal.

2.4 Issues behind the basic principal-agent assumptions

2.4.1 Asymmetric information

The principal-agent relationship becomes more complex when there is uncertainty about relevant information. Two broad categories of principal - agent uncertainty are dealt with in the literature. One is hidden action, or moral hazard; the other is hidden knowledge, also known as adverse selection. Hidden action is the situation where the agent's *action* cannot be directly observed by the principal. This hidden action is further complicated when the outcome is influenced but not completely determined by the agent's action (Harris and Townsend, 1981; Baron and Besanko, 1984; Arrow, 1986). For example, a forest company could attempt to plant trees, but climatic conditions, microclimate effects and other random factors could significantly alter the success of regeneration. Hidden knowledge is present when the agent has *information* which the principal does not have, and the agent decides on his/her action based on that information. The action itself might be seen, but the principal does not know if it is the most appropriate action to take (Besanko and Sappington, 1987).

2.4.1.1 Hidden action

Most hidden action cases involve the hidden effort of the agent. The agent is assumed to be averse to effort. That is, the marginal disutility of effort increases with effort. At the same time, effort has value for the principal because it can alter the outcome. In other words, the probability of realizing any given level of outcome is increased with greater effort. An example of this type of principal-agent interaction is the relationship between stockholders and management in a company. The stockholders are principals, who cannot fully determine whether or not their agent, the management, is making appropriate efforts on their behalf (Arrow, 1986). A similar example is the classic principal-agent example of sharecropping. The landlord prefers a contract which gives incentives for higher crop production to a straight wage rent, since the landlord cannot directly inspect the farmer's work. At the same time, the tenant, who does not want to bear extreme risks, wishes to avoid a fixed rent. Although incentives to produce would be maximized with a fixed rental rate, such a structure would expose the agent to all the risks of weather and market fluctuations (Arrow, 1986; Stiglitz, 1974).

Problems of hidden action are likely in the forestry setting where the government is the principal, and forest companies are agents. The government is trying to persuade industry to conduct regeneration activities, but they do not know for certain how much effort companies are putting into reforestation. The principal must therefore design the agreement to maximize incentives for the companies to reforest to the extent desired by the public.

2.4.1.2 Hidden knowledge

When hidden knowledge affects the principal-agent relationship, the agent has some information which the principal does not have. The agent uses this information to decide on actions. Given the asymmetry of information, the principal is unable to determine if the agent has used their information wisely from the principal's perspective (Arrow, 1986).

A common example of the hidden knowledge case is that of pollution control, where regulators are uncertain about firms' cleanup or abatement costs. The regulators attempt to get information about effort levels, new technology for abatement, the effectiveness of current technology, or the cost to the firm of implementation. The firm has the incentive to misrepresent these details in order to maximize profits. The principal must discover the approximate true levels of these variables in order to enforce pollution abatement (Roberts and Spence, 1976; Kwerel, 1977; Epple and Visscher, 1984; Baron, 1985a; Baron 1985b; Malik, 1993).

When applying this theory to forestry, the challenge is to design incentives which induce companies to give the government more information. Agents with management responsibilities may have more information than the principal from on site experience, and will have incentives to overstate the difficulty and costs of reforestation. Relevant information for the government might include a firm's reforestation capabilities, the type of land managed by the company and how successful reforestation efforts are likely to be.

2.4.2 Attitudes toward risk

An important element of principal-agent interactions is risk sharing. If the agent is risk-neutral, the bonus or penalty could be based entirely on outcome, and place all risks of non-performance on the agent. In this case, the asymmetric information would be inconsequential (Shavell, 1979; Besanko and Sappington, 1987). In sharecropping arrangements, the principal could keep a fixed amount of the produce for him/herself with the remainder of the benefits going to the agent. Under the same circumstances, the principal might pay a set amount of the costs, and the agent would be obliged to pay the rest. Because the agent would perceive the risks in the same proportions and relative magnitude as would the principal, both parties would have the same incentives, and accordingly the agent would behave in the principal's best interests (Shavell, 1979). In the pollution example, the government regulator would charge the firm a fixed penalty for polluting in excess of some regulated standard regardless of the firm's abatement efforts. This would give the firm incentives to avoid the penalty by abating pollution. If the incentives are correctly designed, the agent would react to the penalty by reducing pollution to the level desired by the principal.

Assigning all risk to the agent is not ideal if the agent is risk-averse. Simply assigning all risks to the agent is no longer optimal if the risks are large compared with the agent's wealth because agents may be assumed to be averse to comparatively large risks (Arrow, 1986). Generally, with a risk-averse agent, the penalty or payment amount will be a function of the agent's effort as well as the outcome, so that the risk will be shared with the principal (Shavell, 1979).

Risk may or may not be a concern when examining companies that are involved in forestry. If sufficiently low proportions of the companies' overall budgets are devoted to regeneration activities and the risks of these operations are pooled over large areas, the companies could be assumed to be risk-neutral for the purposes of this study. This issue is discussed in more detail in chapter four.

2.4.3 Monitoring the agent

The assumption that the agent's actions are publicly observable is rarely the case. Because of the obscurity of the agent's actions, economic literature dealing with applications of principal-agent theory has often recommended monitoring significant variables related to the agent's action[5] (Besanko and Sappington, 1987). The principal may thereby obtain information about the agent's unobserved effort in addition to that revealed by the outcome. For example, if the government checks silviculture operations to verify that companies are undertaking a satisfactory

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[5]This could include monitoring the agent's effort, random variables known to affect the outcome, or other relevant available information.

amount of regeneration effort, these details provide information about effort in addition to results and may increase the efficiency of the penalty or reward. If the monitoring reveals a reasonably accurate reflection of effort, then a portion of the firm's risk can be removed by making the fee or payment dependent on the monitored information as well as the outcome[6] (Besanko and Sappington, 1987).

2.4.4 Multiple agents and multiple time periods

This chapter has thus far focussed on a single principal, single agent, and a single time period. In the event that there are multiple agents for one principal or repeated interactions between agent and principal, different approaches may be necessary. In situations where there are multiple agents and only one principal, each agent chooses an action, and the outcome is a function of the combined actions. The principal cannot observe the individual actions, however it may observe other information, such as individual output or total output. The principal and agents might come to an agreement in advance which outlines the fees to be paid to the individual agents, or the penalties paid by the agents, as a function of the principal's observations (Sappington and Stiglitz, 1987). When there are many agents, the principal can discover hidden actions (or hidden information) if the uncertainty of the connection between the action and the principal's observation of the outcome is identical across all agents. In this case, the principal can

[6]However, if the monitoring is very inaccurate, basing the fee or payment on the additional information can *increase* the firm's risk (Besanko and Sappington, 1987).

approximately determine the individual efforts by comparing the combined outcomes of the different agents. The outcome of each agent's action could be compared with the average, or the ordinal ranking of the agents' outcomes could be used to infer actions, and this ranking could be used to calculate penalties or payments (Holmstrom, 1982). However, when there are only a few large FMA holders, as in the prairie provinces, as well as great differences in site conditions, these methods are not likely to effectively reveal agents' actions.

When there are repeated interactions between a principal and an agent, there are other ways to obtain information. For example, with most types of insurance the premium rate charged depends on past experience. This means that the amount of information on which the fee is based increases over time. If the principal wants the agent to take a particular level of action, the action is hidden for any single interaction. However, if enough actions are observed, the principal should be able to ascertain statistically whether or not the agent is achieving the desired level of action (Arrow, 1986).

However, under such a system, the agent might have incentives to adjust current actions so as to affect future regulations. For example, future regeneration standards might be made more exacting as companies are more successful at compliance with existing standards. Accordingly, companies might exert less than optimal effort in order to secure more lenient future standards. In addition, the forest company will realize that any investment it may make in more efficient or successful technology or silvicultural techniques will result in the government seeking information about its new cost structure and the effectiveness of the new technology in order to set regulations appropriate for the new efficiency level of the agent. As a result, when setting standards, the principal must take into account the effect of standards in earlier periods on the information that will be generated in future periods.

2.5 Conclusions

Principal-agent theory has been adapted to many types of contractual relationships. This chapter has briefly described examples of some of these relationships to illustrate the components of principal-agent theory. However, there have been few studies making specific application to forestry agreements. How well does this theory transfer to the forestry situation? Can this approach provide direction for regeneration contract arrangements? Principal-agent theory is clearly applicable for the Canadian prairies, with their large areas of public land[7] managed for the most part by large Forest Management Agreement (FMA) holders. Asymmetric information and imperfect knowledge of the forest companies' actions require that this economic theory be capable of encompassing these information asymmetries and providing guidance for designing reforestation policies.

[7]Ninety-four percent of Canada's forests are publicly owned (Natural Resources Canada, Canadian Forest Service, 1993, p. 8). In Manitoba, 94% of forest lands are owned by the province, with 97% provincially owned in Saskatchewan, and 87% in Alberta (Natural Resources Canada, Canadian Forest Service, 1993, pp.96-97).

The next chapter discusses reforestation standards in the prairie provinces. Specific information about the provinces allows chapter four to propose a principal-agent model for use in the designing of reforestation incentives.

CHAPTER III

CURRENT REGENERATION STANDARDS IN THE PRAIRIE PROVINCES

3.1 Introduction

Many individuals and groups in society today are insisting that current forest practices and regulations be designed so that regeneration is done quickly after logging. The effective maintenance of new forests will ensure that trees continue to grow for generations to come. The government as the representative of the public is responsible for carrying out public wishes in this matter. While there are various means of accomplishing forest renewal at present, there are regulations or standards of some sort in place in all the Canadian provinces. Reforestation regulations vary over provinces and Forest Management Agreements. In this section, existing regulations will be summarized for Alberta, Saskatchewan, and Manitoba.

3.2 Alberta[8]

To support sustained yield policies, Alberta has had mandatory reforestation since 1966. New reforestation standards, called "Free to Grow", were legislated on March 1, 1991. These standards require that at least four check-offs be done to make sure that growth is progressing at acceptable rates while the new forest is

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[8]This section is based on personal communication with Lindsay Kerkhoff, Lands and Forest Service, Edmonton, Alberta (1994-5); the Province of Alberta Forests Act Timber Management Regulation (1994); and on the Alberta Regeneration Survey Manual, Alberta Forestry, Lands and Wildlife (1992).

being established. Forest companies are required to submit a reforestation plan to the government. The plan must meet government requirements, and then must be implemented. Over the first fourteen years of the new forest on coniferous and mixedwood cutovers, companies must meet the standards of: 1) an informal site preparation survey; 2) an Establishment and Performance survey; and 3) a Free to Grow check-off.

3.2.1 Informal site preparation survey

Appropriate site treatment within two years of harvest is mandatory. If harvesting activity does not result in a suitable site for tree establishment, scarification is required. Site treatment is usually followed by seeding (naturally or by humans) or planting seedlings. The provincial government conducts informal surveys to determine if sufficient reforestation treatments have been performed. If treatments are inadequate, companies must retreat the area to meet the standards[9]. Penalties or fines are imposed after two years on cutblocks where treatments have not been completed and these fines are assessed for each month that treatments are late, as summarized in Table 3.1.

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[9] To date, over 90% of the blocks meet the standard after the first retreatment (personal communication, Lindsay Kerkhoff, 1995).

Table 3.1 Alberta penalties for failure to meet two-year reforestation requirements

Areas cut before March 1, 1991	
Failure to carry out silviculture treatment within 2 years of harvest	$25 per hectare for each year of contravention
Failure to carry out necessary reforestation operations	$25 per hectare for each year delay in carrying out necessary reforestation operations
Areas cut on or after March 1,1991	
Failure to carry out reforestation treatments within 2 years of harvest	$2.50 per hectare for each month of contravention

Source: Province of Alberta Forests Act Timber Management Regulation, February 24, 1994, p. 51.

3.2.2 Establishment and Performance surveys

Two independent surveys monitor the success of the initial two-year treatment and any subsequent retreatments needed to ensure that replanting is accomplished. These are the Establishment Survey (which is 4-8 years after harvest) and the Performance Survey (8-14 years after harvest). For deciduous cutovers, the Establishment Survey must be conducted 3-5 years after harvest, and no Performance Survey is required.

To ensure that reforestation is succeeding, forest companies may hire contractors to survey their cutblocks and report on the state of forest renewal to the government. The survey system employed requires plots to be distributed evenly throughout the cutblock. The number of plots measured is dependent on the block size, but most cutblocks fall in the 4.1 to 24.0 hectare range and require at least 64 plots[10].

Ten percent of the Establishment and Performance surveys submitted to the provincial government are randomly checked for accuracy and adherence to the specifications outlined in the Alberta Regeneration Survey Manual. Each "Check Survey" involves verifying the information on at least 25 plots (depending on block size) (Alberta Forestry, Lands, and Wildlife, 1992). Under the pre-1991 standards, companies were given a rebate of 25% of the cost of doing the survey. This rebate was given as an incentive for companies to use the Alberta Regeneration Survey System to assess cutblocks, and to use certified surveyors to do the surveys[11]. The rebate applies only to cutblocks harvested prior to March 1, 1991.

If a forest company fails to submit an acceptable Establishment or Performance survey, then penalties will be assessed following the end of the year in which submission of the report was required (see Table 3.2). These penalties are repeated each year surveys are late, in addition to penalties from previous years, until acceptable submission of the report is received. If the survey reveals that reforestation operations have been inadequate, or that regeneration has been less than satisfactory, then the company is required to carry out retreatment efforts at their own expense within one year after the failed survey. The block is then re-surveyed within three years after retreatment. This process must be repeated until

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[10]The Alberta Land and Forest Service is confident that with the number of plots checked, and the design of the survey system itself, it is easy to detect when a surveyor tries to 'fudge' results (personal communication, Lindsay Kerkhoff, 1995).

[11]At present, all companies have to use the Alberta Regeneration Survey System. In addition, while it is not mandatory, all companies currently use certified surveyors (personal communication, Lindsay Kerkhoff, 1995).

the cutblock is brought up to regeneration standards. There are no explicit penalties for failing to reforest to standard, only for failing to turn in an acceptable reforestation survey. Implicit penalties exist, however, in that the company is required to make any expenditures necessary in order to bring cutblocks up to standard, as revealed by the repeated Establishment or Performance Surveys.

Table 3.2 Alberta penalties for failure to submit an acceptable Establishment or Performance Survey*

Month following end of year in which acceptable submission of report was required	Penalty per hectare
May	2 cents for each day of the month until submission received
June	62 cents plus 5 cents for each day of the month until subm'n received
July	$2.12 plus 7 cents for each day of the month until subm'n received
August	$4.29 plus 10 cents for each day of the month until subm'n received
September	$7.39 plus 10 cents for each day of the month until subm'n received
October	$10.39 plus 10 cents for each day of the month until subm'n received
November	$13.49 plus 10 cents for each day of the month until subm'n received
December	$16.49 for subm'n received on any date in the month
January-April	$17.30 for subm'n received on any date in the month

* Note: this does <u>not</u> mean failure to regenerate to standard.

Source: Province of Alberta Forests Act Timber Management Regulation, February 24, 1994, p. 51-52.

By themselves, the penalties listed in Table 3.2 may not bring about effective reforestation, if companies simply choose to submit surveys reporting reforestation failure, and then do not undertake reforestation operations to redress the failure. However, there is a cost to doing these surveys properly. Therefore it may become more costly to continue surveying than to carry out the necessary reforestation treatments. Also, while not specifically stated in these penalties, the provincial government wields additional motivation for regeneration in the form of potential reductions in AAC if companies are found to be deliberately submitting surveys which continuously report reforestation failure in lieu of completing required reforestation operations.

3.2.3 Free to Grow check-off

After the Establishment and Performance surveys have been submitted, companies must obtain a "Free to Grow" designation in order to fulfil the final reforestation requirements for their harvest area. When trees are considered "Free to Grow", they are growing free from competing vegetation. Until cutover areas meet stocking and height requirements and are free from competing vegetation, the forest companies must strive to meet the standards or retreat the area until regeneration is up to standard.

Alberta has made progress in promoting and experimenting with efforts to regenerate forests. Nevertheless, governments and industry continue to update and enhance reforestation standards. Compliance with existing standards has been satisfactory, however the system is being re-evaluated and refined. By 1996, the Alberta government hopes to have a revamped system of regulations in place, giving forest companies more responsibility for reforestation and monitoring.

3.3 Saskatchewan[12]

In Saskatchewan, forest renewal standards are less specifically defined than in Alberta. The Saskatchewan Forest Act does not deal with reforestation. However, a new Forest Act is scheduled for 1995, and this document is expected to include regeneration requirements.

The three major forest companies in Saskatchewan are Weyerhaeuser Canada, L&M Wood Products, and Norsask. They signed their Forest Management Licence Agreements (FMLAs) September 9, 1986, March 6, 1987, and June 17, 1988, respectively. The reforestation activities required of these companies by the Saskatchewan provincial government are very similar, differing only by a few words in each document[13].

Currently, companies are required to maintain the productivity of their forest, which includes forest renewal. According to their FMLAs, companies must undertake suitable reforestation efforts to establish new timber growth. Stocking standards have been determined in order to maintain the long run sustained yield (LRSY) of the License areas. Companies are responsible to make sure that the

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[12]This section is based on personal communication with Andrea Atkinson, Forest Branch, Prince Albert, Saskatchewan.

[13]L& M Wood Products (1985) Ltd. Forest Management Licensing Agreement, 1987; Norsask Forest Products Inc. Forest Management Licensing Agreement, 1988; and Weyerhaeuser Canada Ltd. Forest Management Licensing Agreement, 1986.

LRSY of their FMLAs is not diminished by their forest operations while their agreements are in effect.

Each new Forest Management Licence Agreement signed (since 1986) contains the requirement that FMLA holders put dollars into a "Forest Management and Renewal Fund", and contribute sums of money for every cubic metre of wood harvested in their areas (see Table 3.3). The holders can only spend the money on approved forest activities or treatments[14]. Companies may not run deficit balances on their Renewal Funds; even though these funds may not cover all costs of potential reforestation and forest management, additional reforestation expenses must be paid for out of company profits. However, if the fund is not depleted in a one-year period, the remaining amount may be carried into the next year. The provincial government has the right to check the books, and the government conducts an annual audit. The companies report annually how the money from these funds was spent. If the activities are questionable, the government can require that the money be returned to the fund. To date, there have only been a few cases where companies have had to put the money back into the fund when challenged.

[14]Smaller quota holders pay a fee as well which goes into the fund, or into general revenues if they are harvesting areas outside an FMLA.

Table 3.3 Saskatchewan Renewal Fund contribution amounts

	Softwoods	Hardwoods
L&M Wood Products	$1.30/m^3$	$0.50/m^3$
Norsask		
Core Area	$2.30/m^3$	$0.50/m^3$
Reserve Timber Supply Area	$1.15/m^3$	$0.30/m^3$
Weyerhaeuser		
Core Area	$4.00/m^3$	$1.40/m^3$
Reserve Timber Supply Area	$2.00/m^3$	$0.85/m^3$

Source: Andrea Atkinson, Forest Branch, Prince Albert, Saskatchewan

According to the agreements, the Renewal Funds will be evaluated every five years. The government of Saskatchewan and the companies can mutually agree to modify the amounts to be contributed to the fund to indicate more closely the amounts projected to be spent on reforestation and other forest management operations, or to offset a surplus or deficit in the Renewal Fund. Each year, the companies must submit a written report demonstrating the amounts and sources of all contributions to the Renewal Funds and the amounts and applications for any withdrawals from the Renewal Fund. The provincial government has access to the records of the companies so that they can verify the accuracy of the annual reports.

Companies are required to submit a reforestation plan to the Forestry Branch by a specific date (before April 1 for Weyerhaeuser, before April 30 for Norsask and L&M). This plan outlines information on the areas to be treated, the types of treatment planned, and a detailed report of the previous year's activities. Since different forest sites require diverse treatments, varying intensities of treatment, or perhaps no treatment, adjustments may be made to the reforestation plans without any further approval by the provincial government. Companies are not required to obtain provincial approval for their reforestation plans[15].

Stocking standards are in place, based on the species to be reforested, but Saskatchewan does not currently have "Free to Grow" standards. Forest companies are responsible for doing regeneration surveys, which can be paid for out of the Renewal Fund. Companies must carry out regeneration surveys within three growing seasons following harvest. If manual tree-planting is required to maintain LRSY, the company must conduct plantation assessments within three years of planting. Based on these surveys, reforestation treatments must result in the satisfactory establishment of the new timber growth to provincial stocking standards. Currently, monitoring of company survey reports by the provincial government is less than complete[16], as Saskatchewan no longer has regeneration crews to check on the success of reforestation[17]. There are no formal monetary rewards or penalties associated with regeneration activities. As a last resort, however, if companies do not meet reforestation standards, they can lose their FMLA.

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[15]There have been some discussions about making the reforestation plan part of the Operating Plan (which has to be approved by the Minister before any harvesting begins), but to date nothing has been finalized (personal communication, Andrea Atkinson, 1995).

[16]Personal communication, Larry Stanley, Forest Branch, Prince Albert, Saskatchewan.

[17]According to Andrea Atkinson, Saskatchewan lost their provincial regeneration crews in the spring of 1987, after Weyerhaeuser signed to the first of the new FMLAs.

To aid forest companies in meeting the regeneration requirements, the government provides seed or planting stock to the companies free of charge[18]. If a company has a nursery and therefore uses its own seed or planting stock, the government reimburses the company for the cost of providing these supplies, at a price agreed upon by government and the company.

Because the FMLAs were all signed so recently, it is difficult to assess the effectiveness or appropriateness of regulations. The first five-year review was too early in the life of the new forests to tell whether regeneration is satisfactory. It was hoped that the next 5 year review, in 1996, would provide a more realistic assessment. However, Saskatchewan is undergoing a review of its FMLAs, and there may not be a new 5 year review, as first conceived[19].

3.4 Manitoba[20]

Three Forest Management Agreements have been established in Manitoba -- Pine Falls Paper Company (formerly Abitibi-Price), Repap Manitoba, and Louisiana Pacific. Each company's Forest Management Agreement includes their obligation to reforest sites to forest renewal standards established by the Province. Forest Renewal Trust Funds created to pay for forest renewal activities receive contributions based on the volume of wood harvested by each company.

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[18]This provision may be changing (personal communication, Andrea Atkinson, 1995).

[19]Personal communication with Steve Price, Regional Development Division, Northern Forestry Centre, Canadian Forest Service, September 1994.

[20]This section is based on personal communication with Jeff Delaney, Silviculture Forester, Manitoba Forest Branch, 1995.

New Forest Renewal Standards have been set using a four-step approach[21]. First, the number of stems per hectare found in mature forest stands must be determined. (The number of stems required comes from stand stock volume tables developed from temporary sample plot data.) Second, appropriate survival or mortality rates are assigned for conifers and hardwoods, based on literature reviews. Third, calculations determine the number of stems required to result in acceptable survival rates at age seven. Stocking:density relationships have been developed for naturally regenerating and planted sites from more than 1500 surveys performed on more than 100,000 hectares. Finally, to arrive at the Forest Renewal Standard for the area, regressions must be performed on the stocking and density values. In this way the stocking levels required to achieve the number of stems required at age seven are determined.

There are three sets of standards that display the differences between the stocking:density relationships observed on planted softwood sites, naturally regenerating softwood sites, and naturally regenerating hardwood sites. Free To Grow Survey methods have been developed for Manitoba and related standards will be developed in late 1995.

Since the establishment of the first Forest Management Agreement in 1979 more recent agreements (1989 and 1994) have incorporated greater safeguards to ensure reforestation standards are achieved. The specific regeneration requirements stipulated in the FMAs are as follows. The first agreement established

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[21]The Forest Renewal Standards continue to employ the systematic stocked plot survey methods established in 1986.

in 1979 was with Abitibi-Price, now Pine Falls Paper Company. This agreement requires that harvested areas achieve forest renewal standards by the tenth year after harvest. There are no specific penalties or incentives mentioned in the agreement. The second agreement was established with Repap Manitoba in 1989 and states that the company must meet forest renewal standards by the seventh year after harvest. Sites that do not meet these standards must be reforested at the company's sole expense by year ten. There are no explicit penalties if reforestation does not take place by year ten; the company is still expected to reforest to standards at its own expense after this deadline. The third agreement was established with Louisiana Pacific in 1994. It states that the company must survey all areas by the seventh year after harvest and ensure that all areas meet forest renewal standards by year ten or reforestation activities must be performed by the province which would then charge the company two times the cost of treatments.

The province trains and licenses company or contract regeneration surveyors, and these surveyors check on the success of reforestation treatments. Company representatives check a minimum of ten percent of all surveyors' work and report their findings to the province within ten working days of the first of the month. The province conducts periodic informal checks to confirm that the company check surveys are accurate, but there are no penalties charged if the companies are found to be misrepresenting the state of forest renewal on their cutblocks. The Silviculture Forester may recommend that formal inspections be performed to verify the company's surveys have been done correctly or that certification of the company regeneration surveys may proceed.

3.5 Conclusions

In this section, existing forest renewal standards in the three prairie provinces have been described. While each has a system for attempting to ensure reforestation, there are differences among the provinces.

The purpose of this research is to investigate the use of principal-agent theory for encouraging optimal forest regeneration. In chapter four, the features described above for the three provinces will be incorporated into a principal-agent model which will prompt companies to make optimal effort towards reforestation.

CHAPTER IV

A PRINCIPAL-AGENT MODEL FOR PRIVATE REFORESTATION EFFORTS ON PUBLIC LAND

4.1. Introduction

This section will summarize the relevant aspects of regulations governing reforestation in the Canadian prairies, thereby giving direction to the construction of a principal-agent model. Based on the current regulations presented in chapter three, and the general characteristics of principal-agent models discussed in chapter two, a model will be devised for application to Alberta forest management.

4.2. Characteristics of the model

Assume that the principal is the government, representing society, with regulatory authority over operating forest companies. The agent is the forest company that is required to meet regeneration standards. Hidden action exists in the forest renewal arrangement in that the firm must undertake some costly effort to reforest to standards, but the government is unsure of the actual level of effort put forth by the companies. There is also hidden information, because firms might know more than the regulators about the effectiveness of a specific silvicultural investment on a particular site within their tenured area. The following sections will address the issues identified in chapter two.

4.2.1 Multiple agents

There is more than one agent currently operating in the forests of the prairie provinces, as outlined in chapter three. The outcome of reforestation across the prairie provinces is a sum of the reforestation successes within each FMA. However, there are individual agreements reached with each forest company, and each site within a given FMA is expected to meet regeneration standards. While the provincial governments are concerned with achieving a particular level of forest regeneration over the whole province, the governments of the prairie provinces still deal with each company's responsibilities individually[22]. In this study, we will assume that the agents are acting independently, and the results of the actions of one agent do not impact the actions of the other agents. Because each area can be viewed separately, there is no need to estimate the actions of one agent by comparing the combined outcomes of the different agents (as discussed in section 2.4.5).

4.2.2 Multiple periods

The time period over which a forest company is responsible for establishing a new forest is approximately ten to fourteen years following harvest of the area. Despite this time frame, there are not 'multiple principal-agent games' during these years. For example, while several checks and surveys are required over the life of

[22]Personal communication with Lindsay Kerkhoff, Alberta Land and Forest Service; Andrea Atkinson, Saskatchewan Forestry Branch; Jeff Delaney, Manitoba Forestry Branch, February 1995.

a new forest in Alberta, each survey is not the same scenario repeated. Rather, for each survey (replanting, Establishment, and Performance) there are different expectations and a different starting point. Therefore, the reforestation requirements and the monitoring of standards would appear to be a 'single game', ten to fourteen years long.

Forest regeneration regulations may be viewed as policy prescriptions, that set up rules for one round of the game. Given that a policy's life is probably less than ten or fourteen years, and that new information and interactions will likely be in place before the principal-agent game is completed, it is not necessary to consider these principal-agent interactions as a repeated game. As a result, a multiple period principal-agent format will not be used when developing a model of regeneration activities.

4.2.3 Future equity or command and control

A key variable in this problem is the degree to which reforestation is accomplished using "command and control" regulations, as compared to the situation where companies voluntarily make efforts toward regeneration because there is some portion of future benefits from the forest, as in sharecropping, which will accrue to the company. Given the length of the forest rotation and the uncertainty of government policy regarding forest tenures and stumpage fee systems which frequently do not distinguish between old growth stocks and flows created and maintained, the expected Net Present Value (NPV) of reforestation activities is probably very low. Therefore, it is unlikely that forest companies have incentive to voluntarily ensure that future crops are in place (Luckert and Haley, 1989).

Even if tenures were structured to facilitate future equity in growing trees, there are reasons to believe that investment in reforestation may occur at a sub-optimal level. Only with a very low discount rate do silvicultural activities become profitable[23]. A social rate of discount is perhaps sufficiently low to realize some benefit in ensuring that forests are replaced in the future, but private rates of discount may be too high for forest companies to undertake reforestation of their own accord, in the hope of capturing the profits of future harvests on these sites[24]. This divergence between social and private discount rates is one justification for provincial governments, on behalf of society, to attempt to ensure that reforestation is accomplished on public lands. Another justification is the presence of positive externalities from non-timber values associated with growing trees. The benefits gained by society from these positive externalities are not equally received by the private company. Since there are less benefits flowing to the firm, they may

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[23]According to Anderson (1979), Veeman (1986), and Benson (1988), intensive management costs are very high, and when applied to Canada's forested lands with their low average productivity, the NPV of intensive silviculture treatments are very low or negative. Only when lower discount rates are used do such treatments result in positive NPVs.

[24]The discount rate is the weight placed on future events. Discounting allows us to compare the value of costs or benefits at different points in time. The present value of an amount is the future amount, expressed in terms of its value today. A high discount rate implies that the future is discounted more heavily compared to the present, and a lower discount rate implies that the future is discounted less, while still valued less than the present. In this way, at a discount rate of 0%, the future and the present are valued equally.

Economic theory suggests that the social rate of discount should be lower than the private rate. This divergence exists because it is assumed that the government on behalf of society has a responsibility to look out for the wellbeing of future generations and to consider future events more carefully than does the private sector. Since the future benefits derived from forests are comprised of public benefits from forest lands as well as private (forest company) benefits, social welfare may be increased when forest regeneration takes place. In the case of forest renewal, it is therefore appropriate to use the social discount rate rather than the private discount rate.

underproduce the good which provides the positive externality.

The lack of assurance of future equity and the uncertainty of tenure combine with the already higher private rate of time preference perceived by private industry, resulting in a low present value of future revenues. This result makes it unlikely that forest companies will invest sufficiently in silvicultural activities to provide the socially optimum level of reforestation.

There may be some cases where the forest companies might recognize some future equity, if there is any percentage of future benefits of reforestation which may be captured by the firm. For example, under an even flow constraint like that found in the prairie provinces (Natural Resources Canada, Canadian Forest Service, 1993), the "allowable cut effect"[25] begins immediately, as current harvest limits are adjusted in light of expected future timber crops on the forest area. Therefore the companies could obtain some immediate benefits from current regeneration operations, and may undertake reforestation for this reason. However, Luckert and Haley (1995) have identified several reasons why ACE incentives may not promote silvicultural activity, and therefore should not be relied upon to produce optimal forest regeneration.

Whether reforestation is stimulated by a command and control situation or a promise of future equity is a matter of degree -- a continuous variable rather than a discrete choice. The model developed in chapter five takes this relationship into

[25]The "allowable cut effect" is defined by Schweitzer et al. (1972) to mean an "immediate increase in today's allowable cut which is attributable to expected future increases in (timber) yields".

account, and allows for structuring reforestation incentives according to the degree of future equity held by the forest industry.

4.2.4 Effort or outcome

When developing incentives for firms to reforest, a contract can be designed with a penalty function that determines the amount that a company must pay the government if it does not reforest to required standards[26]. This penalty would be based on outcome -- the size of the area that is not adequately regenerated. Alternatively, a penalty function could be devised that depends on the level of effort expended by forest companies toward achieving adequate reforestation. Such a penalty could be constructed as a negligence standard, where the penalty would be zero if efforts were equal to or greater than some critical level, and therefore the forest company would only be penalized if the failure to regenerate successfully was "caused" by the company's lack of effort. A combination of the above penalty function options could also be used. The overall penalty could be determined according to the outcome (that is, reforestation failure), with an additional penalty imposed if effort was below some predetermined level. The type of penalty chosen depends on the costs of monitoring the system and the agent's attitude toward risk.

Monitoring outcome alone will place all the risk of reforestation failure on the firm, if the penalty function is set correctly. As noted above, natural disasters may

[26]Alternatively, this contract could include a bonus the government pays if the company does meet standards. However, this does not appear to be politically feasible, given the trend toward spending reduction, and the public opinion that forest companies should be made responsible for replacing forests after harvest as a condition of their right to harvest timber on public lands.

result in reforestation failure through no fault of the forest company, who undertook a "reasonable" amount of effort to ensure forest regeneration. If only outcome is measured, the firm will pay the penalty for failure even if it was not "their fault". This practice, it may be asserted, is not fair! By contrast, the forest company could do everything wrong when establishing seedlings, and "luck out" due to ideal weather conditions. However, if a firm is risk-neutral, natural disasters or windfalls should not make a difference to the amount of effort they are willing to exert to reforest to standards. The company will absorb this cost as part of their expectations. If a company is risk-averse, some risk-sharing will be necessary to enable them to make optimal effort toward forest renewal. Effort must be monitored, and a negligence standard may be required (Holmstrom, 1979; Shavell, 1979). Therefore, it is essential to determine whether the firm is risk-neutral, or whether it is risk-averse. If forest companies are risk-neutral, monitoring outcome alone will not affect the firm's decision, while effort should be monitored in order to ensure that risk-averse companies are carrying out appropriate regeneration operations.

Risk aversion for individuals or groups can be indicated by two interrelated characteristics (Sugden and Williams, 1978). The first factor is the magnitude of the potential change in wealth, or the proportion of wealth at stake for the proposed endeavour. Usually, individuals or firms will be risk averse when large portions of their wealth are at risk. An additional characteristic is the independence of risks associated with different projects. If an individual's wealth changes by the same amount regardless of which project is chosen, then that person is more likely to be risk neutral with respect to initiating one project compared to the other.

Across the prairie provinces, the forest industry is characterized by a small number of large, integrated firms. These firms are diversified and therefore the costs and returns of projects can be spread over a large number of individual shareholders and smaller components of the large companies. For such large, diversified firms, only a large change in a company's net revenues would have significant effects on the profitability or the feasibility of individual enterprises or investments such as reforestation expenditures.

As an example of the sizes of reforestation expenditures, in 1991, Alberta forest industry expenditures on silviculture were $8.902 million, representing 1.8% of the $489.3 million spent on wages, salaries, and total forest management[27]. Forest regeneration expenses are a smaller component of silviculture expenditures, which also encompass spending on site preparation, tending, marking, and silvicultural support (Canadian Council of Forest Ministers, 1994, p. 122). The addition of harvesting, processing, transportation, and other costs would further lower the proportion of expenditures on forest regeneration by Alberta industry. These numbers indicate that forest industry spending on regeneration activities is relatively small.

In Alberta, forest industry firms are large and vertically integrated, and regeneration expenses are spread over a large forest management area and over the much larger scope of the firm's total activities. The structure of the industry,

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[27]Natural Resources Canada, Canadian Forest Service, 1993, page 97.

combined with the above percentages of expenditures on reforestation, indicate that it is reasonable to assume that forest companies in the prairie provinces are risk neutral with respect to regeneration.

With the assumption that tenure holders are risk neutral, the relative costs of monitoring effort and outcome (that is, size of reforestation failure) will determine which indicator will be used in the model. Discovering effort would likely be much more difficult, time-consuming, and costly than monitoring outcome. Based on these differences in costs, a strict liability standard (based on outcome alone) would be more appropriate for monitoring forest tenure holders, and might yield higher net social welfare then a penalty which includes the measurement of the agent's effort. As a result, the penalty developed in the next section will be based on outcome.

There are additional reasons why a strict liability standard is preferable to a negligence standard. There may be some technological advances that would reduce the probability of reforestation failure or the extent of the failure for a given effort level. The strict liability standard provides incentives for the company to invest in research and development to find better technology or techniques for regeneration, since the company would be required to pay all the costs. If a negligence standard were used, then there would be less incentive to invest in research and development because the specified level of effort is based on current technology.

4.3 Optimal regeneration contracts: a principal-agent model

The model used as a basis for assessing the forest regeneration situation was developed by Epple and Visscher (1984) and further adapted for use in oil spill regulation by Cohen (1987). Cohen examined government monitoring and enforcement of regulations intended to prevent the occurrence of oil spills and the resulting pollution. The Cohen principal-agent model investigates and suggests an optimal enforcement strategy for a government regulator. The model proposes an enforcement strategy which provides the firm with incentives to spend time and money to prevent oil spill pollution. When compared with other principal-agent models, this approach was identified as the most readily adaptable to the Canadian forestry situation (see Chapter 3). The Cohen model was designed for several agents with one principal (a government regulatory agency), but each agent was dealt with separately. The firm had to make a costly effort to meet regulations, but this action was hidden from the principal. A strict liability penalty function based on outcome (area polluted) was designed, rather than a negligence standard depending on monitoring the agent's effort. Because of the similarities in the parameters of the two situations, the Cohen model was selected as a starting point for applying a principal-agent framework to forest regeneration.

To demonstrate how such a model might be applied to forest regeneration, let x indicate an area which has not been reforested. This inadequacy might be due to replanting or natural regeneration failure, or perhaps no replacement of the trees whatsoever. The government regulators (the principal) require that the harvested area be reforested to provincial reforestation standards. While the forest company is not able to entirely control the success of reforestation, it can make some level of effort, *e*, to increase the likelihood of successful regeneration. If reforestation does not succeed, the probability that the regulators will discover the situation is $P_D(x,m)$, where *m* is the level of government resources assigned to detection of infractions. If the company's reforestation treatments are found to be failing, the government could impose a penalty of $T_D(x)$.

The company may experience some private loss, $v(x)$, equal to the value of lost resources due to failure to reforest. This variable is distinguished from the cost of making the initial reforestation effort, *e*, in that $v(x)$ is the loss of any future benefits from regenerated stands the tenure holder might hold, from failing to reforest. That is, $v(x)$ is only positive if the crown is not collecting the full economic rent of future stands of timber.

Using the above notation, and assuming risk neutrality, the company's expected profit (loss) could be written as:

$$EU(e) = -\int_x \{ v(x) + P_D(x,m)T_D(x) \} f(x,e)dx - e \tag{4.1}$$

e	- effort expended by the forest company; also understood as the dollar value of the company's initial reforestation effort;
$EU(e)$	- expected profit, dependent on effort;
x	- area which has not been reforested;
$v(x)$	- value of company's lost resources due to reduced future timber yields;
m	- amount of government resources devoted to detection of infractions;
$P_D(x,m)$	- probability that reforestation failure will be detected, dependent on x and m;
$T_D(x)$	- penalty for failure to reforest, dependent on the size of x;
$f(x,e)$	- a probability distribution function which has outcome and effort as arguments.[28]

[28]Expected profit, $EU(e)$ and the function $f(x,e)$ could also be dependent on random elements.

Now assume that the principal is seeking to maximize the net benefits derived by all parties[29]. The government could maximize social welfare by minimizing the sum of: timber "damages" from failed or delayed reforestation $D_T\,[(1-r)x]$; non-timber "damages" from failed or delayed reforestation $D_N\,[(1-r)x]$[30]; reforestation costs $C(rx)$[31]; private resource loss $v(x)$; prevention expenditures e; and monitoring expenses m. The principal's expected utility, taken as a measure of social welfare, can be written as:

$$(4.2)\; EW(e, m, r) = -\int_x \{ D_T[(1-r)x] + D_N[(1-r)x] + C(rx) + v(x) \} f(x,e)dx - e - m$$

$EW(e,m,r)$	- expected social welfare;
r	- portion of the harvested area that must be treated after an initial failure to bring it up to standard;
$D_T[(1-r)x]$	- timber "damages" (social costs) from failed reforestation;
$D_N[(1-r)x]$	- non-timber "damages" (social costs) from failed reforestation;
$C(rx)$	- reforestation costs incurred to bring an area back up to standard after an initial reforestation failure.

The portion r is chosen by the principal so that, given reforestation failure of size x, $D_T\,[(1-r)x] + D_N\,[(1-r)x] + C\,(rx)$ is minimized. In other words, the optimal size of r would derive from making the marginal damages from reforestation failure equal to the marginal costs of regeneration. The government's decision about r

[29]In the forest renewal situation, it is assumed that the government is a principal with interest in achieving a Potential Pareto Improvement (PPI), that is, maximizing the net benefits to be received over all parties. It is not acting according to some other type of incentive as we might see in reality.

[30]These might include benefits from timber, aesthetics, recreation, wildlife, biodiversity, existence value, or spiritual aspects of the forest.

[31]These refer only to the costs incurred in re-doing the reforestation after the first attempt is unsuccessful. $C(rx)$ does not refer to the costs incurred in first attempting to meet regeneration standards, which are represented by the variable p.

would depend on how costly reforestation is and how undesirable it is to let areas remain denuded. For a failure of size x, the regulators might stipulate that $(1-r)x$ can remain untreated and rx will have to be done over again.

From formula (4.2), it can be seen that no fine ($T_D(x)$) is included in the social welfare function. Given the principal's objective of maximizing net benefits to all parties, the principal is not intending to maximize the amount of the fine collected from companies which do not meet standards. The fine is a transfer of wealth, and society's marginal benefit from reforestation does not depend on the amount of the penalty imposed. However, the amount of the fine does affect the agent's incentive to meet standards, and may therefore impact the outcome.

In seeking to maximize social welfare, the government would try to design a penalty system which results in a desired level of effort, detection expenses, and retreatment area to maximize (4.2). To determine the optimal level of e, we take the first derivative of (4.2) with respect to effort, to derive the marginal social benefit:

$$(4.3) \qquad - \int_x \{ D_T [(1-r)x] + D_N [(1-r)x] + C(rx) + v(x) \} f_e(x,e)\, dx = 1$$

In this way, the marginal social benefit of an increased level of reforestation effort is equated to its marginal cost (here normalized to 1). However, since the government has limited control over the reforestation efforts and expenditures a company makes, an arrangement must be devised so that the company achieves its maximum profits and private benefits (modelled by equation (4.1)) by making the socially optimal level of effort. This may be done with the following penalty function:

$$T_D(x) = \frac{D_T[(1-r)x] + D_N[(1-r)x] + C(rx) + m}{P_D(x,m)} \quad (4.4)$$

If (4.4) is substituted into (4.1), the result is (4.2). Given this penalty, the company would expend the level of effort *e* which maximizes social welfare.

In order for the penalty to work, $P_D(x,m)$ must be greater than zero. In the model which follows it will be assumed that *m* is exogenously determined. That is, for some given level of *m*, an optimal penalty will be derived. If all failure to reforest is detected, (that is if $P_D(x,m) = 1$), then (4.4) would imply that the expected penalty should be set equal to the expected "damages" from failure to reforest, plus the cost of bringing the area up to standard, plus the costs of monitoring. Consequently, the penalty would ensure that the company takes into account the social costs of failure to reforest in addition to its private costs, which are contained in its profit maximization equation (4.1).

However, because not all failures to reforest may be detected, the probability of detection $P_D(x, m)$ is also part of the penalty function. For example, suppose that the probability of detection is fifty percent. In this case, the portion of the penalty based on the social costs of reforestation failure is doubled. Although the companies that are discovered pay more than the social cost of reforestation failure for their area and the undiscovered companies pay nothing, the possibility of paying this penalty gives all companies the incentive to make optimal effort toward reforestation success.

The probability of detection in this model is shown to depend on the size of the area x and the amount of government monitoring, m. However, other factors to consider are the size of the forest operation, proximity to civilization, proximity to roads, government resources, or other variables. P_D may therefore be complex and may make an optimum penalty difficult to ascertain[32].

This chapter has formulated a general model of a principal-agent arrangement. In chapter five, this general model will be applied to current reforestation requirements in Alberta, thus demonstrating the use of the optimum penalty function to potentially improve forest regeneration.

[32] It may be possible for forest companies to spend time and money to circumvent government regulators and to lower the probability that they are detected. Indeed, the incentive to do this will increase as the penalty gets higher.

CHAPTER V

APPLYING THE PRINCIPAL AGENT MODEL TO ALBERTA

5.1 Introduction

As described in chapter three, Alberta has the most defined standards for forest regeneration of the prairie provinces, therefore the principal-agent model can be most readily applied to this province. The model will be applied to the initial reforestation requirements, as there are not penalties for failing the Establishment and Performance surveys, and no Establishment or Performance surveys have been conducted to date in Alberta. In this chapter, the model which was developed in chapter four will be applied to a reforestation case study in part of the Weldwood FMA near Hinton, Alberta. The model will first be adjusted for use in Alberta. Using this adjusted formula, values for a penalty will be estimated. Following these calculations, this chapter will conduct sensitivity analyses on the variables of the model. Finally, policy suggestions will be outlined.

5.2 Adjusting the penalty for Alberta forestry

The optimal penalty for Alberta will be explored using formula (4.4) from chapter four:

$$T_D(x) = \frac{D_T[(1-r)x] + D_N[(1-r)x] + C(rx) + m}{P_D(x,m)}$$

More simply, this penalty can be understood as:

$$\frac{[(\text{Forgone timber benefits} + \text{Forgone non-timber benefits}) + \text{2nd attempt reforestation costs}] + \text{monitoring costs}}{\text{Probability of detection}}$$

In order to use the penalty function (4.4), all the right-hand-side values must be estimated. In Alberta, as described in Chapter Three, $C(rx)$ is part of the penalty imposed on the company by the requirement that the companies be responsible for retreatment costs, if necessary, after initial reforestation efforts have failed, to bring cutblocks up to the Free To Grow standards. This requirement implies that $C(rx)$ is included in the company's profit maximization equation (4.1), causing it to cancel out of the optimal penalty function:

(5.1) $$EU(e) = -\int_x \{v(x) + P_D(x,m)T_D(x)\}\, f(x,e)dx - e - C(rx)$$

(5.2) $$EW(e,m,r) = -\int_x \{ D_T[(1-r)x] + D_N[(1-r)x] + C(rx) + v(x) \}\, f(x,e)dx - e - m$$

(5.4) $$T_D(x) = \frac{D_T[(1-r)x] + D_N[(1-r)x] + m}{P_D(x,m)}$$

Costs to society from regeneration failure include the loss of the stream of social benefits derived from the forest. However, no detailed study has been undertaken in the prairie provinces to suggest a value for benefits derived from forests. Literature suggests that society enjoys benefit from timber, recreation, aesthetic values, bequest values, and existence values. Methods to determine the non-timber portion of these values include travel cost models, hedonic pricing models, and contingent valuation models (e.g. Condon and White, 1995). However, explicit use of such methods is beyond the scope of this paper. Instead, a timber supply model will be used to estimate the loss in timber volumes due to delayed reforestation efforts. Timber volumes will be multiplied by estimates of economic rent to approximate the costs of timber forgone, while non-timber values will be treated as a variable with an unknown value. Therefore, to the extent that non-timber values are positive, the social costs of delayed reforestation will be even greater than those indicated by the numbers derived from the value of lost timber.

A perpetual stream of annual social costs may be represented by the following formula:

(5.5)
$$D(x) = \frac{D_T[(1-r)x] + D_N[(1-r)x]}{i}$$

i - discount rate

Current practice in Alberta under the Alberta Free to Grow regulations requires forest companies to reforest all coniferous and mixedwood cutovers, thus setting *r* to 1, which seems to set the damages $D_T[(1-r)x] + D_N[(1-r)x]$ equal to zero. However, social costs are not only dependent on a portion of area *x* remaining denuded, but also arise from delays created by not reforesting promptly. The simplified formula thus becomes:

(5.6)
$$D(x_D) = \frac{D_T(x_D) + D_N(x_D)}{i}$$

x_D - area on which reforestation is delayed.

In this paper, $D_T(x_D)$ is represented by the decrease in Annual Allowable Cut (AAC) resulting from delayed regeneration. In Alberta, the forest sector operates under even flow constraints, where Annual Allowable Cut for a forest is calculated on the basis of the maximum evenflow cut (MEC) derived from stands. In this situation, the use of the decrease in AAC over a forest as a whole is an appropriate measure of the value of timber lost. Following the current practice in the province of Alberta, maximum MAI rotations are used to calculate MEC, rather than other investment analysis calculations using Faustmann or Hartman[33] rotations. This method of calculating social cost can be represented by:

(5.7) $$D(x_D) = \frac{P_S\,(AAC(x_D)_0 - AAC(x_D)_d) + D_N(x_D)}{i}$$

P_S	- stumpage fees in dollars;
$AAC(x_D)_0$	- Annual Allowable Cut with zero regeneration delay;
$AAC(x_D)_d$	- Annual Allowable Cut with regeneration delay.

The planning models used by Alberta forest companies have finite planning horizons[34]. The above formula calculates the net present value of social damages from delayed reforestation for a perpetual stream of annual social costs. This formula must be adjusted to reflect finite planning horizons, as follows:

(5.8) $$D(x_D) = [P_S\,(AAC(x_D)_0 - AAC(x_D)_d) + D_N(x_D)] * [1 - (1+i)^{-n}/i]$$

n - planning horizon, in years, for the stream of annual losses from reduced AAC

[33] Hartman, R. 1976.

[34] Personal communication, Dr. James Beck, Jr., professor, Department of Renewable Resources, Faculty of Agriculture, Forestry and Home Economics, University of Alberta, April 1995.

As derived above, the opportunity cost of delayed regeneration is the discounted value of the reduction in Annual Allowable Cut caused by the delay in meeting reforestation standards[35]. To calculate the reduction in AAC, several scenarios were simulated, using a Cut/Grow Timber Supply Model, called MUNCHER (Beck and Beck, 1995) and a data set compiled from forest data and yield tables from part of the Weldwood FMA near Hinton, Alberta[36]. The loss in timber values is modelled as a change in AAC due to regeneration lags which are assumed to occur due to failed reforestation. Scenarios developed cover increased delays in reforestation treatments from 1 to 5 years, which could result from failure to reforest[37].

In the MUNCHER program, planning horizons must be specified within the program and maximum evenflow cut (AAC) is calculated for these planning horizons using the existing forest data. By convention, planning horizons in Alberta are usually set at approximately twice the longest rotation length[38]. In the simulation which follows, specified planning horizons are increased by two times the regeneration lag (e.g., for a 2 year regeneration lag, planning horizon is 308 years).

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[35] This approach was used to calculate the opportunity cost of removing lands from forest use in a paper by Phillips et. al. (1988).

[36] For the results of the timber supply model, see Appendix A. The Weldwood forest is composed mainly of coniferous stands, so this data would not be ideal for analyzing mixedwood or deciduous forest regeneration.

[37] Recall that, in Alberta, if regeneration is not accomplished by the end of the two year limit, the company is required to retreat the cutblock within one year following the survey. If reforestation is still unsatisfactory, the company must keep making efforts to regenerate their cutblock until it is brought up to standard. According to Lindsay Kerkhoff (Alberta Land and Forests), more than 90% of cutblocks are successfully regenerated following the first retreatment. After the two-year limit, increasing delays of up to seven years were tested to see whether the relationship between regeneration delay and decrease in AAC is linear.

[38] Personal communication, Dr. James Beck, Jr., professor, Department of Renewable Resources, Faculty of Agriculture, Forestry and Home Economics, University of Alberta, April 1995.

5.3 Estimation of penalty amounts

Table 5.1 shows total volumes (AAC) for even flow harvests associated with various regeneration lags using rotations that maximize mean annual increment. The longer the lag the lower is the associated AAC.

Table 5.1 Annual Allowable Cut (AAC) (m3)

Planning horizon* (years)	Regeneration lag (years)							
	0	1	2	3	4	5	6	7
300 + 2 * lag	198745	198654	198555	198456	198346	198236	198126	198015

* planning horizon = 2 * longest rotation length + 2 * regeneration lag

Table 5.2 summarizes the decrease in AAC as regeneration is delayed by longer and longer time periods. According to current Free to Grow regulations, the Alberta government accepts a delay in regeneration of two years following harvest. Because of this two year limit, decreases in AAC are adjusted to show the effect of exceeding the acceptable lag by subtracting the lost timber at two years after harvest from the lost timber at each year's delay in excess of the two year limit.

Table 5.2 Decrease in AAC (m3) due to regeneration lag

Planning horizon* (years)	Regeneration lag (years) in excess of two-year limit				
	1	2	3	4	5
300 + 2 * lag	99	209	310	429	540

* planning horizon = 2 * longest rotation length + 2 * regeneration lag

A range of stumpage fees for timber was used as an estimate of the economic rent[39] from timber. Values of $1/m^3$, $\$20/m^3$, and $\$45/m^3$ were selected to represent a wide range of stumpage values[40]. This range was chosen to investigate the sensitivity of the penalty function to economic rent levels. Also, various potential discount rates are used in formula (5.8) -- 0%, 3%, 6%[41].

In Alberta, the current penalties are imposed on a dollars per hectare per month basis. To compare the principal-agent model's results with current penalties, it is necessary to convert the model's penalty amounts from dollars per cubic metre to dollars per hectare. The MUNCHER program provides harvest data indicating the area harvested per year. By dividing the costs of reduced AAC per cubic metre by the area harvested during the years when reforestation is delayed, a per hectare penalty will be approximated.

Table 5.3 summarizes the estimated present values of per hectare losses in AAC which occur when companies delay regeneration operations past the two year deadline. As shown, the relationship between the length of the regeneration lag and the amount of the cost is close to linear, suggesting that a one year lag cost could be merely multiplied by different lag lengths to derive estimates of costs.

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[39]Economic rent is "... the surplus that remains after revenues from natural resource use have been disbursed to pay all costs of production, including a return on investment, or a "normal profit" equivalent to what could be earned in the next best use of the capital invested" (Gunton and Richards, 1987, as summarized by Anielski, 1991, p.8).

[40]For the time period of 1990-December 1993, stumpage fees ranged from \$0.70/m3 to \$1.22/m3. Since January 1994, stumpage fees for softwoods have been based on lumber prices, and are set each week. An average of these prices from January 1994 through May 1995 is approximately \$20/m3 (Alberta Lands and Forest Service records, May, 1995). \$45/m3 is used as a "high" estimate.

[41]This paper is dealing with social costs from failure to regenerate forests, and so the use of the social rate of discount is appropriate (Harou, 1985).

Table 5.3 Per hectare cost ($) of reduced AAC, less two year lag

300 year planning horizon, increased by regeneration lag
(planning horizon = 2 * longest rotation length + 2 * regen. lag)

Interest rate (%)	Stumpage ($/m³)	Years exceeding two year limit 1	2	3	4	5
	1	41.95	89.02	137.42	185.68	234.97
0	20	839.07	1780.46	2748.39	3713.61	4699.49
	45	1887.90	4006.04	6183.87	8355.62	10573.84
	1	4.57	9.63	14.77	19.84	24.94
3	20	91.39	192.67	295.49	396.71	498.84
	45	205.63	433.51	664.86	892.61	1122.38
	1	2.29	4.82	7.39	9.92	12.47
6	20	45.70	96.35	147.76	198.38	249.44
	45	102.83	216.78	332.47	446.35	561.24

5.4 Comparison of estimates with Alberta two-year reforestation penalties

As outlined in chapter three, there are three separate criteria which must be met to satisfy Free to Grow standards in Alberta. These are the initial regeneration at two years after harvest, the Establishment Survey at four to eight years after harvest, and the Performance Survey at eight to fourteen years after harvest. These criteria may be further divided into two categories -- those which are explicitly penalized for failure and those which are not. The initial regeneration requirements must be accomplished within two years, or a penalty of $2.50 per hectare per month will be charged. The Establishment and Performance surveys must be passed, or the company must regenerate to standard at their own expense. There is no further monetary penalty.

The MUNCHER program is not able to accomodate time periods of less than one year, but the current monthly penalty may be compared to the results of the principal-agent model by multiplying the \$2.50/ha/month by twelve, yielding \$30/ha/year. Combining the results of Table 5.3 and equation (5.4) discloses that with zero non-timber values, zero monitoring costs, and a probability of detection of 1.00, the current penalty would approximate the optimal amount if stumpage was between $\$1/m^3$ and $\$20/m^3$, with a discount rate between 3% and 6%.

As shown in Table 5.3, the suggested social costs from timber losses are generally higher than the current penalty for regeneration failure. These differences between social costs as calculated by loss in AAC and the current penalty may possibly be explained by several variables. The divergence in values may arise from differences in discount rate, non-timber values, the probability of detection, monitoring costs, or stumpage fees. Each of these factors will be discussed with respect to their effect on social costs implications for reforestation policy.

5.4.1 Discount rates

As the discount rate increases, the social costs due to reforestation delay decrease. The 0% discount rate scenario yields the highest numbers, because in this case the future is valued just as greatly as the present. To illustrate, with a one year regeneration lag, $20/m^3 stumpage, and a 0% discount rate, the net present cost to society from foregone timber benefits is estimated to be $839.07/ha/year delayed. The corresponding net present social cost calculated using a 6% discount rate is $45.70/ha/year delayed.

With $20/m^3 stumpage prices, the current penalty of $30/ha/year would imply a discount rate of higher than 6%, which could be considered too high for a social rate of discount which should be used by the government for making decisions about net present social benefits or costs from reforestation operations.

5.4.2 Non-timber values

The numbers in Table 5.3 only represent the lost timber values from failed or delayed reforestation efforts. To the extent that NTVs are positive, and social costs of forgoing these benefits are positive, the resulting penalty will be greater than that generated using timber values alone. Where the revealed timber penalty amount is less than $30/ha/year delayed, as with the $1/m^3 stumpage fee scenarios, it may be that the government was adjusting for non-timber values when designing the current penalty system. However, where the penalties suggested by the principal-agent model are higher than that imposed at present in Alberta, the presence of NTVs would exacerbate discrepancies.

5.4.3 Probability of detection

The numbers in Table 5.3 are calculated assuming that the probability of detection is 1.00. If the penalty of detection is less than 1.00, however, the values for $D_T(x_D)$ will be higher, and the additional penalties will be greater.

The Alberta Land and Forests Service is confident that they have designed their reforestation check surveys in such a way as to easily tell if company surveyors are misrepresenting results, and that therefore $P_D = 1.00$[42]. Therefore those surveys which are monitored should have a 100% chance of detecting reforestation failure. However, only 10% of the surveys are randomly selected for monitoring. This indicates that the probability of detection could be lower than 1.00. To the extent that $P_D < 1.00$, the values in Table 5.3 would be increased, suggesting larger estimated penalties.

5.4.4 Monitoring costs

For the initial reforestation treatment requirements, there is no specific provincial survey, according to prescribed methods, to be carried out. Instead, monitoring is done on an informal basis by the Alberta Lands and Forest Service. Because there are no set guidelines for monitoring initial reforestation operations, it is not possible to identify the current monitoring costs. However, monitoring costs are probably lower than those for the more rigourous Establishment or Performance

[42]Personal communication, Lindsay Kerkhoff, Alberta Lands and Forest Service, April, 1995.

check surveys.

Although exact numbers are not available for check survey monitoring costs, it is possible to estimate future costs from current harvest information. Weldwood harvested 16 different dispositions, or working areas, in 1991. These working areas included a total of 200 cutblocks harvested, covering an area of 3680.2 hectares[43]. The Alberta government would need to check 24 of these cutblocks to satisfy the recommendations of the Free to Grow Establishment or Performance standards, using approximately one person-day per cutblock to verify company survey reports. Assuming the person conducting the check survey would be a Forest Officer 2, making a daily income of $132.34, the cost of doing check surveys on the Weldwood FMA at Hinton would be approximately $3176.16 per year[44]. Dividing this number by the total area harvested yields a monitoring cost of approximately $0.86/ha/year. Costs for conducting the informal two-year check are likely lower than this amount, but any positive values would increase the values in Table 5.3.

5.4.5 Stumpage fees

As the value of stumpage increases, the principal-agent model demonstrates that the loss to society from reduced AAC is also increased. At the time when the Free to Grow standards were developed, stumpage fees ranged from $0.70/m^3$ to

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[43] Alberta Lands and Forest Service, 1995.

[44] Personal communication, Doug Schultz, Forest Revenue division, Alberta Lands and Forest Service, August 1995.

$1.22/$m^3$ [45]. Perhaps at the time when these policies were instituted, with low stumpage fees, the $30/ha/year penalty was approximately correct, if non-timber values were positive or the probability of detection was less than 100%. However, if non-timber values were zero, monitoring costs were zero, and the probability of detection was 100%, a penalty of only $2.29 to $4.57 per hectare per year delayed would have sufficed to prompt optimal regeneration effort, .

At present, stumpage fees average approximately $20/$m^3$. When this value is used to calculate social costs, the damages from failed or delayed forest renewal become larger than $30/ha/year delayed. Because the stumpage fees have risen, *ceteris paribus*, existing penalties no longer adequately cover social costs. If the other parameters of the model remain the same, the principal-agent model shows that the existing penalties will not promote optimal reforestation.

In Alberta, economic rents may be divided between the government (through stumpage fees) and the forest companies (the residual rents not paid in stumpage fees). Because the principal and the agent may share in these rents, incentives to avoid reforestation delay are also shared among the provincial government and the FMA holders. The more economic rent captured by the government, the more need the government has to confirm through regulations that reforestation is accomplished quickly on crown lands, because the tenure holder gains little if reforestation is accomplished. Therefore, as stumpage fees increase, there are diminishing incentives for forest companies to reforest their FMAs in the absence

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[45]Personal communication, Alberta Lands and Forest Service, May 1995.

of government regulation. To ensure that sufficient reforestation takes place in the face of increasing stumpage fees, the government must increase penalties imposed on forest companies, placing more of the social cost of delayed reforestation on the companies whose management has caused the delay in forest renewal.

If the government is seeking to maximize the net benefit created by reforestation efforts, then the government's incentive to ensure that reforestation is accomplished is the same regardless of the amount of stumpage charged. However, as stumpage fees get lower the incidence of the cost of delay in forest renewal shifts to tenure holders. As stumpage decreases, command and control penalties can become less severe. The model developed above is set up to consider different levels of command and control versus future equity.

Social damages from lost timber are made up of the loss to society from foregone stumpage and losses borne by the tenure holder because of foregone future benefits from their regenerated stands. That is:

(5.9) $$D_T(x_D) = v(x_D) + P_S\,(AAC(x_D)_0 - AAC(x_D)_d)$$

If the government is collecting the full economic rent from future stands of timber, then the lost stumpage values, $P_S\,(AAC(x_D)_0 - AAC(x_D)_d)$, would be equal to timber damages, $D_T(x_D)$, and lost equity, $v(x_D)$, would be zero. The tenure holder would have no equity in future stands of timber, and thus no incentive to regenerate. The social costs from timber losses would be fully represented by stumpage prices lost. The optimal penalty for timber losses would be equal to the losses from foregone stumpage revenues. There would be no incentive to reforest on the part of the forest companies, so command and control penalties would have to be high, to pay the full costs of lost stumpage.

If the government is not collecting full economic rent, then forest companies would have some equity in future stands of timber. That is, if $P_S\ (AAC(x_D)_o - AAC(x_D)_d)$ is less than $D_T(x_D)$, then $v(x_D)$ is positive. The tenure holders would thus have some incentive to reforest in order to generate revenues from future timber harvests. A greater proportion of social losses from failure to reforest would be internalized into the firm, therefore a lower penalty would be required to accomplish optimal forest renewal.

If stumpage prices are zero, then $v(x_D)$ would be equal to $D_T(x_D)$. Under this scenario, if non-timber values for Alberta forests were zero[46] and the social and private discount rates were equivalent[47], then the costs of reforestation delay could be internalized by charging zero stumpage fees, and allowing the companies to manage their FMAs for future equity.

These relationships may be summarized as follows:

If	$P_S\ (AAC(x_D)_o - AAC(x_D)_d)$	$=$	$D_T(x_D)$;	$v(x_D) = 0$
	$P_S\ (AAC(x_D)_o - AAC(x_D)_d)$	$<$	$D_T(x_D)$;	$v(x_D) > 0$
	$P_S\ (AAC(x_D)_o - AAC(x_D)_d)$	$=$	0;	$v(x_D) = D_T(x_D)$;

[46]In reality, however, non-timber values exist, and to the extent that they are positive, additional penalties would be required to compensate society for non-timber losses due to regeneration delay, and to prompt companies to make optimal effort toward reforestation.

[47]Because the private discount rate may be higher than the social rate, the costs of losing future timber revenues will be smaller when discounted to present value terms. Therefore the private companies would not reforest to the satisfaction of the Alberta public, even if they retained all the economic rent from future forests.

These observations illustrate that it is not necessary to know the full value of foregone timber due to regeneration failure. Instead, the command and control penalty may be based on the price of stumpage. Currently in Alberta, penalties for failed reforestation are set legislatively. They are not tied to the value of stumpage prices. As shown by the results in Table 5.3, since stumpage prices have risen, *ceteris paribus*, the penalty does not appear to be optimal. In order to obtain optimal forest renewal, the penalty system could be adjusted so that the amount of the penalty is linked to the price of stumpage.

5.5 Assessments of Alberta Establishment and Performance Surveys

At this time it is not possible to accurately model these future surveys of the Free to Grow standards. The timber supply model MUNCHER is not able to include delays in acheiving reforestation standards after the initial reforestation lag. To illustrate, a forest company could meet the standards for regeneration treatments on their harvested area at two years or perhaps some reforestation delay. When conducting the Establishment or Performance survey , the company could discover that certain areas of their cutblocks contain trees, but not in sufficient numbers or size to fulfil the regeneration requirements. Perhaps the area fails to meet standards because of insufficient thinning of established trees. These situations constitute failure to adequately reforest, but the harvested areas still contain stands of trees. MUNCHER, which assumes that the area is insufficiently stocked until the time of a specified regeneration lag, cannot incorporate these scenarios into its timber supply models. Suppose that at year 9 following harvest, forest renewal had still not been accomplished. The MUNCHER model could specify a nine-year regeneration lag, and the costs of such a delay could be calculated as in section 5.3. However, these numbers would not accurately represent the situation where the two-year standards had already been met, but regeneration was insufficient at the time of a later survey.

Despite these drawbacks, some insights may be found using the numbers already calculated in the model. If a forest company Establishment or Performance survey reveals that reforested areas are not progressing according to Free to Grow standards, then Alberta companies are required to redo reforestation operations until they are successful. This arrangement suggests that the Alberta Lands and Forest Service is implicity setting penalties (T_D) equal to reforestation costs ($C(rx)$).

Because Free to Grow standards were instituted in 1991, the first Establishment surveys of cutblocks will only begin to take place in the fall of 1995. Provincial check surveys have not been completed for any FMAs, therefore results from these surveys are not available to determine reforestation success or failure.

No Establishment surveys have yet been submitted in Alberta, so there is no documented monitoring cost, m, to incorporate into the penalty function. However, it is possible to suggest a possible value of $0.86/ha/year for monitoring costs from current penalties as outlined in section 5.4.4.

5.6 Conclusions and suggestions arising from application of the model

Based on the results of the MUNCHER model for part of the Weldwood FMA near Hinton, Alberta, the social timber costs of delayed reforestation appear to be higher than current penalties. The province-wide penalties are presently $30/ha/year for inadequate initial reforestation operations, indicating that current penalties levels may be less than optimal.

Assuming a 300 year specified planning horizon, a 3% discount rate, $20/m^3$ stumpage fees, zero non-timber values, 1.00 probability of detection, and $0.86/ha/year monitoring costs, for every year that initial reforestation treatments are delayed this model would suggest a penalty of $92.25/ha/year delayed.

There may be differences among FMAs in regeneration rates, costs of reforestation , monitoring costs, and the probability of detection. If further research shows that optimal penalties are significantly different across FMAs, it may be necessary to calculate penalties on a case by case basis. These penalties could be based on actual site and harvest data, which are available to the Alberta Land and Forest Service soon after harvest. If penalties are changed to an FMA basis, the policy instrument could be more precise, and might more accurately reflect the effect of reforestation delay on social welfare than current penalties, which are the same across the province. However, costs of calculating and administering penalties on an FMA basis could counteract these benefits.

At present, penalties are set legislatively, with no built-in mechanism for flexibility (Alberta Regulation 60/73,1994). Because the social costs from reduced

AACs, and therefore penalties, are so directly affected by changing stumpage fees, a set penalty amount may not result in optimal regeneration for maximum social welfare. Instead, the penalty could be tied to stumpage fees, which are now tied to weekly timber prices. Making the penalty responsive to the price of timber in this way could result in greater policy incentives for achieving maximum social welfare from forested land. Furthermore, this chapter has shown that it may not be necessary to have stumpage prices reflect full economic rent when estimating optimal penalties.

The following chapter will summarize the findings of this research and suggest directions for future research in the area of principal-agent theory and forest tenures.

CHAPTER VI

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

6.1 Introduction

The issue of forest renewal after harvest and the role of governments in regulating and promoting regeneration operations has gained importance for the general public in recent years, becoming one of the most important forest policy issues facing provincial governments in Canada. A discussion of the social costs of reforestation delay as well as incentives and/or penalties is particularly timely, given the recent increase in harvesting activities in the prairie provinces and public concern about the large areas of land managed by forest companies. As the Canadian public places increasing pressure on their provincial governments to ensure prompt regeneration, governments are seeking efficient ways to attain optimum regeneration. Toward this end many provinces are considering the assignment of more responsibility to the forest industry for achieving and monitoring regeneration success. Policy incentives must be designed with care in order to maximize social welfare from forested lands.

In Alberta, penalties may be charged to companies which fail to meet reforestation standards. However, these penalties are not explicitly derived from an estimation of social costs due to reforestation failure, and so may not provide the right amount of reforestation effort to acheive maximum social welfare from forested lands. This thesis estimates the social costs of failed or delayed forest regeneration and develops a penalty formula based on these estimated costs. The penalty revealed by the model is then contrasted with current penalties in Alberta to investigate whether current penalty amounts would result in optimal reforestation to Alberta's Free to Grow standards. There are few studies which make use of principal-agent theory to evaluate reforestation agreements and it is hoped that this thesis will stimulate further research into forest economics and policy

6.2 Study results

This thesis has two major components. First, a principal-agent model was developed to yield a penalty function. This penalty function was designed to promote optimal regeneration. Second, the social costs from lost timber due to reforestation delay were estimated for part of an FMA in Alberta and these numbers used to suggest optimal penalty values.

A principal-agent model was developed for the forestry sector, based on the characteristics of regeneration regulations and composition of the forest industry. Asymmetric information existed between any given agent and a principal, because the effort of the agent was hidden from the principal. Alberta forest companies were assumed to be risk-neutral, because only a small portion of their total expenditures was devoted to reforestation operations. The costs of monitoring and detecting the effort of firms were thought to be high, compared with those of monitoring and detecting the outcome of reforestation effort. Under the above circumstances, a strict liability penalty function was deemed to be most appropriate for inducing optimum compliance with Free to Grow standards. This penalty function was derived from the agent's profit maximization function and the principal's social welfare maximization function. The penalty was based on social costs due to regeneration failure, the cost of reforestation operations, the probability of detection, and costs of monitoring the firm's activities.

The penalty function was used in chapter five to estimate optimal penalty amounts for part of the Weldwood FMA near Hinton, Alberta. Because the forest industry in Alberta is required to manage by even flow, decreases in AACs due to regeneration delays were used as an appropriate measure of the value of lost timber. A Cut/Grow timber supply model called MUNCHER calculated reduced Annual Allowable Cuts on the cutblocks in the study area, and thus estimated the timber loss as a result of increasing delay in reforesting these cutblocks. These values ranged widely from approximately $1887.90/ha to $2.29/ha for every year delay in regenerating past the two-year deadline specified by the Free to Grow standards. Given that current penalties are approximately $30/ha/year, the numbers generated by the model suggest that current penalties in Alberta may be too low, given current stumpage fees of $20/m^3$. Instead, this paper estimates that a more appropriate level might be approximately $92.25/ha/year for each year's delay in reforestation[48].

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[48]Reflecting loss of social benefits from timber with a 300 year planning horizon, 3% discount rate, 100% probability of detection, $20/m^3$ stumpage fees, zero non-timber values, and $0.86/ha/year monitoring costs.

The values of critical parameters were estimated in section 5.3, and each was discussed as to its implications for reforestation penalty levels. These parameters indicated that present penalty levels are too low to acheive optimal effort toward regeneration.

6.3 Policy implications arising from the study results

This model allows the variation of key parameters such as discount rate, probability of detection, monitoring expenses, stumpage fees (rent collection), rotation length, and regeneration lag. As designed, the model is very flexible, and could be adapted for other Forest Management Units in Alberta as well as in Saskatchewan and Manitoba.

The specific application of the principal-agent penalty function in this research was for part of a Forest Management Agreement. Tenure holders are presently required to submit detailed harvest and regeneration information to the provincial government. Therefore, it is possible to design and implement reforestation incentives at the level of FMAs, rather than the existing legislation which establishes a single penalty amount for infractions anywhere in Alberta. The model developed in this thesis can be adapted for other FMAs, allowing provincial governments to more easily account for variations in tree species, site characteristics, and costs of reforestation operations. Adjusting penalties to specific FMAs may be particularly important given that the existing growing stocks and therefore the results of the ACE will likely vary significantly among FMAs. If the additional costs of devising and administrating these other penalty functions are less than the increased social welfare resulting from their imposition, penalties could be calculated at the FMA level. This policy could provide more efficient incentives than those given by using one provincial charge.

As numbers for non-timber values become available, penalties should be adjusted to provide a more precise reflection of society's benefits from forests, and the losses which arise when forests remain denuded after harvest. To the extent that non-timber benefits are positive, penalty amounts would increase accordingly.

An interesting aspect of this research was the pivotal role played by stumpage prices. Current penalties were legislated in 1991, and do not cover the social costs of reduced timber volumes under existing stumpage prices. The model was sensitive to changes in these prices, and at current levels of stumpage prices the present penalties differ widely from those suggested by the principal-agent model. To illustrate, given present stumpage fees, penalties would have to range from approximately $46.56/ha to $839.93/ha in order to achieve optimal reforestation, assuming zero non-timber values and 100% probability of detection. The effect of stumpage prices on penalties can be very large because of the Allowable Cut Effect, which causes yearly losses in AACs from reforestation delays. Because changes in stumpage prices so directly affect optimal penalty levels, this study suggests that penalties should be linked to stumpage prices, which are in turn based on timber prices.

By basing penalties on stumpage prices, this research shows that the total social values for timber may not need to be precisely calculated. The penalty for reducing social benefits from timber may be calculated merely on the basis of the stumpage prices, as any non-collected rent reduces incentives of tenure holder fail in their reforestation efforts. If the government captures all economic rent through stumpage fee collection, penalties will have to be high. With no benefits received by the firm from regeneration, all loss to society must therefore be compensated through the penalty amounts. At the other extreme, in theory, if no non-timber values are present, and social and private discount rates are equivalent, the provincial government could set stumpage fees to zero. This policy would internalize all social costs into the firm and the firm would therefore maximize social welfare by making effort toward optimal reforestation.

6.4 Limitations and suggestions for future research

Some limitations of this study should be noted. The values generated by the model are based only on timber values; there are no estimated non-timber values included. This omission might have a large impact on social welfare, depending on the forest site. However, the model does provide a way to incorporate these numbers, because it includes a variable D_N, which can be assigned a value as non-timbers values are estimated. Non-timber valuation studies could be conducted on Alberta's forest lands to determine social non-timber benefits from regenerated forests, and the loss of these benefits could then be included as the cost, D_N, in the penalty function. This addition could create more accurate penalties to compensate society for loss of benefits from forested lands and might encourage optimal efforts by tenure holders toward forest renewal.

The model has been constructed under the assumption that the even flow harvest constraint on Alberta forest companies is binding, giving rise to the Allowable Cut Effect. If this constraint is not binding, the efficiency losses to society due to reduced Annual Allowable Cut would not be as great as those suggested by this model. Luckert and Haley (1995) suggest a number of reasons why AACs may not be binding constraints. Future studies could investigate the costs of regeneration delays when companies have incentives to cut below their AACs.

There are no specified monitoring protocols for the initial two-year requirements in Alberta; the monitoring is done on an informal basis. This absence of particulars makes estimating the probability of detection and the costs of monitoring less accurate. Also, it is difficult to pinpoint the success or failure of these requirements because the monitoring system is much more subjective than the government check surveys for the Establishment or Performance surveys. This uncertainty suggests that penalty amounts may be underestimated for the two-year reforestation requirements. Alternate monitoring schemes and different probabilities of detection could be investigated to suggest more accurate values for these variables. If the probability of detection is less than 1.00, this would directly affect the suggested penalty amounts, and therefore penalties should be adjusted to reflect the lower probability of detection. If monitoring costs increase, suggested penalties should increase accordingly, to compensate society for the additional government resources spent to check on the success of reforestation. Further research and sensitivity analysis into these parameters may aid the development of more precise reforestation incentives.

The amount of government resources devoted to detecting reforestation failure may directly affect the probability of detection. However, in this model, monitoring costs and the probability of detection are exogenously determined. In future research, this approach could be modified to solve for an optimal level of m.

Because Free to Grow standards were only initiated in 1991, no Establishment surveys have been performed to date. Thus there are no records showing the number of cutblocks surveyed and regeneration success on these areas. Harvest records exist for each FMA, so survey percentages can be very accurately predicted. However, predictions cannot be contrasted with actual data to emphasize any divergence. As actual data become available, this principal-agent model could be used again to evaluate the incentives given by current penalties in Alberta.

The flexibility and simplicity of the model developed in this thesis allows for its easy adaptation to evaluate other silviculture and forest management operations. For example, as information becomes available, the loss of timber and non-timber benefits due to pests and disease could be estimated, and substituted into the $D_T(x_D) + D_N(x_D)$ portion of the penalty function. The resulting numbers could be used to charge penalties to firms who do not control pests and diseases to socially optimal standards. Another area that could be estimated is the social benefits from biodiversity. Companies could be required to maintain and improve biodiversity, and then could be penalized if biodiversity on their FMAs falls below some predetermined standard. Future studies could investigate the application of this principal-agent model for these and other forest policy incentives.

The assumption that the government's main motivation is social welfare maximization, as defined by Potential Pareto Improvement, may not always be the case, as assumed in this paper. There may be other considerations, like reducing public expenditures, increasing public revenues, lowering the deficit, or other incentives, and the effects of these additional goals on optimal social welfare could be investigated in future studies.

Finally, it is possible that a penalty is not the only internalizing force available to government regulators. For example, the overall threat to lose the FMA and the desire for good public relations may internalize private reforestation efforts already. Alternate methods of internalizing social losses from foregone timber and non-timber benefits could be studied in more detail in future research.

6.5 Concluding remarks

As with most forestry situations, special considerations are involved when designing reforestation incentives. The principal-agent framework must be guided by the physical, social, and political realities that constrain forest activities. The long growing period and the remoteness of forested areas make it more difficult to monitor activities and determine whether adequate reforestation has taken place. In addition, there is disagreement about what constitutes successful or desirable forest regeneration. Multiple use complications arise, because conditions which are desirable for some uses are in conflict with other uses. These conflicts are not unique to the regeneration situation, but are recurrent throughout forest research.

It is clear from the preceding issues that discussions about the enforcement of government regulations cannot be held in isolation from discussions about the policy itself. Regulation and enforcement must be guided by careful examination of the standards that are to be implemented. Forest renewal is a complex issue, and an interdisciplinary approach is necessary to gain a more complete picture of what desirable regeneration might be. If standards are inappropriate, the penalty scheme will be a waste of government and private resources, as well as a less than socially optimal regeneration rate. However, given a particular set of reforestation standards, when the goal of the government is to maximize social welfare, principal-agent models can be a valuable aid to designing regulatory policies. The principal-agent framework can be combined with current standards of regulation and enforcement to design more socially optimal regeneration contracts.

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APPENDIX A

Annual Allowable Cut (maximum evenflow cut) with zero years regeneration lag

Forest_Muncher_3.6 2
Extra Regeneration Lag Version 2 for M. Pattison Last Change November 9 1995 Copyright 1995
Authors Barbara H. Beck Ph D. and James A. Beck Jr. Ph.D. R.P.F.

FOREST DATA This is a sample of a pre-expansion working circle at Weldwood

YIELD TABLES These yield tables are part of Weldwoods old yield tables

TEMPORARY EXTRA REGEN LAG = 0

RULES FOR CUTTING:
  Cut to maximize future growth.
  Areas can be cut before they reach rotation age
  Use rotations which give maximum mean annual increment
  Minimum Volume Cut = 50.0
  Areas designated as reserves not cut
  Use volume 1 of yield table to calculate evenflow cuts and growing stocks

OTHER OPTIONS:
  The age in the forest data is tree age
  Maximum uncertainty in maximum evenflow cut calculations = 0.0010%
  Large polygons split at end of each time period and when required for accurate volume calculations

FOREST SUMMARY

DEFINITIONS: T = Number of years of harvest at CUT units per year
  MEC = Maximum evenflow cut
  TSR = Number of years cut before stock rupture to occurs
  TMC = Number of years of harvest at maximum evenflow cut, MEC
  TU = Number of years of harvest at uncertain maximum evenflow cut, UC
  AVG AGE = Average age of the cut
  AVG AREA = Average area cut per year during time period
  AVG RR = Average return rate
  PL HORIZ = Planning horizon used to calculate the MEC
  EGS = The ending growing stock used in calculating the MEC

  AVG CUT = average cut over time period of each volume in the yield table.
  G. STOCK = growing stock of each volume type in yield table
  TOT GS = Total Growing Stock on Forest (all volumes)
  AVG TOT CUT = Sum of the average cuts of all volumes in yield table
  * Indicates selected for evenflow

FULLY REGULATED FOREST: Longest Rotation 150 LRSYA = 192688
  Regulated Growing Stock = 9227769

FOREST 1 Original Forest
  Growing Stock = 14300106
  TOTAL AREA = 103516 TOTAL MERCHANTABLE AREA = 103516
  G. STOCK (14300106 0)

FOREST 2 Starting Forest = 1 TMC = 300.0 MEC = 198745* AVG AGE = 144
  Growing Stock = 9227811* Year = 2295.0 AVG AREA = 782 AVG RR = 132
  PL HORIZ for MEC = 300 EGS for MEC = 9227769
  AVG CUT (198746* 0)
  G. STOCK (9227811* 0)
  AVG TOT CUT = 198746 TOT GS = 9227811

Annual Allowable Cut (maximum evenflow cut) with one year regeneration lag

Forest_Muncher_3.6.2
Extra Regeneration Lag Version 2 for M. Pattison Last Change November 9 1995 Copyright 1995
Authors: Barbara H. Beck Ph.D. and James A. Beck Jr. Ph D. R.P.F.

FOREST DATA: This is a sample of a pre-expansion working circle at Weldwood

YIELD TABLES: These yield tables are part of Weldwoods old yield tables

TEMPORARY EXTRA REGEN LAG = 1

RULES FOR CUTTING:
  Cut to maximize future growth.
  Areas can be cut before they reach rotation age
  Use rotations which give maximum mean annual increment
  Minimum Volume Cut = 50.0
  Areas designated as reserves not cut
  Use volume 1 of yield table to calculate evenflow cuts and growing
    stocks

OTHER OPTIONS:
  The age in the forest data is tree age
  Maximum uncertainty in maximum evenflow cut calculations = 0.0010%
  Large polygons split at end of each time period and when required
    for accurate volume calculations

FOREST SUMMARY
DEFINITIONS: T = Number of years of harvest at CUT units per year
  MEC = Maximum evenflow cut
  TSR = Number of years cut before stock rupture to occurs
  TMC = Number of years of harvest at maximum evenflow cut, MEC
  TU = Number of years of harvest at uncertain maximum evenflow cut, UC
  AVG AGE = Average age of the cut
  AVG AREA = Average area cut per year during time period
  AVG RR = Average return rate
  PL HORIZ = Planning horizon used to calculate the MEC
  EGS = The ending growing stock used in calculating the MEC

  AVG CUT = average cut over time period of each volume in the
   yield table.
  G. STOCK = growing stock of each volume type in yield table
  TOT GS = Total Grow[illegible]k on Forest (all volumes)
  AVG TOT CUT = S[illegible]erage cuts of all volumes in yield table
  * Indicates selected f[illegible]

FULLY REGULATED FOREST: Longest Rotation 150 LRSYA = 192688
  Regulated Growing Stock = 9227769

FOREST 1 Original Forest
  Growing Stock = 14300106
  TOTAL AREA = 103516 TOTAL MERCHANTABLE AREA = 103516
  G. STOCK (14300106 130)

FOREST 2 Starting Forest = 1 TMC = 302.0 MEC = 198654* AVG AGE = 144
  Growing Stock = 9227763* Year = 2297.0 AVG AREA = 783 AVG RR = 132
  PL HORIZ for MEC = 302 EGS for MEC = 9227769
  AVG CUT (198655* 1)
  G. STOCK (9227763* 140)
  AVG TOT CUT = 198656 TOT GS = 9227903

Annual Allowable Cut (maximum evenflow cut) with two years regeneration lag

Forest_Muncher_3 6 2
Extra Regeneration Lag Version 2 for M. Pattison Last Change November 9 1995 Copyright 1995
Authors Barbara H Beck Ph D and James A Beck Jr Ph D R P F

FOREST DATA This is a sample of a pre-expansion working circle at Weldwood

YIELD TABLES These yield tables are part of Weldwoods old yield tables

TEMPORARY EXTRA REGEN LAG = 2

RULES FOR CUTTING
  Cut to maximize future growth.
  Areas can be cut before they reach rotation age
  Use rotations which give maximum mean annual increment
  Minimum Volume Cut = 50.0
  Areas designated as reserves not cut
  Use volume 1 of yield table to calculate evenflow cuts and growing
    stocks

OTHER OPTIONS:
  The age in the forest data is tree age
  Maximum uncertainty in maximum evenflow cut calculations = 0.0010%
  Large polygons split at end of each time period and when required
    for accurate volume calculations

FOREST SUMMARY

DEFINITIONS: T = Number of years of harvest at CUT units per year
  MEC = Maximum evenflow cut
  TSR = Number of years cut before stock rupture to occurs
  TMC = Number of years of harvest at maximum evenflow cut, MEC
  TU = Number of years of harvest at uncertain maximum evenflow cut, UC
  AVG AGE = Average age of the cut
  AVG AREA = Average area cut per year during time period
  AVG RR = Average return rate
  PL HORIZ = Planning horizon used to calculate the MEC
  EGS = The ending growing stock used in calculating the MEC

  AVG CUT = average cut over time period of each volume in the
   yield table.
  G. STOCK = growing stock of each volume type in yield table
  TOT GS = Total Growing Stock on Forest (all volumes)
  AVG TOT CUT = Sum of the average cuts of all volumes in yield table
  * Indicates selected for evenflow

FULLY REGULATED FOREST: Longest Rotation 150 LRSYA = 192688
  Regulated Growing Stock = 9227769

FOREST 1 Original Forest
  Growing Stock = 14300106
  TOTAL AREA = 103516 TOTAL MERCHANTABLE AREA = 103516
  G. STOCK (14300106 12417801)

FOREST 2 Starting Forest = 1 TMC = 304.0 MEC = 198555* AVG AGE = 143
  Growing Stock = 9228037* Year = 2299.0 AVG AREA = 782 AVG RR = 132
  PL HORIZ for MEC = 304 EGS for MEC = 9227769
  AVG CUT (198557* 118340)
  G. STOCK (9228037* 13320383)
  AVG TOT CUT = 316897 TOT GS = 22548420

Annual Allowable Cut (maximum evenflow cut) with three years regeneration lag

Forest_Muncher_3.6.2
Extra Regeneration Lag Version 2 for M. Pattison Last Change November 9 1995 Copyright 1995
Authors: Barbara H. Beck Ph D. and James A Beck Jr Ph D R.P F

FOREST DATA: This is a sample of a pre-expansion working circle at Weldwood

YIELD TABLES: These yield tables are part of Weldwoods old yield tables

TEMPORARY EXTRA REGEN LAG = 3

RULES FOR CUTTING:
Cut to maximize future growth.
Areas can be cut before they reach rotation age
Use rotations which give maximum mean annual increment
Minimum Volume Cut = 50.0
Areas designated as reserves not cut
Use volume 1 of yield table to calculate evenflow cuts and growing stocks

OTHER OPTIONS:
The age in the forest data is tree age
Maximum uncertainty in maximum evenflow cut calculations = 0.0010%
Large polygons split at end of each time period and when required for accurate volume calculations

FOREST SUMMARY

DEFINITIONS: T = Number of years of harvest at CUT units per year
MEC = Maximum evenflow cut
TSR = Number of years cut before stock rupture to occurs
TMC = Number of years of harvest at maximum evenflow cut, MEC
TU = Number of years of harvest at uncertain maximum evenflow cut, UC
AVG AGE = Average age of the cut
AVG AREA = Average area cut per year during time period
AVG RR = Average return rate
PL HORIZ = Planning horizon used to calculate the MEC
EGS = The ending growing stock used in calculating the MEC

AVG CUT = average cut over time period of each volume in the yield table.
G. STOCK = growing stock of each volume type in yield table
TOT GS = Total Growing Stock on Forest (all volumes)
AVG TOT CUT = Sum of the average cuts of all volumes in yield table
* Indicates selected for evenflow

FULLY REGULATED FOREST: Longest Rotation 150 LRSYA = 192688
Regulated Growing Stock = 9227769

FOREST 1 Original Forest
Growing Stock = 14300106
TOTAL AREA = 103516 TOTAL MERCHANTABLE AREA = 103516
G. STOCK (14300106 0)

FOREST 2 Starting Forest = 1 TMC = 306.0 MEC = 198456* AVG AGE = 144
Growing Stock = 9227997* Year = 2301.0 AVG AREA = 783 AVG RR = 132
PL HORIZ for MEC = 306 EGS for MEC = 9227769
AVG CUT (198458* 0)
G. STOCK (9227997* 0)
AVG TOT CUT = 198458 TOT GS = 9227997

Annual Allowable Cut (maximum evenflow cut) with four years regeneration lag

Forest_Muncher_3.6.2
Extra Regeneration Lag Version 2 for M. Pattison Last Change November 9 1995 Copyright 1995
Authors: Barbara H. Beck Ph.D. and James A. Beck Jr Ph D R P F

FOREST DATA: This is a sample of a pre-expansion working circle at Weldwood

YIELD TABLES: These yield tables are part of Weldwoods old yield tables

TEMPORARY EXTRA REGEN LAG = 4

RULES FOR CUTTING:
Cut to maximize future growth.
Areas can be cut before they reach rotation age
Use rotations which give maximum mean annual increment
Minimum Volume Cut = 50.0
Areas designated as reserves not cut
Use volume 1 of yield table to calculate evenflow cuts and growing stocks

OTHER OPTIONS:
The age in the forest data is tree age
Maximum uncertainty in maximum evenflow cut calculations = 0.0010%
Large polygons split at end of each time period and when required for accurate volume calculations

FOREST SUMMARY

DEFINITIONS: T = Number of years of harvest at CUT units per year
MEC = Maximum evenflow cut
TSR = Number of years cut before stock rupture to occurs
TMC = Number of years of harvest at maximum evenflow cut, MEC
TU = Number of years of harvest at uncertain maximum evenflow cut, UC
AVG AGE = Average age of the cut
AVG AREA = Average area cut per year during time period
AVG RR = Average return rate
PL HORIZ = Planning horizon used to calculate the MEC
EGS = The ending growing stock used in calculating the MEC

AVG CUT = average cut over time period of each volume in the yield table.
G. STOCK = growing stock of each volume type in yield table
TOT GS = Total Growing Stock on Forest (all volumes)
AVG TOT CUT = Sum of the average cuts of all volumes in yield table
* Indicates selected for evenflow

FULLY REGULATED FOREST: Longest Rotation 150 LRSYA = 192688
Regulated Growing Stock = 9227769

FOREST 1 Original Forest
Growing Stock = 14300106
TOTAL AREA = 103516 TOTAL MERCHANTABLE AREA = 103516
G. STOCK (14300106 0)

FOREST 2 Starting Forest = 1 TMC = 308.0 MEC = 198346* AVG AGE = 144
Growing Stock = 9228104* Year = 2303.0 AVG AREA = 783 AVG RR = 132
PL HORIZ for MEC = 308 EGS for MEC = 9227769
AVG CUT (198346* 0)
G. STOCK (9228104* 0)
AVG TOT CUT = 198346 TOT GS = 9228104

Annual Allowable Cut (maximum evenflow cut) with five years regeneration lag

Forest_Muncher_3 6 2
Extra Regeneration Lag Version 2 for M. Pattison Last Change November 9 1995 Copyright 1995
Authors Barbara H Beck Ph D and James A Beck Jr. Ph.D. R.P.F.

FOREST DATA This is a sample of a pre-expansion working circle at Weldwood

YIELD TABLES: These yield tables are part of Weldwoods old yield tables

TEMPORARY EXTRA REGEN LAG = 5

RULES FOR CUTTING:
Cut to maximize future growth.
Areas can be cut before they reach rotation age
Use rotations which give maximum mean annual increment
Minimum Volume Cut = 50.0
Areas designated as reserves not cut
Use volume 1 of yield table to calculate evenflow cuts and growing stocks

OTHER OPTIONS:
The age in the forest data is tree age
Maximum uncertainty in maximum evenflow cut calculations = 0.0010%
Large polygons split at end of each time period and when required for accurate volume calculations

FOREST SUMMARY

DEFINITIONS: T = Number of years of harvest at CUT units per year
MEC = Maximum evenflow cut
TSR = Number of years cut before stock rupture to occurs
TMC = Number of years of harvest at maximum evenflow cut, MEC
TU = Number of years of harvest at uncertain maximum evenflow cut, UC
AVG AGE = Average age of the cut
AVG AREA = Average area cut per year during time period
AVG RR = Average return rate
PL HORIZ = Planning horizon used to calculate the MEC
EGS = The ending growing stock used in calculating the MEC

AVG CUT = average cut over time period of each volume in the yield table.
G. STOCK = growing stock of each volume type in yield table
TOT GS = Total Growing Stock on Forest (all volumes)
AVG TOT CUT = Sum of the average cuts of all volumes in yield table
* Indicates selected for evenflow

FULLY REGULATED FOREST: Longest Rotation 150 LRSYA = 192688
Regulated Growing Stock = 9227769

FOREST 1 Original Forest
Growing Stock = 14300106
TOTAL AREA = 103516 TOTAL MERCHANTABLE AREA = 103516
G. STOCK (14300106 19[illegible]39984640)

FOREST 2 Starting Forest = 1 TMC = 310.0 MEC = 198236* AVG AGE = 140
Growing Stock = 9228080* Year = 2305.0 AVG AREA = 784 AVG RR = 132
PL HORIZ for MEC = 310 EGS for MEC = 9227769
AVG CUT (198238* 185596368)
G. STOCK (9228080* 20382889984)
AVG TOT CUT = 185794608 TOT GS = 20392118272

Annual Allowable Cut (maximum evenflow cut) with six years regeneration lag

Forest_Muncher_3.6.2
Extra Regeneration Lag Version 2 for M. Pattison Last Change November 9 1995 Copyright 1995
Authors: Barbara H. Beck Ph.D. and James A. Beck Jr. Ph.D. R.P.F.

FOREST DATA: This is a sample of a pre-expansion working circle at Weldwood

YIELD TABLES: These yield tables are part of Weldwoods old yield tables

TEMPORARY EXTRA REGEN LAG = 6

RULES FOR CUTTING:
Cut to maximize future growth.
Areas can be cut before they reach rotation age
Use rotations which give maximum mean annual increment
Minimum Volume Cut = 50.0
Areas designated as reserves not cut
Use volume 1 of yield table to calculate evenflow cuts and growing stocks

OTHER OPTIONS:
The age in the forest data is tree age
Maximum uncertainty in maximum evenflow cut calculations = 0.0010%
Large polygons split at end of each time period and when required for accurate volume calculations

FOREST SUMMARY

DEFINITIONS: T = Number of years of harvest at CUT units per year
MEC = Maximum evenflow cut
TSR = Number of years cut before stock rupture to occurs
TMC = Number of years of harvest at maximum evenflow cut, MEC
TU = Number of years of harvest at uncertain maximum evenflow cut, UC
AVG AGE = Average age of the cut
AVG AREA = Average area cut per year during time period
AVG RR = Average return rate
PL HORIZ = Planning horizon used to calculate the MEC
EGS = The ending growing stock used in calculating the MEC

AVG CUT = average cut over time period of each volume in the yield table.
G. STOCK = growing stock of each volume type in yield table
TOT GS = Total Growing Stock on Forest (all volumes)
AVG TOT CUT = Sum of the average cuts of all volumes in yield table
* Indicates selected for evenflow

FULLY REGULATED FOREST: Longest Rotation 150 LRSYA = 192688
Regulated Growing Stock = 9227769

FOREST 1 Original Forest
Growing Stock = 14300106
TOTAL AREA = 103516 TOTAL MERCHANTABLE AREA = 103516
G. STOCK (14300106 44417956)

FOREST 2 Starting Forest = 1 TMC = 312.0 MEC = 198126* AVG AGE = 141
Growing Stock = 9227356* Year = 2307.0 AVG AREA = 782 AVG RR = 132
PL HORIZ for MEC = 312 EGS for MEC = 9227769
AVG CUT (198126* 423319)
G. STOCK (9227356* 46553808)
AVG TOT CUT = 621445 TOT GS = 55781164

Annual Allowable Cut (maximum evenflow cut) with seven years regeneration lag

Forest_Muncher_3 6 2
Extra Regeneration Lag Version 2 for M. Pattison Last Change November 9 1995 Copyright 1995
Authors: Barbara H Beck Ph D. and James A. Beck Jr. Ph.D. R.P.F.

FOREST DATA: This is a sample of a pre-expansion working circle at Weldwood

YIELD TABLES: These yield tables are part of Weldwoods old yield tables

TEMPORARY EXTRA REGEN LAG = 7

RULES FOR CUTTING:
- Cut to maximize future growth.
- Areas can be cut before they reach rotation age
- Use rotations which give maximum mean annual increment
- Minimum Volume Cut = 50.0
- Areas designated as reserves not cut
- Use volume 1 of yield table to calculate evenflow cuts and growing stocks

OTHER OPTIONS:
- The age in the forest data is tree age
- Maximum uncertainty in maximum evenflow cut calculations = 0.0010%
- Large polygons split at end of each time period and when required for accurate volume calculations

FOREST SUMMARY

DEFINITIONS: T = Number of years of harvest at CUT units per year
MEC = Maximum evenflow cut
TSR = Number of years cut before stock rupture to occurs
TMC = Number of years of harvest at maximum evenflow cut, MEC
TU = Number of years of harvest at uncertain maximum evenflow cut, UC
AVG AGE = Average age of the cut
AVG AREA = Average area cut per year during time period
AVG RR = Average return rate
PL HORIZ = Planning horizon used to calculate the MEC
EGS = The ending growing stock used in calculating the MEC

AVG CUT = average cut over time period of each volume in the yield table.
G. STOCK = growing stock of each volume type in yield table
TOT GS = Total Growing Stock on Forest (all volumes)
AVG TOT CUT = Sum of the average cuts of all volumes in yield table
* Indicates selected for evenflow

FULLY REGULATED FOREST: Longest Rotation 150 LRSYA = 192688
Regulated Growing Stock = 9227769

FOREST 1 Original Forest
Growing Stock = 14300106
TOTAL AREA = 103516 TOTAL MERCHANTABLE AREA = 103516
G. STOCK (14300106 21)

FOREST 2 Starting Forest = 1 TMC = 314.0 MEC = 198015* AVG AGE = 143
Growing Stock = 9227490* Year = 2309.0 AVG AREA = 783 AVG RR = 132
PL HORIZ for MEC = 314 EGS for MEC = 9227769
AVG CUT (198017* 0)
G. STOCK (9227490* 22)
AVG TOT CUT = 198017 TOT GS = 9227512