

Timber Supply on Public Land in Response to Catastrophic Natural Disturbance: A Principal-Agent Problem

by

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B.Sc.F., University of Toronto, 1989

M.F., University of British Columbia, 1995

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of

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in the Department of Geography

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Supervisory Committee

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Abstract

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Managing public forestland is a challenging enterprise as the government must steward the actions of private forest companies while simultaneously considering public values, natural disturbance, markets, revenue generation and environmental services. Governments use timber sales, volume-based, and area-based tenures to delegate forest harvesting activities to individual timber companies. By delegating forest management, government must wisely navigate the principal-agent relationship to avoid unexpected outcomes. However, the agents' response is often overlooked despite the likelihood that the agents may possess company-centric financial motivations.

The British Columbia context, where the government is facing the aftermath of a catastrophic mountain pine beetle epidemic, provides a fruitful location for the study of the principal-agent dilemma. If forest companies share a future forest focus with the government, such that agents respond with actions that lead to the government's first best outcome, the government could reduce policy analysis to an examination of the tradeoff between short-term revenue generation and sustainable differentiated product supply. But review of the silviculture funding mechanism reveals that the very regulatory mechanism used to achieve government's results may affect the future forest estate by reducing the

amount of salvage once the value of the forest is degraded below the cost to harvest and regenerate it. Relying primarily on harvest-based silviculture funding, the principal is shown to forego a 20 per cent increase in forest growth in the study area by not using the agents' forestry expertise to improve the long term productive potential of the forest.

A bi-level linear programming model is developed to merge the goals of government with the behavioural responses of the two predominant volume-based tenures used in BC. Results show that the government's choice of harvest level, timber price and tenure instrument in recognition of agent response is the only way to achieve the government's forest stewardship objective. Treating each element in isolation neglects the nature of the institutional system and will result not only in unintended outcomes, but very likely, policy failure.

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Dedication

This manuscript is dedicated to my God and my family, through whom I find such a clear sense of encouragement and purpose. My wife, Karen, supported me with amazing endurance, given my research trips to Williams Lake, my sojourn as a sessional instructor, and my re-awakening as a student. My children, Scott, Nicole and Kiera, graciously allowed me to upset our ski holidays with this new “daddy endeavour”, always giving support or suggestions when I looked like I needed it. To my “Fathers”, thanks for believing in my return to school, even if you weren’t exactly sure what I was writing about.

Chapter 1: Introduction

1.1 Introduction to Research

Management of public forestland poses a greater challenge than the management of private land. Governments must consider the multiple values of the timber resource and often conflicting societal goals for the forest, ranging from preservation to intensive management and tenure arrangements. Governments rarely retain their own logging expertise so that any tenure structure leads to a principal-agent problem with varying characteristics, the most extreme of which occurs in the case of quota or volume-based tenure.

British Columbia is a jurisdiction characterized by predominantly public forestland, which is why it provides a useful context for study. Further, the interior of the province is undergoing major attack from the mountain pine beetle (*Dendroctonus ponderosae* Hopk. [Coleoptera: Scolytidae]), which is an epidemic that is unique in its scale. The mountain pine beetle (MPB) epidemic exacerbates the principal-agent relationship. And yet, the most common approach used by government to estimate the impacts of the beetle has been simulation modeling using inventory projection tools. The provincial mountain pine beetle projection model is a spatial stochastic simulation model that uses the forest health aerial overview estimates of dead pine occurrence to project beetle population growth and pine destruction (Walton 2009). The outcomes from this model provide estimates to other timber supply models to assess biophysical timber supply impacts and, by extension, economic impacts by timber supply area (British Columbia Ministry of Forests and Range 2003, 2006, 2007; Timberline Forest Inventory Consultants Ltd 2006). The timber supply models project alternate timber supply trajectories depending on the timber types harvested and the length of time that beetle damaged timber can be successfully logged.

Stennes and McBeath (2006) examined one aspect of the economic issue – that related to the use of damaged pine for bio-energy. They used case studies and economic values derived elsewhere to predict possible hurdles to the use of MPB-damaged pine as bio-energy. They explored pricing, durability of supply, and facility pay-back period. Other researchers have extended this knowledge using linear programming techniques. Niquidet et al. (2008) examined

the cost of bio-energy feedstocks as a result of the geographical distribution of damaged pine. Examining only the harvesting and transportation costs, outside of startup and capital development costs, feedstock prices would be projected to double over a 20 year period in a case study in the Quesnel TSA in the interior of BC. They highlight that the viability of bio-energy as an outlet for damaged pine will be linked to what BC Hydro, the main purchaser of electrical power in BC, is willing to pay for energy purported to have green origins. Moreira-Munoz (2008) examined the implications of different timber salvage strategies in an area-based tenure, Tree Farm License 48, located in northeastern BC. His research highlights that allowable annual cut (AAC) uplifts alone do not ensure efficient pine salvage and that the provincial landowner needs to have effective non-pine harvesting policies in conjunction with AAC uplifts, as the harvest of damaged pine affects forest company revenue, to reduce mid-term timber supply impacts.

Another popular economic assessment tool is an equilibrium model. Abbott et al. (2009) used a multi-region spatial equilibrium model to examine the global implications of the change in timber supply as a result of the beetle. Patriquin et al. (2008) used a computable general equilibrium (CGE) model to examine the economic potential of using wood flow arrangements between two pine dominated TSAs in the interior of BC to reduce the impact of the increased short-term harvest on the adjustment to future harvests as a result of the beetle crisis. Patriquin et al. (2007) created a CGE for each of five regions in BC to understand the likely economic vulnerability of these regions to the MPB infestation. General equilibrium models are powerful tools for understanding how the change in timber supply as a result of the MPB will impact the local and then provincial economy.

An alternative approach has been the use of agent-based models to understand what the physical timber supply may be. Schwab et al. (2009) created a provincial scale model of the interaction of a number of virtual forestry firms, representing the current mill configuration in the province, operating under heuristic rules of economic behaviour in response to market signals and forest damage by mountain pine beetle. At each decision step, the firms decide on a course of action from a fixed set of allowable actions. Stumpage is represented as a maximum bid by each firm. The dynamics of the model show the potential for insights into industry development and collapse, especially through examination of cooperative and non-cooperative agent strategies.

Mathey and Nelson (2010) use a cellular automata approach, simulating the profit-maximizing behaviour of a single firm operating in an area-based tenure during a MPB epidemic. They explore essentially two forest management strategies, whether to uplift and whether to focus on pine. They conclude that the provincial landowner, Alberta in their case, could likely implement an uplift strategy, as employed in BC, given that harvesting at an elevated rate is more profitable for a company, resulting in harvesting actions that achieve the government's risk reduction strategy.

A gap in the analysis to date has been the influence of government intervention coupled with forest firm behavior. Mathey and Nelson (2010) point to the key issue: whether government's forest management strategy will produce the desired result. Given the area-based nature of the tenure they examine, Mathey and Nelson reasonably assume that the objective function of the forest firm will include terms for both harvested and standing timber. However, the volume-based tenure holders in BC are unlikely to include the value of standing forest in their profitability ledger but will focus on maximizing the value of harvest activities within the planning period of their license. This creates a conundrum in that government has no definitive means to address this issue in its Mountain Pine Beetle Action Plan (Nelson 2007), while the two types of volume-based tenure holders, replaceable and non-replaceable, possess different objective functions. An important next step is to examine the interplay between how government develops forest policy and the forest companies' responses. This interplay is highly suited to the use of the principal-agent (PA) framework employed in this study. Under the PA approach, the researcher examines the first-best solution from the principal's perspective compared with that from the agent's perspective. Given that the agent generally has the freedom to choose from a range of options, the principal needs to manage the outcome by managing the likely response of the agent to the parameters that the principal controls (e.g., stumpage, silvicultural obligations, harvest level). We are aware of no analysis that has identified the risk associated with the institutional setting — the tenure relationship. Attempting to manage timber supply, the provision of timber through time, without addressing the institutional framework could lead to policy failure.

The current study confronts two separate gaps in current research. First, it provides a valuable quantitative example of principal-agent theory applied to a forestry problem. Second, it provides a counter-factual to the biophysical timber supply projections of the outcome of the

mountain pine beetle infestation using the principal-agent relationship. The following questions are answered:

1) What constitutes the theoretical basis of the principal-agent problem and how does it relate to forest tenure arrangements?

2) What influence does the sporadic progressive pine beetle attack have on government's first-best forest management strategy?

3) What additional light does the principal-agent paradigm shed on the relationships among the silvicultural regime, forest productivity and beetle salvage operations?

4) What is the 'tenure effect' attributable to the tenure instruments government currently uses and what is the impact relative to a first-best management strategy?

1.2 Dissertation Structure

The chapters in this dissertation have been organized to address each question sequentially while building on the principal-agent theme. We begin in Chapter 2 by describing the broad area of new institutional economics, which is where principal-agent theory finds its roots. The chapter explores the application of principal-agent theory to forest resource management, with particular emphasis on the tenure system used in British Columbia. In Chapter 3, the sporadic annual damage caused during a beetle outbreak in a typical BC timber supply area (TSA) is explored. Using mathematical programming, a model is developed to represent the government's first-best outcome; a novel approach to the specification of the forest management objective function is introduced, namely, maximizing the future forest estate value rather than discounted net returns. In this way, it is possible to simulate the optimal harvest of stands despite their negative value due to beetle damage.

In Chapter 4, we examine the silvicultural funding mechanism in BC and how principal-agent theory suggests that the principal may not be achieving its objectives because of inefficient behavior by the agent from the perspective of the principal. The mountain pine beetle has altered the value of pine, reduced timber rents and impacted the silvicultural re-imbursement of regulated practices. The research uses mathematical programming with a PA approach to examine regulation-based silviculture treatments alongside forest company-based regimes to estimate how the current silvicultural funding system is influencing agent behaviour.

In Chapter 5, a bi-level programming representation of the PA problem is developed. The model is used to explore the catastrophic natural disturbance caused by the mountain pine beetle in British Columbia. The principal (government) uses harvest levels and stumpage fees to incentivize two agent types representing two alternative volume-based tenures to harvest beetle-impacted pine, while leaving sufficient living pine and non-pine species to ensure adequate future timber supply.

Finally, Chapter 6 concludes the dissertation, tying the conclusions of the three preceding chapters together in a summarization of the original research hypothesis on the influence of the principal-agent relationship on forest management outcomes.

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Chapter 2: New Institutional Economics and PA Theory in Forestry¹

2.1 Introduction

A forest is much more than a bunch of trees. Scratch the surface of the vast forest landscape, and one will see a myriad of biota and a complex and interesting biophysical world. But when forests are viewed from the perspectives of society, economy and human wellbeing, a complex network of institutions comes onto the scene. It is this dynamic network of institutional arrangements that provide necessary governance structures for an array of activities related to the management and use of forest resources.

A variety of economic approaches have been utilized in the analysis of forestry problems (see van Kooten 1993; van Kooten and Bulte 2000; Hyde 2012). The focus of this chapter is on a particular approach, known as the new institutional economics (NIE), and how it may be applied to forestry. NIE builds upon and extends neoclassical economic theory by incorporating into main stream economics a body of theory pertaining to institutions (Coase 1998, 1984). Since the 1970s, NIE has made a large impact on the social sciences, especially economics and political science. Uniting theoretical and empirical research to examine the role of institutions in economic activities, NIE comprises work regarding transaction costs, property rights, hierarchy and organization, public choice and so on. In recent years, NIE has increasingly provided fresh insights into various aspects of social organization and sectors of the economy, including forestry (Wang and van Kooten 2001). The objective of this chapter is to provide an overview of what NIE contributes to economic practice and, more importantly, the insights it offers regarding forestry. We illustrate the potential contribution of NIE in terms of forest policy using a Canadian case study.

In the next section, we provide an overview of NIE in terms of its origin, scope and main developments. Then, in section 3, we offer a synthesis of the major applications of NIE to important fields of economic analyses, and, in section 4, we present a case study of NIE applied

¹ This chapter is under consideration as a chapter in a forthcoming forest economics handbook, and is co-authored with S. Wang and G.C. van Kooten.

to forest management and policy in the context of British Columbia (BC), Canada. The chapter ends with a few concluding remarks.

2.2 New Institutional Economics: genesis, scope and developments

As a distinct field of economics, the New Institutional Economics traces its origins to the earlier or 'old' institutional economics found in the writings, for example, of Thorstein Veblen, John Commons, Wesley Mitchell and Clarence Ayres. These writers were discouraged by what they perceived to be the lack of explanatory power in neoclassical economics, and its failure to take account of institutions. However, the old form of institutional economics sought to jettison much of neoclassical theory but offered little in its place except descriptive analyses that took each situation as somehow unique – it lacked a solid theoretical foundation that might be applicable more broadly, say outside the particular culture or organization of economic affairs.

The term, 'New Institutional Economics,' was coined by Oliver Williamson to distinguish it from the 'old' institutional economics (Coase 1998). There is now a consensus among scholars that Ronald Coase's 1937 paper, 'The Nature of the Firm,' provided the original and enduring inspiration for the development of NIE. With a focus centering around the theory of the firm and transaction costs, NIE benefitted from the ideas of the Austrian school of economics (Hayek 1937, 1945), the economics of information (Stigler 1961, 1975), human behavior and cognitive science (Simon 1957, 1962), organizations and markets (Williamson 1975, 1985; Simon 1991), the theory of property rights (Alchian and Demsetz 1972; Demsetz 1967; Barzel 1989; Pejovich 1995), institutions (North 1990, 1991), the history of industrial enterprise (Chandler 1992), and, lastly, transaction cost economics (Williamson 1979, 1998; Groenewegen 1996).

NIE is concerned with the role of governance structures in terms of institutional environment and institutional arrangements. As far as the institutional environment is concerned, important aspects include the legal environment, property rights, norms and social conventions. From the standpoint of the theory of the firm, institutional arrangements explain why production is often internalized within an industrial organization as a result of economizing on transaction costs. Although markets act as necessary institutional mechanisms for many productive activities, vertically integrated governance structures will exist for reasons that are best explained by NIE.

2.3.1 *Institutions, property rights, and contractual arrangements*

Institutions are the humanly devised constraints that structure political, economic and social interaction. They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct), and formal rules (constitutions, laws, property rights) (North 1991). Specifically, institutions are defined as the legal, administrative and customary arrangements for repeated human interactions. Their major function is to enhance the predictability of human behavior (Pejovich 1995). The growing literature around institutions point to a distinction between the institutional environment and institutional arrangements. Collectively, the institutional environment and institutional arrangements constitute governance structures. Broadly speaking, institutions provide a system of rules plus the instruments that serve to enforce the rules. In daily life, we observe explicit and implicit contractual frameworks, which include markets, firms and mixed modes within which transactions occur.

The notion of property rights is central to institutions. Property rights refer to the socially sanctioned and enforceable claims that an individual or a group has to the benefits associated with certain physical assets or services subject to the conditions that society places on the use of the assets or services in question. Property rights have a number of dimensions, including comprehensiveness, duration, transferability, benefits, exclusiveness and security. In economic activities, the property rights over an asset indicate the individual's (group's) ability to consume the good or receive the services of the asset directly, or to consume it indirectly through exchange. Property rights include: (1) the right to use an asset, (2) the right to earn income from an asset and contract over terms of use with other individuals, and (3) the right to transfer ownership permanently to another party (Demsetz 1967; Barzel 1989). It is important to note that property rights are claims that are recognized and enforced by authorities, most notably the government (Furubotn and Pejovich 1972, 1974).

Production and exchange involve contractual arrangements. As a legally enforceable agreement between two parties, a contract is a legal commitment to which each party gives express approval (either in written or less often verbal form) and to which a particular body of law applies. Contractual activities take place, not only for the purpose of accomplishing the exchange of goods and services but also to permit the exchange of bundles of property rights (Furubotn and Pejovich 1972). From the point of view of markets and organizations, contract terms are influenced by a number of factors including the access that contractual parties have to

information, the costs of negotiating, and the opportunities for cheating (Simon 1991). While it is of great importance to examine the institutional environment and property rights structure surrounding an economic activity, it would be a mistake to neglect contractual arrangements. In fact, analysis at the level of contractual terms will often yield deep insights regarding economic incentives and transaction costs.

2.3.2 *Transaction cost economics*

In spite of the fundamental role of markets in coordinating economic activities, the firm has been recognized as a primary coordination mechanism. According to Coase (1937), the nature of the firm is to reduce the number of transactions for the purpose of producing a more efficient outcome. As long as the firm can coordinate a transaction at a lower cost than the market, it pays to internalize the function. Once coordination becomes onerous, a firm may need to allocate the function to the market.

The theory of the firm is viewed as the core of NIE, and transaction cost economics (TCE) is at the heart of that theory and at the centre of the economics of organization. The term, 'transaction costs,' has many definitions. Generally speaking, transaction costs refer to costs incurred for the creation, maintenance, use, and change of institutions and organizations. They include the costs of defining rights, the costs of utilizing and enforcing the rights specified, and the costs of information, negotiation and enforcement.

Humans are assumed to be rational economic agents to a certain degree and people are opportunistic. Bounded rationality and opportunism are two key assumptions underlying the TCE theory. While the opportunistic aspect of human nature is easy to imagine, the concept of bounded rationality needs elaboration (see Simon 1957). It is costly for individuals to contemplate and contract for every contingency that might arise over the course of the transaction; this adds to the ex ante cost of drafting a contract. These costs may be so high that the individuals fail to provide for the contingency in the contract or fail to undertake the contemplation necessary to foresee the contingency. According to Williamson (1975, 1971), the central concern for economic organizations is to devise contracts and governance structures that have the purpose and effect of economizing on bounded rationality, while simultaneously safeguarding transactions against the hazard of opportunism.

TCE places an emphasis on the firm. In other words, the firm acts as an institution within which transactions take place – as an alternative to transactions that take place in a market. From the point of view of TCE, firms and markets are alternative means of economic organization. Whether transactions are organized within a firm (hierarchically) or across a market between autonomous firms is a decision variable. Which mode is adopted depends on the transaction costs that attend each. The basic premise of TCE is that transactions tend to be organized in ways that maximize the net benefits they provide, where the cost of the transaction is taken into account. Transactions differ in their attributes and are thus aligned with governance structures that differ in their costs and competence in a transaction-cost economizing way. Differential transaction costs give rise to discriminating institutional alignment according to which some transactions will align with one set of governance structures and other transactions will align with others. Each mode of governance is defined by a series of attributes, whereupon each displays discrete structural differences with respect to both cost and competence.

Williamson extends the scope of TCE to emphasis to all economic organizations. More recently, scholars tend to think of TCE in the context of all economic institutions and institutional arrangements. Hence, it is valid to examine contracts by looking at the transaction costs ex ante and ex post. Ex ante transaction costs include the costs of negotiating a contract, searching and information gathering; ex post costs include the costs of safeguarding the deal that was originally struck, namely, the monitoring and enforcement costs.

Transaction costs are difficult to quantify, but this difficulty is mitigated by the fact that transaction costs are always assessed in a comparative way, in which one mode of contracting is compared with another. Accordingly, it is the difference between rather than the absolute magnitude of transaction costs that matters (Williamson 1985, pp.21-22). Empirical research on transaction costs focuses on the question of whether contracting practices and governance structures line up with the attributes of transactions as predicted (Williamson 1985).

The key technical, human and behavioural dimensions of transactions correspond to asset specificity, bounded rationality, and opportunism, respectively (see Table 1). Generally speaking, the more specific or specialized an asset (or activity), the higher is the possibility of appropriating the benefits arising from its designated and intended uses, but the less adaptable is the asset (or skill) to employment in an alternative use.

Table 2.1: Important Parameters of Transaction Cost Economics

Dimension	Attributes
Specificity	<p>Physical asset specificity is a measure of asset redeployability arising from the special and general purpose of investments. Special purpose investments may be risky because specialized assets cannot be redeployed if contracts are interrupted or prematurely terminated. General purpose investments do not pose the same difficulties. Hence, the more specific a physical asset or skill, the lower is its opportunity cost in its best alternative use; hence, the cost of transacting to re-employ or re-deploy the asset is higher.</p> <p>Human asset specificity is a measure of relation-specific investments, such as bilateral dependency.</p>
Uncertainty	<p>The capacity of the governance structure in adapting to disturbances is measured by the probability of continuation (durability of firm-specific assets). Also, contract length is important because long-term contracts mitigate inefficiencies associated with ex ante underinvestment and ex post opportunism.</p>
Frequency	<p>The degree to which transactions recur is positively related with the specialization of governance structures. For idiosyncratic investment, when frequency reaches a certain point, unified governance comes into being.</p>

Unlike the standard economic approach that is preoccupied with technology and production expenses, TCE examines comparative costs of planning, adapting and monitoring task completion under alternative governance structures. For this purpose, there is a need to identify different types of transactions and how they vary under different circumstances. Specifically, the factors responsible for transaction cost differences need to be identified in order to understand why some transactions are organized one way and other transactions another. Asset specificity is positively correlated with firm size, with small companies more likely to have general purpose plant and equipment. The market is the main governance structure for nonspecific transactions in the case of both occasional and recurrent contracting.

In terms of the advantages that TCE offers, Williamson (1985, pp.17-18) considers the economic importance of asset specificity, the business firm as a governance structure rather than a production function, and the means for comparing the transaction cost implications of alternative contractual arrangements. Williamson notes that any issue that can be formulated as a contracting problem can be investigated in the transaction costs economizing framework.

2.3.3 *Moral hazard, agency, and information problems*

Contracts are important because of their indispensable role in coordinating the exchange of products and services (Hart 1995). In analyzing contracts, the issue of moral hazard needs to be taken into account and the problem of agency should be dealt with by means of appropriate contractual terms. The incidence and effect of moral hazard were analyzed extensively in the literature concerning businesses and other organizations (Holmström 1979; Jensen and Meckling 1976). The notion of moral hazard may best be understood from the perspective of human behaviour, using a principal-agent (PA) setting. The agent has an incentive to hide crucial information from the principal in order to exploit opportunities for gain by pursuing one's own self-interest. It is entirely possible that the agent possesses hidden information or goals that are detrimental to the principal (Holmström 1979). Williamson (1985, p.51) defined this behavior as the 'propensity of human agents to behave opportunistically.' Ross (1973) was one of the first to model formally PA relationships, while Fama (1980) elaborated the agency problem using the theory of the firm.

Economic activities are associated with various types of information. Often the available information is limited, incomplete or irrelevant. Strictly speaking, there are two aspects to the information problem, namely, information deficiency and information asymmetry (Ross 1973; Stiglitz 1974, 1975). The recognition that the transfer of information between principal and agent is a key element to their effective relationship has led to significant theoretical research into the economics of information (Stigler 1961; Campbell 2006).

Two crucial elements that characterize principal-agent problems arise from the asymmetry of information between the two parties. The agent may choose actions that are not in the interest of the principal, termed *adverse selection* (Salanie 1997). Consider as an example a forest landowner (principal) who hires a logging firm (agent) to harvest timber. Suppose the issue pertains to salvage harvesting of wind, pest or fire damaged timber. In some cases the logging firm has the ability to select which timber is to be harvested; thus, the firm will harvest damaged timber with the most suitable properties desired for further processing, leaving more questionable timber standing. By removing more valuable trees and not addressing proximate areas, the agent reduces the value of the principal's resource base. Likewise, if damaged trees could be assigned to a specialty mill with optical scanners (to extract the greatest value from the timber) but the principal chooses a logger associated with a mill owner who has opted not to

invest in the necessary technology, the value of the forest resource is reduced by what amounts to a wasteful practice of which the principal may not be aware.

Given the moral hazard problem, the principal must carefully consider the costs and tradeoffs of alternative actions in order to strike as efficient a contract as possible in a world of informational deficiency. To do so, the principal may use signalling or screening *ex ante* (Slangen et al. 2008), although signalling may also occur *ex post*. A proper design of contractual terms with careful consideration of potential agency problems will help diminish transaction costs and achieve efficient outcomes from an economic standpoint.

2.4 Economic development and natural resources in an NIE context

The problems of economic development, natural resources and social dilemmas (*viz.*, externalities, open access) (Ostrom 2000) are not that neoclassical economic explanations are inappropriate, but rather that they are incomplete. Other than markets and private property, three additional factors have been addressed by NIE – economic institutions, the role of the state and social capital (Fukuyama 2002).

As noted above, a country or state must have a set of institutions within which policy change can occur. Institutions consist of formal rules (constitutions, laws and property rights) that constrain political, economic and social interactions, and include such things as commercial and criminal courts. Unlike cultural constraints, they are more amenable to change, although certain inertia may be required to overcome vested interests. Economists have often ignored institutions, even though existing institutions may not always be the ‘right ones’ (Bromley 1999). Research in economic development now stresses the need for good institutions, as some institutions retard rather than promote growth (La Porta et al. 1999), or become an obstacle to resolving social dilemmas in resource management (Ostrom 2000). In order to remain effective, institutions need to evolve over time in response to changing circumstances, and the rate at which they evolve must not slow the progress of policy change.

Economic policies can only be carried out by the state, but the state must be limited in scope and yet able to enforce the rule of law. The state must be competent and sufficiently transparent in formulating policy, and have enough legitimacy to be able to make painful decisions. The role and performance of government is essential to economic development and the resolution of social dilemmas (La Porat et al. 1999). Good governments protect property

rights and individual freedom, keep regulations on businesses to a minimum, provide an adequate (efficient) level of public goods (e.g., infrastructure, schools, health care, police protection, court system), and are run by bureaucrats who are generally competent and not corrupt. Unfortunately, regulatory agencies often prevent entry, courts resolve disputes arbitrarily and sometimes dishonestly, and politicians use government property to benefit their supporters rather than the population at large.

The third factor needed to resolve social dilemmas is social capital (Putnam 2000), or “the proper cultural predispositions on the part of economic and political actors” (Fukuyama 2002, p.24). The ‘cultural factor’ constitutes informal constraints (sanctions, taboos, customs, traditions, and norms or codes of conduct) that structure political, economic and social interactions. Social capital has both individual and aggregate components (Gelauff 2003). Individual social capital consists of intrinsic aspects (charisma, values) and aspects in which one can invest (trustworthiness, personal networks), although these two aspects are difficult to separate. Aggregate social capital, on the other hand, constitutes the total of the social capital of the individuals in society, varying by form (trust in people, trust in government, level of participation in society), place (firm, region in a city or country, neighbourhood), and group (ethnic and religious groups, service organizations, sport associations, gangs). It is difficult for society to invest in aggregate social capital because the manner in which the social capital of individuals is aggregated is not clear. A society can only invest in culture by somehow affecting individuals who do the investing. For example, society can encourage couples to stay together longer by making divorce more difficult, or encourage church attendance by providing tax incentives for charitable giving, but both actions fail to address culture directly.

Trust is perhaps the most important component of social capital: “Virtually every commercial transaction has within itself an element of trust, certainly any transaction conducted over a period of time” (Dasgupta 2000). Trust is not social capital, but a manifestation of it; trust is related to institutions and affects the costs of transacting. If confidence in an enforcement agency falters, one may not trust others to fulfil their agreements and thus enter into fewer agreements. There is an element of trust in any transaction where one has to decide (make a choice) before being able to observe the action of the other party to the transaction. One has to assume that the other person is not acting with guile, keeping information hidden that could be used to their advantage at the expense of the other party to the transaction. Like other

components of social capital, trust makes an economy function more efficiently (Fukuyama 1999).

In addition to trust, other elements of social capital include social norms, or behavioural strategies (e.g., always do p if q occurs) subscribed to by all in society, and networks of civic engagement (membership in swim clubs, church organizations, etc.) that enhance cooperation. Ostrom (2000) shows how social norms of reciprocity and trust, combined with local enforcement and graduated sanctions, result in effective resource management regimes.

As noted, one important aspect of trust relates to hidden information – the asymmetry of information that exists between two parties to a transaction or contract. This evolved into principal-agent (PA) theory, with studies of PA problems paralleling developments in transaction cost studies. Significant progress has recently been made into the PA problem and the role of property rights in resource exploitation and environmental protection. The latter line of inquiry evolved into new thinking about collective action, led by the late Nobel laureate Elinor Ostrom (1990, 2005). Her 1990 book, entitled *Governing the Commons: The Evolution of Institutions for Collective Action*, quickly became a classic as it showed that economic governance structures are multi-faceted and complex, making analysis trickier. Ostrom (2005) subsequently demonstrated that common property could be successfully managed by the users of a resource, given a set of conditions that includes trust and carefully designed cooperation-enhancing incentives. Her work in the area of collective action and political economy provides a link between the fields of organizational theory and political science via a separate body of literature known as public choice. These writings have made significant contributions to advancing our understanding of how the institutions governing natural resources evolved and how they can be efficiently managed.

In the context of forest ecosystems, Ostrom (1998) rejected simple, large-scale, centralized governance units, arguing that forest biodiversity needs to be matched by institutional diversity. In the next section, we examine the role of institutions and insights that NIE thinking has on forest policies and management.

2.5 Applications of the new institutional economics framework to forestry

Economists having an interest in forests are keenly aware that the institutional framework will significantly influence both the policy choices available to the public landowner and the responses of the forest firms (Nelson 2007). Where past approaches tended to focus on the economic response to rules, Luckert (2005) indicates that economists are now beginning to examine alternate arrangements, where economic behaviour influences the development of the institutions or rules.

2.5.1 Relevance of new institutional economics to forestry

In the context of the institutional reforms made to British Columbia's forestry sector at the end of the last century, Wang and van Kooten (2001) applied NIE to investigate forest companies' decisions to contract out silvicultural activities or to perform them in-house. A model was developed to test the relationship between a firm's choice of contractual forms and (a) the attributes of the activity (e.g., specificity of technical skills and physical assets, frequency of operations, and uncertainty in controlling performance quality), and (b) the characteristics of the firm (e.g., company size). Data from a survey of forest companies in BC were used to test several hypotheses arising from the NIE approach. The empirical results confirmed the transaction cost logic that silvicultural activities performed in-house are likely those that are complex to manage, have a low degree of seasonality, require high levels of human skills, and involve highly specialized physical assets. As asset specificity or specialized skill increased and the duration of the activity decreased, contracting an activity became more attractive to the firm.

Recently, the application of NIE approaches has increased in intensity. For example, van Kooten et al. (2002) examined the institutional arrangements and economic incentives needed to encourage landowners in Canada to plant trees on a large scale. They concluded that the transaction costs of getting landowners to convert agricultural land to forest plantations were a major roadblock to their adoption. The analytics of transaction costs has been used in the examination of biological carbon sinks (van Kooten 2009), and the institutional context of forest management systems in China has been examined from the perspective of NIE (Zhang 2001).

One important concept, as noted above, deals with asymmetry in contracting, which has led the adoption of principal-agent (PA) theory to the issue of forest tenures. In its simplest form, the PA relationship is one of delegated choice where the principal (public landowner) delegates management to another party (forest company), called the agent (Rees 1985). Delegation arises when tasks are "... too complicated or costly to carry out oneself" (Sappington 1991). In the next section, we adapt the principal-agent framework to contemporary forestry issues in Canada's province of British Columbia.

2.5.2 The principal-agent problem in the forestry context

With specialized assets, the agent may wish to keep the proprietary interests that may be created hidden for competitive advantage in the marketplace. A forestry example of this is provided by Nelson et al. (2009), who examined whether the managers of BC forest companies (mill managers) were maximizing their economic options. They found that managers (the agents) were readily willing to discuss general questions about perception in the forestry business, but were highly wary about discussing specific financial issues related to their firm.

On the surface, the PA relationship developed because it is mutually beneficial to both parties. If the parties share a common objective and management understanding then the agent's choices (actions) will bring about outcomes desired by the principal. Stiglitz (1974) produced one of the earliest examples of a unified description of the PA problem in natural resources; he explored the landlord-labour relationship in agriculture. He concluded that, when direct supervision is either costly or ineffective, the use of sharecropping has an incentive and risk-sharing effect, making the principal-agent relationship more efficient than internalizing the activity. Sterner (2003) notes that information asymmetry in natural resources between the principal and agent can be so severe that simple rental agreements may be the only appropriate policy instrument.

The principal-agent theory has often been used to describe differentiated contractual services in forestry. Wang and van Kooten (2001) used the PA theory to explain the emergence of silvicultural contractors when the BC government chose to shift responsibility for regeneration (and hiring of individual tree planters) to the forest companies. Vedel et al. (2006) provide an elegant theoretical principal-agent explanation for why private forest companies initially switched to differentiated contracts for forest advisory services, while Paarsch and Shearer

(2009) recently examined the effectiveness of incentives offered to tree planters in determining the optimal piece-rate contract. The piece-work context has been suggested as the sole application of the PA theory, but this assertion has been challenged because the paradigm has such broad applicability (van Ackere 1993). In fact, Miller (2005) points out that there is no single solution to the principal-agent problem, as it is the juxtaposition of the two party's beliefs, goals, and willingness to deal with risk that produces the necessary blend of actions between the two parties.

For this reason, many qualitative forestry examples use PA theory's explanatory power. Kufuor (2004) uses the PA theory to describe the policy failure that plagued attempts to create sustainable forestry conditions in Ghana. Gray (2002) uses it to describe forestry concession policies with respect to government revenue systems, while Karsenty et al. (2008) apply the theory to forestry concessions in Central Africa and South America, stating that the economic value of the forest to the principal is contingent on the efficiency of the forest company. A number of qualitative studies have used the framework to describe forestry certification systems (Cousins 2006; Rametsteiner 2002; Kiker and Putz 1997). And Bowers (2005) applies the theory to examine incentive instruments that could be used to motivate private forestry firms to carry out sustainable forestry activities as defined by the principal or regulator.

Quantitative examples of the use of the PA theory in a forestry context are more difficult to find. Krepps and Caves (1994) use the theory to explain why the value obtained from tribal forestland was dependent on whether tribal lands were managed internally (by the principal) or externally under contract with the United States Bureau of Indian Affairs. It was found that both the quantity and quality of timber increased when the tribal leaders retained services in house rather than contracting to agents with a lower stake in the financial outcomes for the tribe.

Laffont and Martimort (2002) have pointed out that the principal uses the tactic of *screening* to obtain a certain type of agent. For example, until recently, provincial governments in Canada regularly required appurtenancy in forest tenures – the forest company (agent) had to operate a mill as a condition for obtaining access to large timber quota. Appurtenancy introduced an explicit commitment level for a company and served many purposes, including investment in infrastructure, the employment of local people and the increased likelihood that the company would take a longer rather than shorter term view of the forest resource. This screening mechanism was seen as an impediment to a competitive forest industry and was eliminated under

the BC government's 2003 Forestry Revitalization Plan (British Columbia Ministry of Forests and Range 2003; Niquidet 2008). Agents are then able to *self-select*, not taking contracts that are outside their specialization or beyond their capacity (Slangen et al. 2008).

2.5.3 *Mountain pine beetle and forest policy in British Columbia*

Government news releases can be seen as a *signalling* mechanism used to provide insights into how government views a certain situation. British Columbia's provincial government sent a strong signal concerning the catastrophic nature of the mountain pine beetle (MPB) epidemic by creating a geographic salvage area defined in Order-In-Council 661-08. This provided forest companies with some valuable funding from the federal government, but also put existing tenure holders (agents) on notice that pine salvage was a key priority. Multiple reports released by the BC government showed that the signal was picked up by the agents, with most responding by increasing the proportion of pine in harvests above the proportion of pine on the land base (Forest Analysis and Inventory Branch 2007). However, signals can only be effective if the agents' response has a limited impact on their economic well-being.

Once the principal becomes convinced that agent activities could impact the value of the future forest, something beyond monitoring simple harvest content is required. In response to concerns that agents had begun to include more non-pine in the harvest mix in regions affected by the MPB epidemic, the BC government implemented something called 'partitioning,' whereby the harvest level determined in a management unit was distributed between stand types or species mixes in an attempt to regulate or constrain the harvest activities of the agents. This increased the principal's monitoring requirements. As the difficulty of monitoring increases, the principal may find it is better to incentivize truth telling.

An interesting forestry example meant to facilitate truth telling is the historic use in BC of a dead timber grade (Grade 3), which was charged a nominal fee of C\$0.25 (pre-2006). Although the principal lost some resource rent if the value of a dead tree was nonetheless significant, the principal used Grade 3 to encourage the use of deteriorating logs thereby leading to greater lumber recovery while obtaining a clear signal of the agent's activity. When the BC government altered its timber grading system to capture additional rent, representing a more differentiated stumpage, dead timber could be assigned a sawlog Grade 1 or Grade 2, with stumpage rates in excess of \$10/m³. Companies responded by kiln drying entire logs before grading occurred,

because logs could erroneously be assigned Grade 1 or 2 when in fact they were eligible as Grade 4 (called ironically a lumber reject), as kiln drying of logs exposes the cracks that might be completely hidden due to the length of time the logs are exposed to elements such as rain or snow. Exposure to moisture causes the wood to expand and seal up the previously visible checks (Oliveira and Kostiuk 2008). Although an extreme process, companies could realize substantial savings by kiln drying low-grade, beetle-damaged logs. With stumpage accounting for 25% of log cost and reforestation costs also born by the forest company, the management of these costs can play a significant role in defining the economic land base (van Kooten and Folmer 2004, pp.48-53; Luckert 2007). This is an example of the *time inconsistency* problem, whereby the principal may change its policy and thereby weaken an agent's sense of certainty with respect to planning for the future (Slangen et al. 2008).

To engage an agent to provide a service or product, the principal must be fully aware of the minimum *participation condition* required to entice the agent to agree to a relationship or sign a contract. Once a contract is in place there is 'institutional lock-in' so that the principal may be able to use 'coercion-focused' constraints to affect the agent's behaviour (Stanbury and Vertinsky 1998). However, if the effort required by the agent or the asymmetry of information is above some threshold, the principal must include an *incentive condition* if it hopes to manage the agent's behaviour by relying on the agent's self-interest.

In the case of forestry, the most common PA relationship likely pertains to the timber disposition on public forestland. The principal must decide on the tenure arrangement and the bundle of property rights and responsibilities to allocate to a forest firm, which, in turn, influences the complexity of the PA relationship. Public forestland can be managed in various ways, but the common ones include standing timber sales, volume-based tenures and area-based tenures. At 95%, BC has one of the highest proportions of public forestland ownership in the world, making it an ideal location for exploring the principal-agent relationship (Niquidet 2008). Gray (2002) points out that government typically lacks the internal capacity, capital and industry experience to operate logging operations, and chooses instead to contract this out to specialized forestry firms. This leads to a PA relationship.

To manage this relationship, the BC government uses standing timber sale licenses administered through BC Timber Sales (TSL), two types of volume-based tenures – non-replaceable (NR) and replaceable (R) – and an area-based tenure. The latter tenure consists

primarily of tree farm licenses (TFL) operated by a forest company, although there are smaller area-based tenures such as woodlots managed by individuals and community forests managed by community groups. In Figure 1, we provide an indication of the control over management that the principal grants the agent. Three management characteristics are displayed in the figure: (1) the exclusivity of property rights enjoyed by the license holder (vertical axis), (2) the term of the license agreement (horizontal axis), and (3) the size of the extent to which an agent can impact the forest footprint (with a larger font indicative of a greater footprint).

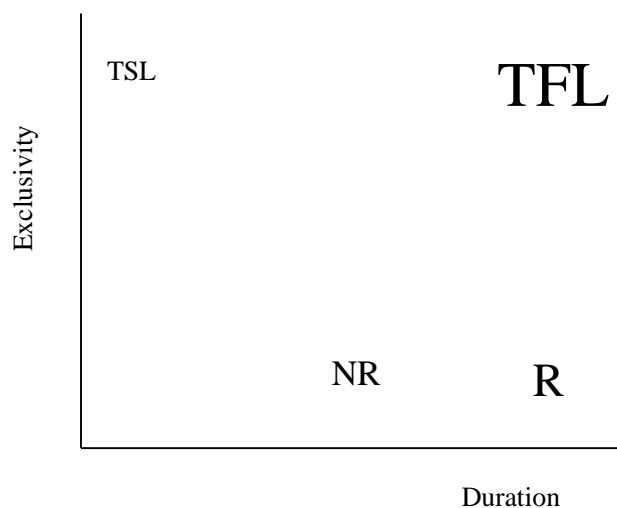


Figure 2.1: Tenures compared by exclusivity, duration and influence on the forest estate: timber sale license (TSL), non-replaceable license (NR), replaceable license (R), and tree farm license (TFL) (Greater influence indicated by increasing font size.)

A timber sale license provides complete exclusive rights within the physical boundaries of the timber sale area developed for harvest by the principal, but rights are short-lived. This tenure maximizes control that the principal can exert over the management of harvests. With standing timber sales, the principal develops the forestlands for harvest and limits the influence that the agent has on the forest, but it needs to retain a highly specialized work force to develop these sales. The agent is provided exclusive rights to the area defined by the TSL, but the principal must still be aware of incentive constraints to ensure the best possible outcome from its perspective. Given the repeatability of these transactions and their short duration, the principal gains knowledge of the various agents so as to modify quite easily future contracts and even refuse certain bidders (Leffler and Rucker 1991). While providing the highest level of control, in managing TSLs for multiple values the public landowner may be criticized for failing to achieve the best financial benefit and may even result in a burden on the public purse because

administrative cost may be incurred when the agent decides not to harvest a site (Rucker and Leffler 1988). To address concerns raised by U.S. softwood lumber producers concerning lack of transparency (market forces) in setting stumpage fees, the provincial government shifted 20% of the volume allocated under long-term R and TFL tenure forms to TSLs sold at auction, thereby also creating a government timber development agency, BC Timber Sales (Niquidet 2008).

At the other extreme, forest management activities on a particular forest may be completely delegated to the holder of a Tree Farm License; a TFL grants exclusive timber rights over a much larger area and for a long duration than a TSL, which implies that the license holder is able to plan not only short-term harvest decisions but also longer term management without interference from another licensees. In this case, however, the principal must consider how the agent will behave. Using appropriate differentiated stumpage mechanisms, the principal can ensure that the forest is not high-graded during the term of the license agreement (Amacher et al. 2001).

Mathey and Nelson (2010) considered optimal decision-making within an area-based tenure when mountain pine beetle struck, concluding that the tenure-holder's most profitable strategy would actually achieve the government's risk reduction strategy on public land, a key consideration in the principal-agent relationship. However, it is the exclusivity of operations that is assumed to protect the value of the forest and, indeed, evidence indicates that area-based TFL holders spend more on silviculture than volume-based TSL holders, but not as much as private landowners (Zhang and Pearse 1996). The harvesting rights for this tenure type currently constitute 17% of the provincial annual allowable cut (AAC), with the distribution skewed geographically towards the BC coast (where 47% of the public forestland is under area-based tenure) and much lower in the BC interior (only 8%) (Ministry of Forests, Lands and Natural Resource Operations 2012).

A replaceable (R) tenure holder may experience the same duration of access to timber as a TFL, but the holder may share the area with other tenure holders and thus lacks exclusive rights. The main reason why the license is replaceable is because the tenure holder owns a sawmill or other manufacturing facility that creates employment for a local community, and the government is committed to maintain community and employment stability. Arguably, the asymmetry of information, whereby the agent is more knowledgeable than the principal may be the most extreme in the volume-based tenure. Gray (2002) warns that the use of volume-based tenures,

also known as timber quotas, can overlap and create significant complexity in monitoring the activities of the firms. The principal needs to create the most effective performance measures in delegating work through agents to ensure that the outcome meets the principal's desires as closely as possible. BC currently manages 35% of its AAC using this tenure.

Similarly, the non-replaceable (NR) tenure holder may have harvesting rights in the same general area as the replaceable holder, but such rights have a fixed duration. The NR tenure holder generally does not own a sawmill or other manufacturing facility. It turns out that these two tenure types actually encourage different types of agent behaviour because the objectives of the agents differ. BC has often used the NR license for salvage harvesting as its fixed duration implies that the license is not meant to be sustainable in perpetuity and conditions can be tailored to describe the timber types eligible for harvest, allowing the principal more discretion in influencing the harvest choices of the licensee and the state of the forest. However, the discretion does not allow the principal the ability to change the contractual relationship at a later date. Currently 26% of BC's AAC is allocated to this form of tenure, primarily in response to the damage caused by the mountain pine beetle.

If we consider how well designed this continuum of timber tenures is to changing forest conditions and catastrophic natural disturbance, several recent studies provide insight into the PA dilemma faced in BC and other jurisdictions. Chapter 3 uses the PA theory to derive a simple monitoring rule for the principal to use in determining the efficacy of the agent's actions towards achieving the principal's post-salvage forest objectives. It highlights the very real risk to the principal's objective (assumed to be the maximum future value of the timber portfolio) when the agent can privately survey and select the most profitable stands to harvest (hidden information). In an area-based tenure, the agent can confidently manage the entire forest to the company's strategic advantage, an incentive not enjoyed by the agent with quota-based tenure. Lack of coordination between quota-based tenure holders can be expected to not only affect the principal's objective, but the outcome will also be adversely impacted by the multiplicity of agents operating in the region, especially when natural disturbance is considered (Cumming and Armstrong 2001, 2004).

Stumpage allowances are the predominant means used to fund silviculture in BC – that is, silvicultural costs are recognized as a claim against stumpage fees. These benefits are estimated to provide \$200 million annually to silvicultural operations (Ministry of Forests, Lands and

Natural Resource Operations 2011). Chapter 4 uses the PA theory to describe the influence of agent responses to stumpage allowances on silvicultural outcomes. It explains that allowing agents to manage silvicultural budgets to attain the future timberland productivity outcomes, rather than simply enforcing regeneration standards of harvested stands, could lead to improvements in the future productivity of the forest as it incentivizes agents to include silviculture decisions as part of their harvesting decision. The obstacles to improving forest productivity through silvicultural techniques have long been known (Pearse 1985), but, under the quota-based tenure arrangement, incentivizing agents to manage the silvicultural outcomes in the forest in addition to their regeneration obligations creates an even more complex PA relationship.

Chapter 5 explores a bi-level mathematical programming approach to the PA problem in the context of catastrophic disaster caused by the MPB. The bi-level formulation separates the policy variables controlled by the principal from the behavioural variables controlled by the agents, and both from impact variables such as beetle damage and lumber markets that are uncontrollable. Using stumpage fees and harvest rates as policy variables, we examine outcomes under two agent types – vertically integrated R license holders and NR license holders, who are primarily market loggers. We assume that R types will generally have built a mill (as historically they were required to under appurtenancy) and thus minimize the costs of harvesting their quota, while NR license holders are considered to be market loggers that maximize net income, or difference between log value and log cost, for the short duration of their license. The cost minimization behaviour of the R tenure holder can lead to an outcome that is better aligned with the principal's objectives than the actions of non-replaceable tenure holder. If the principal does not take into account these behavioural differences, policy failure is assured.

Salvage operations create a very real challenge to the public landowner already using quota-based or area-based tenures, because the harvest of dead timber poses a financial risk to the agents. As noted by Nelson (2007), the government has little recourse but to alter the existing property rights of license holders. This was strongly highlighted in the 1980s' mountain pine beetle infestation on the Chilcotin Plateau in BC's central interior. At the time, the government was unable through the regular bidding process to find a company interested in harvesting timber under an NR license. The timber was marginal in quality and located over 200 kilometres from the nearest mills in the Town of Williams Lake. The government received a single detailed proposal by Carrier Lumber Ltd. that included stumpage provisions before it would undertake

harvesting. The company had developed an innovative approach that altered the economics of the poor quality timber by on-site milling using portable mills. However, it was the total package submitted by the company that altered the economics to make the license viable.

In subsequent years, the Ministry of Forests changed a number of forest policies, both in terms of timber pricing and silvicultural obligations. Carrier attempted to operate under the original agreement but the government revoked those timber cutting rights for failing to supply silviculture performance bonds, which were a new obligation under the revised policies. However, in 1999, the BC Supreme Court upheld Carrier Lumber's view on the contract (British Columbia Supreme Court 1999) and a \$72 million compensation package was awarded in 2002 (Meissner 2002). This outcome reinforces the idea that, while the government owns the forest resource in BC, property rights and responsibilities are contractual. There is a financial risk within this institutional structure if costs and benefits for the two parties are not kept in balance.

It has long been held that the BC volume-based tenure system is a deterrent to efficient timber management as there are no territorial rights, which frequently leads to the idea that privatization of the forest resource is the most efficient means of ensuring good forest management (Haley 1985). From a timber production and efficiency perspective, this is likely true because the roles of the agent and the principal become one so that all of the effects of harvesting decisions are internalized. However, it is unlikely that privatization will be "environmentally, socially or politically" acceptable and may not even be economically viable (Kant 2009), although the government can regulate activities on private forestlands so that environmental outcomes are realized as they would if the forestland remained in public ownership. Research suggests that areas with long rotations are not likely candidates for industrial privatization as the subsequent future harvest of forested stands is too distant to truly influence firm behaviour (Gray 2002), although sustainable forestry operations do occur on private forestlands. And privatization does not eliminate the principal-agent relationship as the regulator must choose wisely the instruments that can bring about sustainable forest management outcomes when society values forestland for other purposes (Zhang and Flick 2001).

While unwilling to go so far as to privatize public forestlands in BC, the government made a failed attempt to eliminate volume-based tenures by converting them to TFLs in 1988 (Cashore 2000). Part of the justification for such a move was to provide security of tenure and exclusivity of management, key drivers meant to encourage the internalization of harvesting actions and

decisions concerning investment in the forest resource. Tenure reform with increasing the use of area-based tenure is a key element in the discussions of a legislative committee struck in 2012 to discuss options for mitigating the looming mid-term timber supply shortage as a result of damage from mountain pine beetle, because this tenure type is seen as providing the greatest incentive for more intensive forest management practices (Special Committee on Timber Supply 2012).

The tenure relations used in the management of public forestlands in BC leads to an interesting array of principal-agent concerns. Under a timber supply license (TSL), the principal is clearly in charge when it comes to forest management, deciding on which areas to harvest and managing the actions of the agent with straight-forward timber auctions and short-term contracts. However, this requires the principal to be continually active in preparing forestlands for potential timber sales. At the other extreme, by shifting forest management to the exclusive purview of a single tenure holder, as in the case of a tree farm license (TFL), many of the transactions that occur are eliminated and takes advantage of the specialist knowledge of the tenure holder from a silvicultural perspective. But the principal has less knowledge about the forest and logging operations than the agent, potentially causing the private company to benefit from informational asymmetries, such as those that are the object of complaints by U.S. lumber producers. Other tenure arrangements also have their benefits and drawbacks. The government must act wisely in how it chooses institutions and tenure arrangements in managing public forestlands if it is to efficiently and effectively extract the greatest benefits for citizens.

2.6 Conclusion

The new institutional economics complements standard neoclassical economics by drawing attention to the importance of institutions and emphasizing organizational modes and contractual relations. It also emphasizes the role of social capital and the rule of law in facilitating transactions and resolving social dilemmas. NIE provides a framework for analysing problems in forestry, in particular providing insights into the relationship between forestland owners (or even managers) and on-the-ground operators – logging companies and silvicultural contractors. As illustrated here, the principal-agent theory has a particular application to problems of forest tenure, especially in cases where public ownership is the dominant characteristic of the forest sector, as is the case in Canada.

Over the past two decades, the NIE analytical framework has fruitfully been applied by forest economists to real-world problems. Studies in the context of British Columbia, Canada suggest that the choice of contractual forms has implications for opportunities to economize on transaction costs. Appropriate governance structures tend to align with transaction attributes and firm characteristics so that some costs of transacting can be minimized. In essence, the choice of governance mode should be dictated by the nature of the activities and transactions involved.

Principal-agent analysis has been applied to investigate responses to the mountain pine beetle catastrophe in British Columbia. Researchers and policymakers have come to recognize that desired outcomes in responding to the MPB epidemic depend not only on the structure of the incentives (mainly differentiated stumpage fees) that forest companies face, but also on the tenure arrangements in which the forest company finds itself. Using the PA theory, it is possible to target incentives at specific forest companies rather than attempt to regulate outcomes after setting incentives. Public landowners need to recognize that firms will not respond as desired, and especially when they are asked to undertake tasks that lead to negative returns. It is important to recognize information asymmetries.

Finally, we find that in forestry there are too few studies that employ the methods of the new institutional economics to examine important problems related to forest tenures, trade in forest products (e.g., many issues in the on-going Canada-U.S. softwood lumber dispute might best be addressed within an NIE framework of analysis), carbon sequestration in forest ecosystems and the creation of suspect carbon offset credits (van Kooten and de Vries 2012), urban forestry, and forestry's role in economic development. As institutions and governance structures change over time (e.g., Clean Development Mechanism, REDD+), transaction attributes as well as the characteristics of economic agents are also subject to change. In this changing institutional environment, forest economists are unlikely to ever run out of problems to investigate.

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Chapter 3: Why the Beetle Exacerbates a Principal-Agent Relationship²

3.1 Introduction

Public forestlands are managed for multiple purposes using different tenure mechanisms. A common approach is to provide private forest companies with timber quota, but quota can be challenging to administer because they lead to a principal-agent situation (Gray 2002). As the principal, the public landowner seeks to achieve social objectives (financial, employment, community stability, environmental, etc.) through its forest policies. However, the private agent who implements the principal's policies has different information available to it and its own interests in mind, and this may lead to behaviour that does not necessarily coincide with the best interests of the principal. Therefore, the public landowner must be circumspect in developing forest policies. In this context, consider the implications to the landowner when a large portion of the forest undergoes catastrophic disturbance. A private landowner would simply attempt to liquidate the asset as quickly as possible to forestall further loss. A public forestland owner, on the other hand, relies on commercial forest operations as a source of revenues, jobs and rural community stability, and the forest as providing valuable ecosystem services, and must therefore consider the fiscal, social and contractual implications of mitigating the damage.

To explore the implications of natural disturbance on the principal-agent relation and forestry outcomes, we develop a simple policy model in the context of the recent catastrophic natural disturbance resulting from the mountain pine beetle in British Columbia, Canada. The mountain pine beetle (*Dendroctonus ponderosae* Hopk. [*Coleoptera: Scolytidae*]) is a bark beetle that attacks and kills pine trees (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) by burrowing under the bark and laying egg galleries (Safranyk and Carroll 2006). The burrowing beetle also inoculates the sapwood of the host with a blue-stain fungus that interrupts the nutrient flow between the roots and the crown of the tree, causing the tree to die (Waring and Pitman

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1985). The trees begin to dry out in the first couple of years after death, resulting in checks or cracks along the tree bole, which cause the greatest initial loss in commercial value as the orientation of the checks can limit opportunities for creating dimensional lumber (Orbay and Goudie 2006). With many management units in the interior of British Columbia possessing pine volumes in excess of 50% of the timber inventory, timber supply expectations need to be altered because fiber that was assumed to be available over a long time horizon must now be harvested quite quickly. Yet, it is anticipated that damaged timber will not be harvested soon enough to be converted into lumber, the primary and most valuable product of the forest industry in British Columbia (Wood Products Advisory Council 2006).

The provincial government, which owns 96% of the province's timberlands, is promoting bio-energy as an alternative use of the damaged timber (Government of British Columbia 2007). However, studies examining the use of damaged timber for bio-energy have raised issues concerning the high costs of hauling fiber located at increasing distances from bio-energy facilities (Niquidet et al. 2012; Stennes et al. 2010; Kumar et al. 2008; Stennes and McBeath 2006). Meanwhile, lumber values depend on the length of time between initial attack and the time a tree is no longer usable for dimensional lumber, which is known as the shelf life. Once the shelf life is surpassed, timber can be used only as bushchips for bio-energy. Bushchips result from on-site chipping of timber deemed unusable for lumber and are used for bio-energy purposes; other chips are residual to sawmilling, but are allocated to existing secondary processing facilities such as pulp and paper mills. A rising pine beetle infestation at the stand level and the shelf life combine to diminish a stand's value. The decision maker must balance diminishing timber value against effective harvest implementation in the search for successful strategies for maintaining timber supply.

Studies such as those cited above have examined the economic consequences of mountain pine beetle (MPB) attack at the aggregate level, while neglecting the more difficult features of the MPB epidemic that occur at the stand level. In this regard, two particular issues are examined in the current study:

1. The forest is not homogeneous. Pure pine stands can be found in certain locations, but pine usually co-exists with other species. If traditional clear-cut practices are implemented in an effort to harvest all dead pine, this results in an estimated average 'by-harvest' of 1.3 cubic metres (m^3) for every cubic metre of pine harvested (Eng et al. 2005). Minimizing the by-

harvest is necessary to maintain future timber supply.³

2. The beetle does not, in a given year, completely attack each stand or kill every pine tree in a stand. This is a confounding issue because, while some trees remain alive and retain a high value, others in the same stand become marginal or useless by the time harvesting occurs.⁴

We examine the intersection of these two issues in the context of the principal-agent problem in order to understand the tradeoffs required to make good strategic decisions. To explore the tradeoffs, three questions will guide the analysis: What are the product supply implications of the beetle attack? Is the province's current policy to increase short-term harvests a reasonable approach? How does the 'shelf life' of MPB-infected timber affect outcomes?

A final innovation concerns the objective function. Since the focus here is on government policy objectives as opposed to maximization of discounted net social benefits, our objective function represents the public landowner's primary conundrum – to salvage as much damaged forest without impacting the ability of the forests in the region to continue to provide employment and ensure long-term stability of a resource-based economy, while regenerating the forest in a cost-effective manner through salvage harvesting. Salvage harvesting reduces short-term timber values if its scale is sufficient to reduce timber prices, but, in the longer term, the effect of the MPB is to reduce timber supply, which increases the value of remaining timber (Prestemon and Holmes 2000). Therefore, a key objective for sustaining the local economy after the salvage period might well be to retain as great an economical supply of future timber as possible. In that case, constraints related to fiber flows will need to be implemented to ensure a smooth transition period.

As noted, the government as principal has delegated the harvesting of timber to agents (the private forest companies). While the government wishes the agent to harvest as much damaged pine as possible, and as much threatened pine as well before it is infected by the MPB, it does

³ The harvesting system employed in BC continues to be clear-cutting (B.C. Ministry of Forests, Mines and Lands 2010), although a more recent practice has been to leave reserves within clear-cut blocks in beetle salvage areas, thereby providing legacy forest structure for the future. However, this has come about because cutblock sizes in MPB-damaged areas have increased (Snetsinger 2005). Peter and Bogdanski (2010) provide a stand-level review of alternative silvicultural methods available in BC, noting, in particular, that silvicultural options in areas damaged by the beetle are limited by low productivity.

⁴ Trying to capture anything beyond a single estimate of the damage to all pine in the forest inventory is practically impossible, although researchers are exploring remote sensing methods to estimate the dynamic spatial dimension of the attack.

not really want the agent to harvest young, healthy pine or non-pine species as these are to be left for the time when the harvest uplift to eliminate MPB damaged stands is completed. Our model seeks to provide insights into this situation that might be useful in similar contexts elsewhere.

3.2 Methods

We simulate a canonical forest estate with similar characteristics to management units in the interior of British Columbia. We assume the forest estate is made up of fifty stands of equal area, age and site productivity. Forest and stand sizes are unimportant for the analysis, so we simply assume each stand is one hectare, and upscale the results to a 10,000 ha forest. Each stand is randomly assigned a pine proportion ranging from 0% to 100% in such a way that it produces a forest with roughly 50% pine and 50% non-pine on average. Each stand is assigned an initial standing inventory of 200 m³, representative of the study region, and a unique randomly-determined beetle attack pathway to mimic the rate and time of pine death in each stand.

The possible beetle pathways replicate the general distribution of pine death at the forest level as an epidemic grows and then collapses. The cumulative annual forest-level attack is shown in Figure 3.1. Pine death occurs between years 1 and 8 and eventually sums to 100% of the pine in the stand.

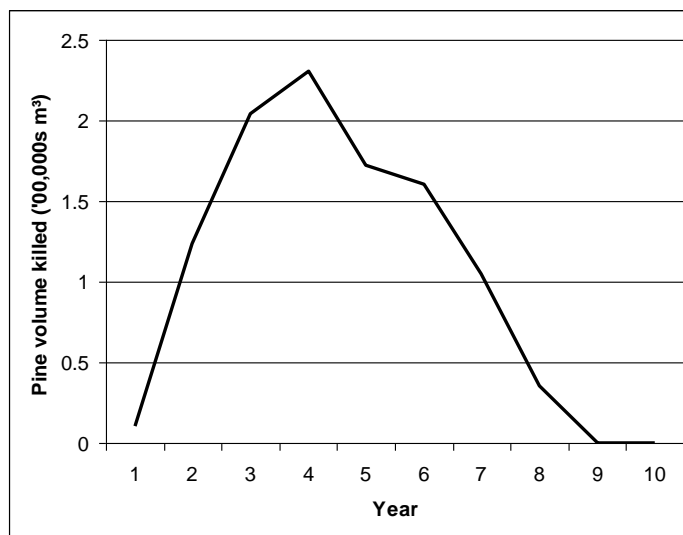


Figure 3.1: Annual volume of pine killed by mountain pine beetle after initial attack at the forest level

A crucial determinant for our study is the salvage period over which the policy decision is made. We assume that the beetle epidemic occurs over a span of eight years and that the longest shelf life for use of beetle-damaged trees as dimension lumber is 10 years. Thus, we employ a salvage period of twenty years to explore the options available to government (the principal) in dispensing harvesting rights to forest companies (agents) for addressing damaged timber, recognizing that many of these rights are already in existence. In the case of a different damage vector, such as wildfire, we would consider a much shorter salvage period of one to five years, depending on the scale of the damage. Here we restrict the planning horizon to the salvage period for two main reasons. First, the tenure system employed in our study area uses harvesting rights in five to 10 year increments (non-replaceable licenses) and 20 year increments (replaceable licenses), which reduces the options available to the principal. Second, if the principal wishes to focus on sustaining future timber supply, a simple rule-of-thumb is to reserve the greatest amount of growing stock, which we employ in developing our objective function.

Table 3.1: Model parameters

Parameter	Value	Description
T	20 years	Length of the planning horizon
t	Annual	Time step
p_1	\$150/m ³	Price of lumber ^a
p_2	\$75/m ³	Chip price obtained as a by-product of lumber manufacture ^b
p_3	\$55/m ³	Cost adjusted price of bushchips (assumed \$20/m ³ cost of roadside chipping in the forest)
v	200 m ³ /ha	Volume per hectare in each stand
h	\$70/m ³	Average logging cost ^c
β	$=1/(1+\delta)$	Discount factor (assume discount rate of 2.5%, so $\delta = 0.025$)
c	\$10/ha	Fixed administration cost per harvested hectare
r	\$1200/ha	Fixed planting cost per harvested hectare

Sources: ^a BC Statistics (2011); ^b Wood Products Advisory Council (2006); ^c Tedder (2011)

A number of fixed parameters used in this study are provided in Table 3.1. Each of these parameters exerts an important influence on the economics of timber supply, but the main policy driver from the landowner's perspective is the negative influence of damaged pine stands on the value of the forest estate when harvesting is carried out by private forest companies. The

parameters are within the range experienced in BC, although this is not our primary concern as our purpose is to explore the necessary thought processes needed in dealing with catastrophic natural disturbance on public land. We do not examine other values of the parameters or their potential variability, leaving this to future research that considers how the agents (forest companies) might respond to the principal's decision. Within a policy model, the government is able to choose a first-best feasible solution, which is the method commonly applied in BC using a biophysical timber supply framework (BC Ministry of Forests and Range 2010).

Choice of an appropriate objective function is also difficult. While the government has chosen to increase short-term harvest levels significantly to capture value from the damaged timber and ensure regeneration occurs on logged sites, it is also concerned about the stability of forest-dependent communities and ensuring a stable supply of timber in the near future. The BC government's MPB Action Plan outlines a number of important objectives, three of which are to (1) recover the greatest value from dead timber, (2) prevent or reduce damage to susceptible forest, and (3) restore areas affected by the epidemic (Government of British Columbia 2006). Thus, rather than minimize costs or maximize net returns (or net social benefits, however measured) over some time horizon, we choose to focus on the value of the standing timber at the end of the time horizon – in our case, 20 years. The objective function captures the implication of the damaged pine on stand value, releasing heavily damaged stands to be harvested while simultaneously reserving the best possible forest estate to bolster future timber supply.

One purpose of the investigation is to examine how shelf life and the government's harvest flow control policy interact to create an optimal strategy. The 'even-flow' (non-declining) harvest control policy is applied firstly to the total harvest and then to the flow of wood products, which consist of lumber and wood chips/residue for bio-energy; in the case of wood chips and residue, an even flow is required to ensure a stable input of fiber for a biomass electric generating facility. The harvest flow for bushchips is assumed to begin two years after the shelf life is surpassed; this ensures that an adequate bushchip supply exists for power production and avoids poor or infeasible solutions. The investment required to create a bio-energy facility also demands certainty of supply (likely exceeding 10 years).

The constrained optimization problem can be formulated as a linear programming model. The objective is:

$$\text{Maximize TV} = \sum_{k=1}^P \sum_{j=1}^S \{p_k v_{j,T} z_{k,T} - h v_{j,T} - c - r\} (1 - a_{j,T}), \quad (1)$$

where TV is the value of the standing timber inventory at the end of the time horizon (T); P refers to the number of products (=3), S to stands (=50); $(1 - a_{j,T})$ is the proportion of stand j remaining unharvested at time T ; $v_{j,T}$ is the volume of standing timber on stand j at terminal time T ; $z_{k,j,T}$ represents the proportion of product k from stand j at terminal time T with an associated value p_k ; h represents the average harvesting cost per cubic metre; r represents average regeneration cost; and c is per hectare management cost. Parameters are described in Table 3.1.

The model constraints are as follows:

Each stand can only
be harvested in its
entirety once

$$\sum_{t=1}^T a_{j,t} \leq 1, \quad \forall j \quad (2)$$

Even flow of total
timber volume

$$\sum_{j=1}^S v_{j,t+1} a_{j,t+1} \geq \sum_{j=1}^S v_{j,t} a_{j,t}, \quad t = 1, \dots, T - 1 \quad (3)$$

Even flow of
product volume

$$\sum_{j=1}^S z_{k,j,t} a_{j,t+1} \geq \sum_{j=1}^S z_{k,j,t} a_{j,t}, \quad t = 1, \dots, T - 1, \quad \forall k = \{\text{lumber, bushchips}\} \quad (4)$$

Non-negative
annual net return

$$\sum_{k=1}^P \sum_{j=1}^S [p_k v_{j,t} z_{k,j,t} - h v_{j,t} - c - r] a_{j,t} \geq 0, \quad t = 1, \dots, T \quad (5)$$

Non-negativity

$$a_{j,t} \geq 0, \quad \forall j, t \quad (6)$$

Constraints (3) and (4) are modified, or lagged, in harvest control scenario 3 to account for shelf life and an adequate supply of bushchips to avoid infeasibility or sub-optimal harvest levels; if the shelf life is zero, the even-flow constraint for bushchips would begin in the second year. In a particular model run, only one harvest flow objective, either constraint (3) or constraint (4) is employed. In the discussion of results that follows, it is important to keep in mind the exploration of tradeoffs rather than the absolute numeric values displayed as these depend on the economic parameters chosen.

3.3 Results

Scenarios are described by harvest control policy (denoted by a number) and shelf life assumption (denoted by a letter) and are summarized in Table 3.2. For each scenario, we provide the discounted net financial returns, total production of lumber, chips and bushchips, area harvested, the remaining inventory by species, and the value of the end-period timber portfolio (TV). For the baseline scenario where there is no beetle infestation, the forestlandscape would produce about 283,333 m³ of lumber and 170,000 m³ of chips with a net present value of \$35.5 million (which includes the value of the terminal timber portfolio), and result in the annual harvest of 167 hectares for a total harvest of 3,333 hectares (Table 3.2). Without price differentiation between species, the total harvest is composed of 48% pine. As indicated in Figure 3.2, the total inventory begins with 886,380 m³ of pine and 813,620 m³ of other species. By the end of 20 years, the growing stock is expected to decline to 625,883 m³ of pine and 535,783 m³ of non-pine. The terminal timber portfolio value is \$34.6 million. In the baseline scenario, there are no bushchips as only lumber and the additional chip by-product are produced.

Given the need to sustain harvests, the minimum annual harvest in all scenarios is set to the baseline harvest of 28,333 m³ of timber to ensure the model adequately reduces boom and bust outcomes. As a reference, we first found the maximum terminal condition for harvest control scenario 1, using the three different shelf life values (0, 5, 10), disregarding the requirement of constraint (5) that annual harvesting must achieve a non-negative net return, thus mimicking the use of a biophysical timber supply projection (Scenarios 1A, 1B and 1C). The TV for each of these scenarios is \$13.47 million and yields similar ending-state inventories for pine (~248,000 m³) and non-pine (~631,000 m³). Thus, if the government were strictly examining a biophysical timber supply outcome and economic conditions could be ignored, the best solution relegates one quarter of the pine inventory to bushchips to minimize the by-harvest and maintain future timber supply.⁵ The resulting TV is only about 40% of the no-beetle baseline. Clearly, the distribution of pine in the forest and the use of clear-cutting create a lasting implication for future timber supply.

⁵ Because of the simple forest structure used in this model, the quarter of the pine inventory that is ‘lost’ may yet reappear as a result of the improved productivity of the residual forest over the 20 year period, as observed by Romme et al. (1986).

Table 3.2 Scenario description and results

Scenario	NPV ^a (\$ × 10 ⁶)	Pine as a proportion of harvest	Total lumber (‘000 m ³)	Pulp chips (‘000 m ³)	Bushchips (‘000 m ³)	Harvested area (ha)	Pine inventory (‘000 m ³)	Non-pine inventory (‘000 m ³)	Portfolio value in year 20 (\$ × 10 ⁶)
Baseline scenario (no mountain pine beetle)	35.5 (11.6)	0.48	283.3	170.0	0	3333	633	529	34.60
1A. No net annual return condition & shelf life = 0 yrs	11.6 (3.2)	0.78	209.7	125.8	506.5	5000	248	631	13.47
1B. No net annual return condition & shelf life = 5yrs	21.3 (9.6)	0.78	307.8	184.7	275.7	5000	248	631	13.47
1C. No net annual return condition & shelf life = 10 yrs	20.6 ^b (10.4)	0.78	319.4	191.6	248.5	5000	242	636	13.47
2A. Even flow of total harvest, shelf life = 0 yrs	7.7 (1.8)	0.72	224.9	135.0	699.4	6143	165	543	12.69
2B. Even flow of total harvest, shelf life = 5 yrs	16.6 (7.1)	0.76	279.8	167.9	406.3	5324	225	616	13.40
2C. Even flow of total harvest, shelf life = 10 yrs	22.7 (11.6)	0.78	337.6	202.6	205.6	5000	252	641	13.47
3A. Even flow of product harvest, shelf life = 0 yrs	7.1 (2.6)	0.68	262.6	157.6	768.5	6932	121	462	11.17
3B. Even flow of product harvest, shelf life = 5 yrs	12.6 (5.4)	0.72	283.3	170.0	587.2	6269	161	539	12.52
3C. Even flow of product harvest, shelf life = 10 yrs	17.4 (8.2)	0.75	304.6	182.8	400.3	5585	214	607	13.28

^a NPV is net present value and includes terminal values. The sum of annual returns without consideration of terminal value is given in parentheses.

^b NPV of scenario 1C is counter-intuitively below 1B. Recall that there is no maximization of NPV in these scenarios. The model increases harvests in scenario 1A and 1B in the first five years while waiting for years 11-15 in scenario 1C, which results in a lower discounted value.

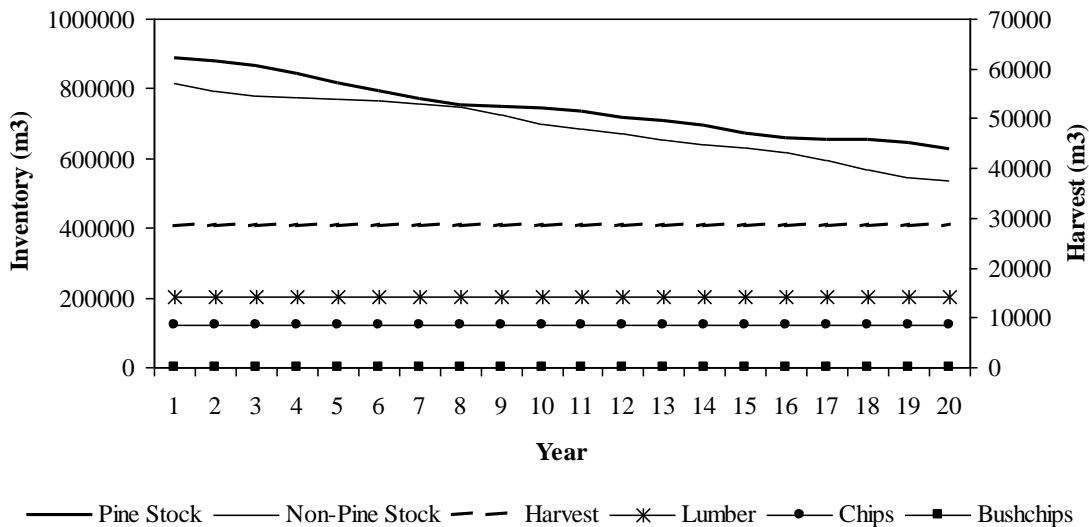


Figure 3.2: Baseline harvest with no beetle infestation (Harvest control scenario 1)

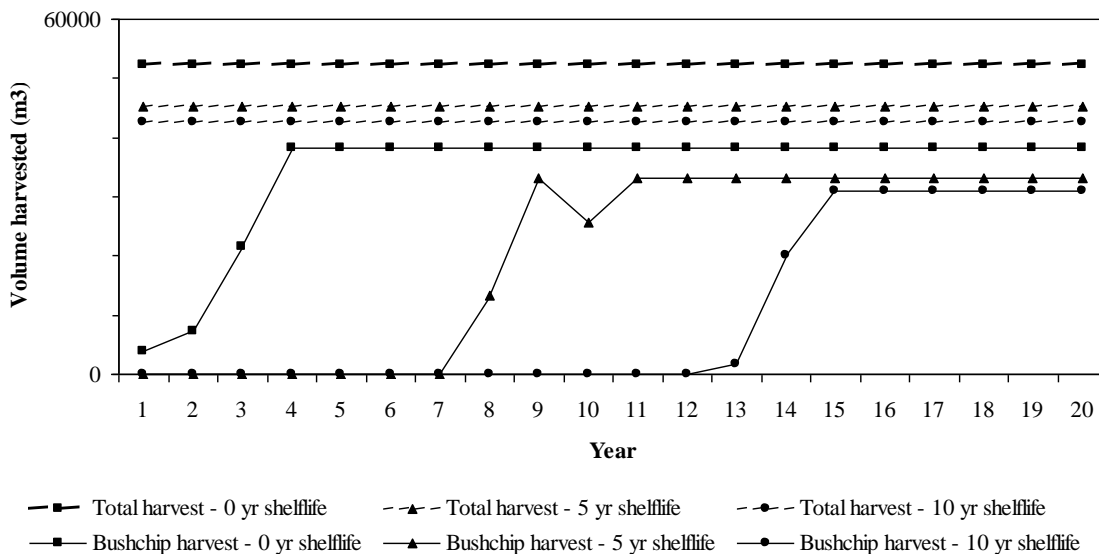


Figure 3.3: Even flow of total and bushchip harvest with different shelf life values for damaged timber (Harvest control scenario 2)

While harvest control scenario 1 provides an indication of the best possible terminal condition, the government must consider the economic supply of timber because the agents will take this into account in making on-the-ground harvesting decisions. To replicate this, we constrain annual net returns to be greater than or equal to zero in harvest control scenarios 2 and 3 by now including constraint (5).⁶ In harvest control scenario 2, we examine the even flow of total timber harvest for three shelf life conditions as graphed in Figure 3.3. The dashed lines represent total harvest and the solid lines represent bushchip harvest.

As shelf life increases, there is a steady decline in total harvest and bushchip harvest, as well as a delay in when bushchips become available. If shelf life is longer, maintaining a lower harvest is desirable as less area will be harvested, resulting in a higher non-pine inventory and a higher TV. Despite a higher harvest level when shelf life is short (i.e., zero years), net present value is quite low with net returns in most years equal to zero as a result of reduced lumber production. As shelf life increases, more lumber is produced than under the baseline scenario with no beetle.

Now consider what happens if government focuses on the flow of outputs, particularly ensuring that enough bushchips will be available to provide feedstock for a bio-energy facility, while also sustaining an even flow of lumber. The even flows of lumber and bushchips under different shelf life value assumptions for scenario 3 are summarized in Figure 3.4. In this case, as shelf life increases, the model increases the supply of lumber and bushchips simultaneously. The strategy for managing product recovery does have negative implications, which is evident upon comparing harvest control scenario 2 with 3 in Table 3.2. For identical shelf lives, management for even flow of product output yields lower NPV, lower TV, and requires more area to be harvested than management for even flow of total harvest. Due to the even-flow constraints, harvest levels do not increase significantly over the reference harvest level until bushchip harvests begin.

⁶ Whenever additional constraints are imposed, the value of a maximized objective function must fall. Although our objective is maximization of terminal value, imposition of added constraints will reduce NPV (see Table 2). In harvest control scenario 1, we disregard the requirement for non-negative annual net returns and simulate a biophysical timber supply. Then, in scenarios 2 and 3, we include constraint (5), annual net return must break even. This new constraint further reduces NPV. Now we can observe the impact on NPV of managing an even-flow of total harvest, as in scenario 2, or the even-flow of individual products, as in scenario 3. The reduction in NPV is a function of meeting the annual net return constraint by balancing the harvest of higher valued lumber products with lower valued bushchips.

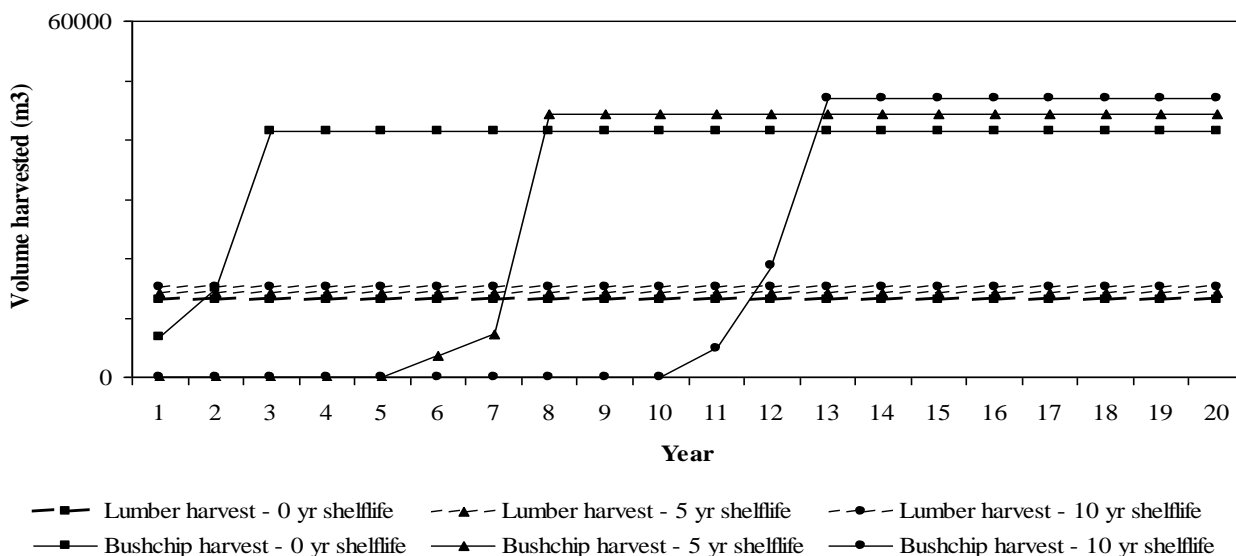


Figure 3.4: Even flow of lumber and bushchips with different shelf life values for damaged timber (Harvest control scenario 3)

Based on a number of criteria, sustaining total harvest over 20 years yields a more attractive outcome than attempting to sustain product harvests. However, government revenues are generally projected annually and fiscal planning has traditionally been predicated on a continued annual revenue stream to offset the provision of public services. Figure 3.5 shows the annual net returns by harvest control strategy for each shelf life value. The even flow of total harvest produces a windfall of short-term revenue, as net returns are extremely high while elevated harvests focus on converting pine trees into lumber. As the lumber component declines and the bushchips component increases, annual net returns go to zero. Conversely, by fixing the amount of output produced over the time horizon, a minimum net return can be achieved regardless of the shelf life. It is clear that under the economic conditions modelled, lumber value subsidizes the harvest of bushchips, as all of the stands with significant pine components would possess a negative terminal value if left unharvested. All negatively-valued stands within the harvest control scenarios are harvested, leaving no stand rehabilitation responsibility for the public landowner.

For the public landowner in our simple example, a straight forward policy is to ensure that the agent (forest companies) only harvests stands with at least 70 percent MPB damaged or threatened pine, even if such stands might be uneconomic to harvest. This is shown by the proportion of pine harvest in Table 3.2. This outcome holds regardless of the harvest control

method. The BC government uses a similar threshold in developing its forest policy, employing it as a criterion when monitoring harvest performance in pine management units (BC Ministry of Forests, Lands and Natural Resource Operations 2011). However, our conclusion obviously depends on the economic parameters that have been used. With higher or lower product values, alternative activity costs and alternative feasible silvicultural options, the landowner would face a different harvest level decision and a different desired buffer stock needed to sustain future timber supply. The possibility of incurring a rehabilitation responsibility may also arise, if agents avoid harvesting negatively-valued timber.

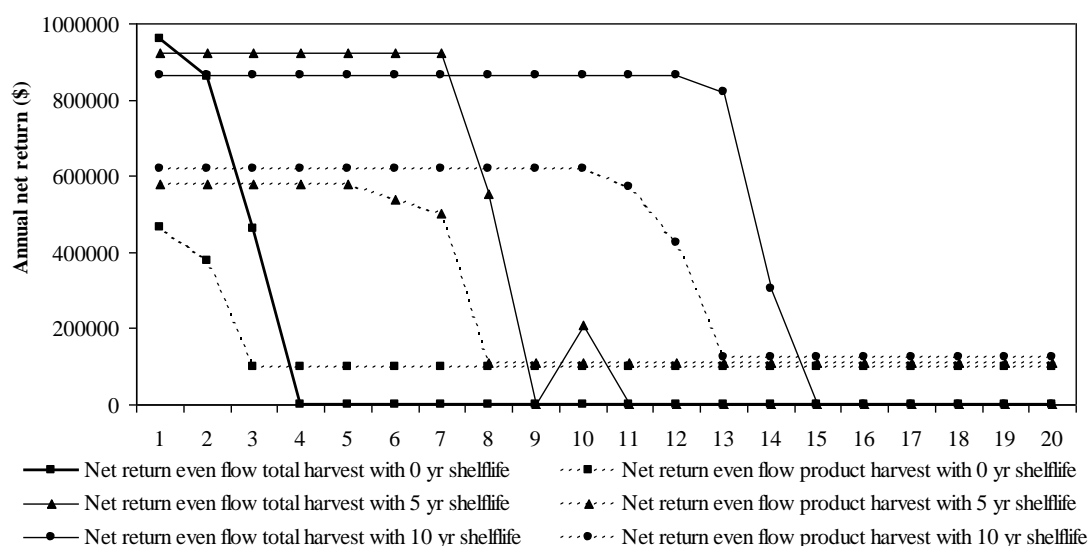


Figure 3.5: Annual net returns for different even-flow considerations and various shelf life values

3.4 Discussion and Conclusions

The traditional economic objective of maximizing discounted financial (or social) benefits is not conducive to maintaining future timber supply. Therefore, in this study, we maximized the value of standing timber at the end of the time horizon, which is consistent with the government's desire to protect future timber supply, while, at the same time, addressing the need to salvage beetle-damaged timber. To focus the policy concerns, three questions were asked: What are the product supply implications of the beetle attack? Is the province's current policy to increase short-term harvests reasonable? How does the shelf life of MPB-infected timber affect outcomes?

In response to the first question, the analysis has shown that forcing product objectives may not produce the most economically efficient solution. Indeed, by not considering an adequate product threshold, the forest resources needed to sustain future timber supply will be needlessly depleted. This has implications for bio-energy: subsidizing biomass electricity generation may not be a good policy. The analysis also showed that at least a quarter of the pine resource could be harvested after twenty years, when non-pine trees would be harvested. Thus, if traditional clear cutting is practiced, this limits harvests of damaged pine in the short run.

In the scenarios examined here, harvests were consistently elevated above the no beetle reference case. This is the course of action taken by the BC government. However, depending on the shelf life of damaged trees and the harvest control policy, the timing of the harvest uplift could vary from immediate to almost a decade into the future. This results in a key communication challenge concerning when to implement such uplift. An immediate increase in harvests communicates the sense that beetle-damaged pine has a short shelf life and little economic value once it is attacked, and this might ensure production of a much lower level of lumber in the future. Thus, in response to the second question, the province's policy is reasonable, but the messaging focussed on salvage of dead material rather than ensuring sound long term stewardship of the resource.

The variability of the pine resource and the shelf life of standing timber for lumber production define economic access to the timber resource. We find throughout the analysis that lumber production subsidizes harvesting of bushchips for bio-energy. This subsidy is over and above any explicit subsidies to encourage bio-energy, particularly biomass burning for electricity production, a result consistent with Niquidet et al. (2012). If insufficient lumber is recoverable from the pine or non-pine species in a stand, the stand will be left in the timber portfolio as it has little economic value. In our simple model, no such stands were left in the timber portfolio, under the presumption that the principal and the agent agree on the economic harvest implementation. Because the time horizon is short, we do not consider the growth of non-pine once the pine has been denuded by the mountain pine beetle, focussing rather on the visible pine damage. However, the non-pine could become valuable enough some time after the end of our time horizon to justify not harvesting beetle-damaged timber, but leaving it to decay and allowing mature non-pine species and advanced regeneration to flourish (Romme et al. 1986; Nigh et al. 2008).

Regarding the third question, there remains uncertainty about the shelf life of standing MPB-affected timber. Information pertaining to the rate of decay of beetle damaged timber and loss of value comes from sawmill simulation studies (Orbay and Goudie 2006), actual sawmill operating trials (Taylor 2008a, 2008b), and knowledge regarding the biophysical and climatic conditions affecting dead pine trees (Lewis and Hartley 2006). Despite this, the BC government reports uncertainty about shelf life using only two values (five years and 20 years), which form the basis for independent provincial timber supply projections (BC Ministry of Forests, Mines and Lands 2010). While the research clearly indicates that shelf life is affected by the biogeoclimatic zone in which the pine is found, the uncertainty in timber supply outcome is a combination of the volume-based tenure arrangements (where a company determines the stands it can economically harvest) and the difficulty of creating a forest inventory of time-since-death from which to project harvest potential. If an agent (forest company) is liable for sustainable forest management practices, including regeneration costs, it will be very careful in choosing which stands to harvest. This puts the principal (public landowner) that employs quota or volume-based tenure at a considerable disadvantage because the agent can survey and select the best sites to harvest, information that is unavailable to the principal.

The model can easily be modified to include multiple additional geographic zones that would enable us to explore the implications of variable transportation costs and shelf life as a function of location; this is left to future research (although see Niquidet et al. 2012). This could affect the conclusions significantly and thus policy related to the pine beetle. For example, it raises issues related to government tenure arrangements: the feedstock available for bio-energy will decline as shelf life increases if contracts to supply products recognize the principle of maintaining the highest and best use for as long as possible. If this requirement is removed, society could lose valuable forest rents to which it is entitled. Niquidet et al. (2012) find that, once marginal costs of harvesting and hauling are taken into account, it is no longer possible to support a biomass-fired electrical generation facility in the BC interior, highlighting the need to explore the marginal costs in policy decisions.

Clearly, we have greatly simplified the biophysical conditions and the economic conditions. Perfect knowledge about when pine trees are affected by mountain pine beetle and the extent to which stands are infested are clear benefits, as is perfect knowledge about shelf life and timber value. In terms of policy, the BC government is faced with only a few key options:

(1) ensure more or less continuous revenues by mandating the harvest of specific products from the forest; (2) use the more flexible approach of simply managing total harvest, while letting companies decide what outputs to produce; or (3) do nothing to speed up harvests of damaged pine and simply accommodate the damages through reduced harvest levels when the economic supply declines. The second approach may provide significantly larger short-term gains in government revenue during the years of ‘feast’ when damaged pine can still be used for lumber, but will require prudent fiscal management to distribute those gains into the future when expected net returns could decline substantially if harvests continue in the province’s interior pine-dominated zone. The government must also pay attention to the delicate economic balance between lumber and bushchips. Under current economic parameters, it is lumber recovered from damaged pine and by-harvest of non-pine species that enables the harvest of large amounts of bushchips. If the net returns from lumber turn out to be inadequate at some future time then harvest levels must be reduced, thereby increasing the cost of generating electricity from biomass and requiring biomass-harvest subsidies or electricity generated from other sources as a replacement. The current research provides an important policy backdrop as public landowners consider multiple-product management of the public forest.

The model in this paper was developed primarily as a policy tool with observable characteristics that can guide recommendations or policies to manage agent behaviour. It provides a key reference point for the research contained in the following two chapters.

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Chapter 4: Productivity after Natural Disturbance: A PA Approach⁷

4.1 Introduction

Most timber supply areas (TSAs) in British Columbia are adversely impacted by the mountain pine beetle (*Dendroctonus ponderosae* Hopk. [Coleoptera: Scolytidae]). One of the worst hit regions is the Williams Lake TSA, which is a management unit in the central interior of BC (see Figure 4.1) that has a large inventory of lodgepole pine. As a result, there is a risk that much of the damaged pine will not be salvaged and that, as a consequence, current and future harvests will be inadequate to sustain the local economy. While sustainability of future timber supply in the face of the beetle infestation is partly a biological problem, it is also a policy issue because economic prescriptions to this locally-catastrophic natural disturbance can negatively impact salvage operations and future timber availability as noted in Chapter 3. In particular, current policy fails to recognize that the value index, which is the government's proxy for the degree to which log value exceeds log costs, is negative (Council of Forest Industries 2009). A negative value index influences what forest companies do in the woods.

Forest harvesting and silvicultural activities in British Columbia are entirely regulated, with little recourse to economic incentives. As a result, outcomes are not always those expected by the public landowner (the principal), because the forest companies (agents) treat the regulations as a constraint. This is a classic principal-agent problem.⁸ The agents are primarily motivated by economic considerations, while the principal is concerned about social objectives, especially forest sector employment and community stability. With regards to the beetle infestation, the principal desires companies to harvest damaged pine while leaving sufficient live trees, or growing stock,

⁷ A version of this chapter will be published as: Bogle, T.N., and van Kooten, G.C. 2012. Options for Maintaining Forest Productivity after Natural Disturbance: A Principal-Agent Approach. *Forest Policy & Economics* In press.

⁸ See, e.g., Campbell (1995) for a clear discussion of incentives and principal-agent theory as well as the description provided in Chapter 1.

to ensure that there is an adequate future supply of timber. However, the agents have no incentive to protect live trees while harvesting damaged pine because they do not have a right to the future timber.

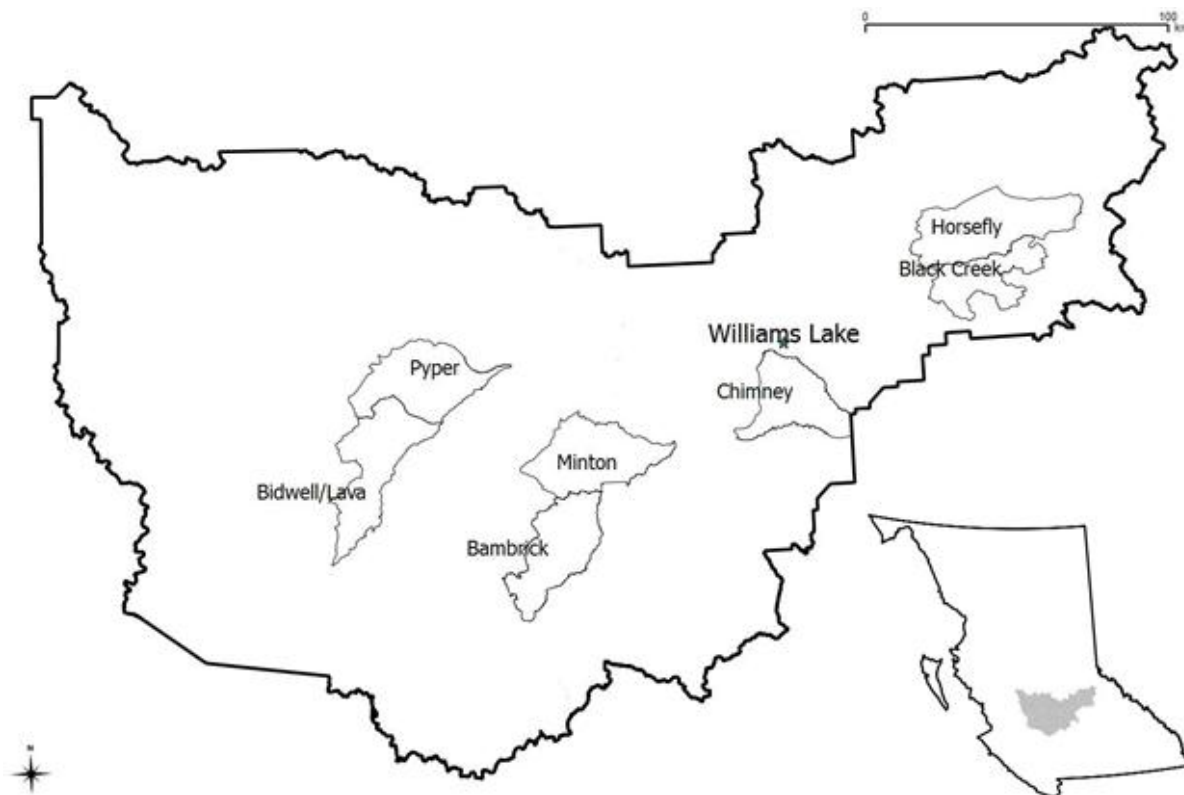


Figure 4.1: Williams Lake TSA and Seven Study Regions

The current research examines options for maintaining current and future productivity of forestland impacted by natural disturbance. The impetus for the research is to provide the Future Forest Estate Planning (FFEP) group in the Williams Lake TSA with evidence that an options-based approach to silviculture could improve cost efficiency while maintaining forestland productivity. The FFEP group is comprised of industry representatives and the BC Ministry of Forests, Lands and Natural Resource Operations (MoFLNRO). A key means for meeting the FFEP vision is through the optimal economic management of growing stock (Anonymous 2009).

It is technically feasible to derive growth projections for each landscape unit within the Williams Lake TSA and then examine how the forest industry's vision of management could maintain forest productivity. However, discussions with two major

companies operating in the TSA, West Fraser and Tolko, suggest that a more appropriate approach would be to compare the outcomes of current regulations with those based on the companies' vision of management. We compare the two management visions using constrained optimization. Because the TSA is large (about two million hectares), we only examine a subset of the TSA, ensuring adequate representation of the characteristics of the entire TSA, such as areas of low productivity pine, Douglas fir managed through selection harvesting, and high productivity spruce, pine and fir. Thus, seven landscape units were selected to cover the range of productivity and timber types in the TSA; these units are Bambrick, Bidwell Lava, Black Creek, Chimney, Horsefly, Minton and Pyper (see Figure 4.1).

To determine the interaction of the current silvicultural funding mechanism and productivity-based objectives, and given the importance of finding economically feasible silvicultural strategies, we focus primarily on growth rates, alternative strategies and long-run sustained yield (LRSY), with the latter acting as a surrogate for productivity and future harvest levels. We do not consider the implications of direct beetle impacts because these are more appropriately addressed through short-term timber supply projections.

Our research employs scenarios to explain the implications of various policy outcomes. Rather than examining a multitude of silvicultural options, three strategies that the companies could use to address FFEP objectives are considered: (1) reduce the costs of regenerating pine-dominated sites to ensure reforestation occurs; (2) begin planting productive areas with genetically superior trees; and (3) thin and fertilize repressed pine stands that have not been impacted by the mountain pine beetle, but are currently too dense to produce a merchantable timber crop. The latter activity is interesting because stand treatments, such as thinning and fertilizing of repressed pine, are not funded at the discretion of the forest company. As discussed below, the agents have little discretion over investment in silvicultural activities because of the way these are funded in BC.

4.2 Silviculture funding in British Columbia

The primary driver of silviculture is the legal requirement of forest licensees to return harvested areas to a free-to-grow state.⁹ Funding for these activities is obtained via an allowance against stumpage payments (Ministry of Forests and Range 2006). That is, companies deduct expected silvicultural expenses from their stumpage payments – from their royalty payments. It is estimated that this has cost the province some C\$200 million of foregone royalty payments annually since 1995 (MoFLNRO 2011).

There are two problems with this approach. First, the silvicultural allowance is defined by the public landowner (principal) for each site type or biogeoclimatic (BEC) variant,¹⁰ and is based on MoFLNRO surveys of the silvicultural expenditures required to achieve free-to-grow status in young plantations, meaning that the allowance is not dependent on the silvicultural outcome but on a fixed fee. Second, since silvicultural expenditures are deducted from stumpage payments, it is possible that not all expenditures are charged against royalties, in which case silvicultural expenditures are simply an added cost of harvesting timber. Silviculture is not viewed as an investment because the agent has no right to the future timber benefits (McWilliams and McWilliams 2009). In the case of the mountain pine beetle, the firm harvesting pine stands damaged by the beetle does not benefit from the future increase in wood supply brought about by precautions taken (costs incurred) during harvest operations to retain spruce trees or living pine trees; indeed, the forest company gains no benefit whatsoever from protecting the living trees on a damaged stand – another company is free to access that volume under its own license.

The situation can be summarized by considering how the value index (*VI*) is calculated for each site (see van Kooten and Folmer 2004, p.60):

$$(1) \quad VI = \text{Log Value} - \text{Log Cost},$$

⁹ Free to grow occurs when trees are of a sufficient height to stand above competing weed and other non-commercial species – that the new stand is sufficiently established.

¹⁰ The BC biogeoclimatic classification system is based on three primary components – the climax tree species, relative precipitation and temperature. Additional information is available at: <http://www.for.gov.bc.ca/hre/becweb/system/how/index.html>.

where log cost depends on planning, harvesting, trucking, silvicultural, stumpage royalties and other eligible costs. Before the mountain pine beetle, lumber prices were sufficiently high to create positive *VI*, with the government receiving adequate stumpage revenue while still funding forest regeneration on public forestland (as companies charge silvicultural costs against stumpage payments). Weak lumber markets and the mountain pine beetle infestation led forest companies to harvest many stands with negative value indexes (Council of Forest Industries 2009). The principal could persuade agents to harvest and regenerate sites with negative *VI*s on the basis of the returns earned on sites with a positive *VI*. However, this is unsustainable because companies cannot continue to absorb losses associated with wood procurement; thus, they will eschew stands with economically unsalvageable beetle-damaged timber (sites with a negative *VI*), a situation the principal would like to avoid. Further, forest companies are likely to take fewer precautions to protect live trees when harvesting beetle damaged stands, because it is costly to do so.

The natural disturbance caused by the pine beetle meant that the practices of the agents increasingly diverged from the desires of the principal. Clearly, the public landowner needs to develop appropriate policies so that the agents (forest companies) have the incentive to harvest damaged pine while retaining living trees to ensure an adequate future timber supply.

4.3 Methods

Forest management practices are highly regulated in British Columbia and the amount that companies can claim against stumpage is pre-determined. That is, the value index for each forest stand is set by the principal, with the agent's actions at the stand (or cut block) level determining actual outcomes. If the principal imposes certain silvicultural treatments for each stand, the agent will seek to minimize costs while just satisfying the principal's requirements without regards to the outcome. On the other hand, if the principal focuses on the outcome, the agent will again minimize the cost of silvicultural treatments while ensuring that the particular outcome is achieved (perhaps to avoid a

penalty); however, the treatments that will be employed are very likely to be quite different than those specified by current regulations.

To formalize this, let M denote the set of management or silvicultural treatment options. We identify three silvicultural management options: (1) do nothing and allow forests to regenerate on their own ($M_N \subset M$); (2) follow the regulated management prescribed by the government ($M_R \subset M$); and (3) implement an alternative and flexible management regime proposed in recognition of the beetle-caused natural disturbance and low fiber prices ($M_F \subset M$). The last is a response to the negative VI experienced on many stands in the Williams Lake TSA.

With the exception of the no management option (M_N), the regulation management (M_R) and flexible management (M_F) regimes constitute various silvicultural treatment options that depend on the stand density, species growing on the site, the age of trees, site index and so on. Regulation management generally requires immediate replanting of the site with pre-specified planting densities, et cetera, but leaves open the possibility of natural regeneration on some sites where, for example, new growth already appears to be taking hold. The alternative vision also requires re-planting in many instances, but allows much greater flexibility in determining when to plant, planting density, survey intensity and timing, and so on. The alternative vision also permits greater flexibility in choosing when natural regeneration is allowed to dominate, perhaps choosing in-fill planting at a much later date than would be permitted under regulation management. In addition and particularly on repressed pine stands, flexible management might call for thinning and fertilizing that subsequently permit the forest company to harvest the stand (i.e., benefit) in the future. Overall, flexible silvicultural management focuses on outcomes rather than inputs as in the case of regulation management.

We employ a constrained optimization approach to investigate the consequences of the two visions regarding silvicultural management of stands affected by natural disturbance, while recognizing that forest management is caught between the conflicting objectives of cost minimization and the need to enhance forest productivity. As noted nearly two decades ago by Swoveland et al. (1993), minimization of silvicultural and other costs is what characterizes on-the-ground forestry in British Columbia. At the same time, as one of its primary functions, the MoFLNRO is legislated in the Ministry of

Forests and Range Act “to encourage the maximum productivity of the forest ... resources.” We construct formal constrained optimization models to represent the tension between minimizing costs and maximizing productivity, and then employ the models to examine how focus on one objective or the other leads to divergence in outcomes under our three alternative silvicultural management regimes.

Let decision variable $x = x_{s,u,b,h,m}$ represent a forest management strategy expressed as the area (in ha) of site s in landscape unit u in BEC variant b that is harvested by clear cutting (CC) or selective harvest (Sel), $h \in H = \{CC, sel\}$, and managed using post-harvest silvicultural treatment $m \in M = \{M_N, M_R, M_F\}$. There are B BEC variants, U landscape units and S stands. Also let $c = c_{b,h,m}$ represent the silvicultural cost of treating a stand in BEC variant b that is harvested by prescribed approach h , and to which post-harvest silvicultural treatment m is applied. The total cost to the forest company of regenerating it to the free-to-grow stage can be determined by the following relationship:

$$(2) \quad C = \sum_{s=1}^S \sum_{u=1}^U \sum_{b=1}^B \sum_{h \in H} \sum_{m \in M} c_{b,h,m} x_{s,u,b,h,m}$$

In a similar way, it is possible to determine the long-run sustained yield (LRSY) as:

$$(3) \quad LRSY = \sum_{s=1}^S \sum_{u=1}^U \sum_{b=1}^B \sum_{h \in H} \sum_{m \in M} g_{s,u,b,h,m} x_{s,u,b,h,m}$$

where $g_{s,u,b,h,m}$ represents the growth rate of the treated stand $x_{s,u,b,h,m}$.

Finally, there is a limit to the area that is considered. Let $A_{s,u,b,h}$ represent the area of stand s in landscape unit u in BEC variant b and harvested under clear cut or selective harvest:

$$(4) \quad A_{s,u,b,h} = \sum_{m \in M} x_{s,u,b,h,m} .$$

The two models can be specified as follows:

I. Minimize silvicultural cost

Minimize C subject to $LRSY \geq G$ and equation (4)

II. Maximize long-run sustained yield

Maximize *LRSY* subject to $C \leq \bar{C}$ and equation (4)

G is the minimum timber supply that is required to meet community stability and economic stability targets, while \bar{C} is the available budget.

4.4 Data

A GIS model was constructed for the Williams Lake TSA. Data related to forest cover, such as stand species composition and inventory site indexes, are available from the detailed ‘Forests for Tomorrow’ Type II silviculture investment dataset (Timberline Natural Resources Group 2008). A predictive ecosystem mapping (PEM) project was recently completed for the Williams Lake TSA at a grid size of one quarter hectare (Moon et al. 2008). We re-sampled the PEM data at the resolution of one hectare and then joined those data with the forest cover data in order to relate the predicted ecosystem type with site productivity estimates available through the SIBEC project, a provincial initiative to provide site index estimates for the BEC classification system (Mah and Nigh 2003).

Site productivity estimates are available at the regional and provincial levels. Joining these data entailed, first, pairing BEC and leading species information with regional data: If the regional data existed, a PEM-based site index (PEM SI) existed for the pair; if the regional data were not available, then a match was sought within the provincial data. In some cases, a species is not listed in the SIBEC database for a BEC and leading species pairing. However, there are provincial species conversion equations that can convert the productivity of one species on a site to that of another species. In that case, an alternate species with a valid site index conversion equation for the species in question was sought in the same BEC. The same search order, namely regional then provincial, was followed. This filled numerous gaps in the data.

The study area of seven landscape units and their respective BEC variants represents about 10% of the TSA area and the productivity estimates for the natural forest (inventory site index) and post-harvest managed forest (BEC derived site index) are shown in Table 4.1. Note that the productivity of the managed forest is expected to be

higher than the natural forest, especially in the case of repressed pine, where high stand densities have caused a serious reduction in height growth, resulting in a low estimate of site productivity (Newsome 2010). In our study area, three landscape units (Bambrick, Bidwell Lava, and Pyper) possess this stand type.

To project stand yields, we employed BatchTipsy version 4.1 software, which is freely available from the BC Ministry of Forests, Lands and Natural Resource Operations (MoFLNRO 2010). BatchTipsy projects the growth of the main timber species in BC. Model input data for each yield table consisted of the species composition, regeneration delay (specifically the length of time the land is bare of trees), site index, density, operational adjustment factors (to account for gaps, endemic losses, waste, etc.), pre-commercial thinning density, height and the age at which fertilization occurs. As noted in the previous section, three regimes were developed for this analysis and these are summarized in Table 4.2. The ‘No Management’ regime serves as a benchmark; it uses inventory forest composition by BEC variant and treatment type based on the area-weighted species composition in the Williams Lake TSA.¹¹

Table 4.1: Description of the Three Regimes

Regime	Species composition	Regeneration			Genetic worth ^a	Thin and fertilize
		Delay	Method	Density		
No management	Inventory BEC	10 years	Natural	Tolko regeneration	0	
Regulation management	Tolko regeneration by BEC	4 years 2 years	Natural Plant	Tolko regeneration	Not practiced	
Flexible management	Assigned by BEC	0 years 2 years	Natural Plant	Assigned	Sx = 18% Fd = 14%	Repressed pine

^a Genetic worth obtained through tree selection trials improves various traits. For species Sx (spruce) and Fd (Douglas fir), the growth rates are expected to increase by the amounts indicated.

¹¹ Supplementary data for each regime are available in an excel file that can be found at: <http://web.uvic.ca/~kooten/documents/BECSilvicCosts.xlsx>.

Table 4.2: TSA Productivity Summary by Landscape Unit, BEC Variant and Harvest Type

Landscape Unit	BEC variant	Harvest Type ^a	Area (ha)	Inventory Site Index	BEC-derived Site Index
Bambrick	ESSFxv2	CC	706	9.7	9.7
Bambrick	IDFdk4	CC	2,735	11.1	11.9
Bambrick	IDFdk4	Sel	202	10.7	12.0
Bambrick	MSxv	CC	17,235	9.2	17.3
Bambrick	SBPSxc	CC	18,435	9.7	13.5
Bambrick	Repressed Pine	CC	3,312	6.3	14.6
Bidwell Lava	ESSFxv1	CC	982	9.9	11.9
Bidwell Lava	IDFdk4	CC	2,257	11	11.5
Bidwell Lava	IDFdk4	Sel	267	10.6	13.0
Bidwell Lava	IDFdw	CC	131	10.6	15.2
Bidwell Lava	MSxv	CC	4,871	10.6	17.3
Bidwell Lava	SBPSxc	CC	26,854	10.1	13.6
Bidwell Lava	Repressed Pine	CC	3,034	5.7	14.3
Black Creek	ESSFwc3	CC	1,431	13.9	14.2
Black Creek	ESSFwk1	CC	3,010	15.1	15.1
Black Creek	ICHmk3	CC	3,070	17.4	21.2
Black Creek	ICHwk2	CC	2,158	15.4	21.1
Black Creek	SBPSmk	CC	604	17.3	19.0
Black Creek	SBSdw1	CC	13,296	18.5	20.1
Black Creek	SBSdw1	Sel	1,027	17.1	20.3
Black Creek	SBSmc1	CC	1,471	17.6	18.1
Chimney	IDFdk3	CC	521	14.4	18.0
Chimney	IDFdk3	Sel	2,765	13.6	17.7
Chimney	IDFxm	Sel	1,130	13.1	14.6
Horsefly	ESSFwc3	CC	1,955	11.8	14.6
Horsefly	ESSFwk1	CC	1,757	14.1	14.3
Horsefly	ICHmk3	CC	7,261	18.8	22.1
Horsefly	ICHwk2	CC	17,653	17.1	21.3
Horsefly	SBSdw1	CC	3,452	20.1	20.5
Horsefly	SBSdw1	Sel	418	19.1	19.4
Minton	IDFdk4	CC	12,065	10.6	12.3
Minton	IDFdk4	Sel	2,156	10.8	14.7
Minton	IDFxm	CC	862	10.6	15.6
Minton	IDFxm	Sel	3,160	10.8	14.9
Minton	SBPSxc	CC	7,068	10.4	13.6
Pyper	IDFdk4	CC	11,749	10.4	11.3
Pyper	IDFdk4	Sel	1,545	10.3	13.1
Pyper	IDFxm	CC	374	9.9	14.7
Pyper	IDFxm	Sel	290	11.3	14.2
Pyper	SBPSxc	CC	22,672	11.4	13.0
Pyper	Repressed Pine	CC	441	5.4	12.3
Total study area			206,382		

^a CC refers to clear cut; sel to selective harvest.

Each regime has been developed to highlight the nature of the forest under different conditions. The intent of the ‘No Management’ regime is to display the estimated productivity of the natural forest as it is projected by the inventory with an extended regeneration delay to simulate natural forest regeneration. This allows the optimization model to choose a costless alternative with poor regeneration performance as a surrogate for doing nothing post-harvest.

The ‘Regulation’ regime portrays the average silvicultural performance of Tolko over the past 20 years as captured in the company’s regeneration database (unpublished Tolko regeneration data). The database was summarized by BEC variant and regeneration method to produce an area-weighted species composition for young plantations. In the Williams Lake TSA, the common practice has been to regenerate most BEC variants back to a stand with 50 percent or more pine. The general exception to this practice is the natural regeneration of fir sites after selection harvesting.

The ‘Flexible Management’ regime captures the vision of the FFEP group, and thus the more flexible operations planned by the agents in pine dominant sites to reduce silvicultural costs. While M_R requires a complete ‘knock down’ of all under-storey trees, necessitating a regeneration delay period for new germinates to arrive post-harvest, the M_F regime envisions using the existing pre-harvest under-storey without any regeneration delay, while only implementing a stand treatment to remove mistletoe infected over-storey stems. Some in-fill planting may be required in gaps where natural regeneration does not occur. This strategy is consistent with findings by others (Coates et al. 2009; Astrup et al. 2008). For example, Coates et al. (2009) found that between 25% and 57% of all plots had basal area equivalent to a 20-year old plantation, depending on the BEC variant. ‘Flexible Management’ also captures a move to planting with genetically improved spruce and fir in the more productive BEC zones (e.g., SBS) where pine is less dominant. To improve growth and productivity in selected fir sites, the companies envision moving from a pure selection harvest to a small patch cut mosaic where planting of genetically improved fir could prove beneficial. There has only been nominal use of genetically-improved seedlings in the Williams Lake TSA, although genetically-improved stock for spruce and Douglas-fir is available. This could provide higher growth

potential, as seen by the genetic worth values of 18 and 14 per cent, if funding for this activity were available.

The last option in the M_F toolkit (as identified by the FFEP group) is the treatment of repressed pine. Research has shown that pine stands with densities on the order of 75,000 stems per hectare at natural establishment respond to a thinning treatment to 5,000 stems per hectare followed by fertilization (Newsome 2010). These sites are not part of the 'Regulation' regime as they will not be harvested in their current condition. If funding was available, these sites could provide important volume contributions in less time than in the case of complete rehabilitation, and they link current investment by agents to their ability to harvest the treated timber. These sites are modelled as inventory site index (< 7 m) for 'No Management' and the SIBEC site index for the 'Flexible Management' regime (range of 12-15 m).

Costs were determined by the silvicultural staff of the two companies (identified earlier) for both the Regulation and Flexible Management regimes, broken down by the proportions and costs of site preparation, planting, fill planting, brushing, spacing, stand treatments and surveys in each BEC/harvest type/silvicultural treatment method.

A reference age of 80 years was assumed for the average annual growth rates for all sites. However, while the reference age for growth rate is assumed to be 80, the actual yield table lookup for repressed pine stands is 100 years because of their advanced age. This places the regeneration strategy of starting with older pine trees on a similar growth reference as bare ground. By using an average annual growth rate, the growth rate multiplied by area treated produces a surrogate for the long-run sustained yield or LRSY. It can also be loosely connected to an allowable annual cut or AAC, but determining AAC requires the incorporation of other management factors, such as wildlife habitat, that may push the harvest age of the forest beyond the reference age used in this study. This would likely reduce the AAC below LRSY. The reference age is also used to derive an average annual expenditure to achieve LRSY by dividing total cost of treating areas by the reference age.

To build a suite of scenarios, various parameters were adjusted to reflect how the optimal response changes with a different set of parameter values. The scenarios are listed in Table 4.3. The scenarios are constructed to build a story that extends from the

inventory site index through current expected LRSY (scenario B), and then through alternatives used to lower cost (C and D), ones that maximize LRSY (E) and, finally, ones with reduced funding levels and reduced funding flexibility (F and G). However, in model II (maximize LRSY) the agents can employ lower-cost FFEP management options.

Table 4.1: Scenario Description

Scenario	Optimization Model	Parameter adjusted
(A) Static No management		
(B) Static current management		
(C) Minimize silviculture cost of current LRSY without FFEP options	<i>I</i>	Sum of growth rates based on current regulatory treatment proportions (<i>G</i>)
(D) Minimize silviculture cost of current LRSY with FFEP options	<i>I</i>	Sum of growth rates based on current regulatory treatment proportions (<i>G</i>)
(E) Maximize LRSY	<i>II</i>	Sum of Ministry allowances by BEC
(F) Maximize LRSY with 80% budget	<i>II</i>	80% of Ministry allowances by BEC
(G) Maximize LRSY with 60% budget and U spending constraint	<i>II</i>	60% of Ministry allowance by BEC & spending occurs within landscape unit

While there is no explicit silvicultural budget in the province, the surrogate source used in this analysis is the MoFLNRO's current BEC-specific silvicultural allowance employed in the appraisal of timber. It is expected that this will be the maximum a forest company would be willing to spend to achieve regeneration of the forest. Unfortunately, this allowance is not static but depends on the timber harvested in a given BEC variant and the costs of regeneration experienced by companies harvesting there. The principal's assumption is that sufficiently large samples will be obtained to smooth this moving average, but as an average it does pose a risk to the forest companies' current operations. Two scenarios focus on budget reductions as surrogates for a reduction in the silviculture allowance because, as companies seek to minimize their silvicultural costs while harvesting stands of damaged timber with a negative value index, their efficiencies will be captured in updates to the silvicultural allowance used in appraising timber.

Outputs are summarized in a strategic manner across scenarios, although detailed results are available in the form of spreadsheets. Important shifts in the optimal solution will be highlighted across the scenarios. To derive an annual budget in the output reports, the silviculture budget is divided by 80 years, resulting in an average silvicultural cost per year assuming proportional activity in each BEC and harvest type in each year. Another useful indicator is the cost per metre (CPM), which is the average silvicultural cost per cubic metre of regenerated volume. This is analogous to how industry currently attributes silvicultural expenditures in their internal accrual systems, although industry uses harvested volume rather than regenerated volume. This indicator could be used by the MoFLNRO as a silvicultural investment indicator to sustain a certain LRSY for a management unit.

4.5 Results

Using the area-weight species composition data from the inventory and the seven landscape units resulted in 118 different LU/BEC/Block/Regime/treatment type combinations and yielded 405 separate yield tables. Multiplying the area by the No Management option and assuming the species distribution and site index found in the inventory for the respective BEC variants, yields a cumulative mean annual increment (MAI) at the 80-year reference age of 226,000 m³ on about 206,000 hectares of land, or an MAI of just over 1 m³ per year (scenario A). An area-weighted site index from the inventory data yields a site productivity estimate of about 11 metres.

When the current silvicultural proportions in the Tolko Regeneration dataset are used with the PEM SI data and multiplied by the corresponding inventory area, the cumulative MAI is about 519,000 m³ per year at an estimated average cost of \$1.57 million per year. This translates into an average MAI of 2.5 m³ per year (scenario B) and a CPM of \$3/m³. The influence of the site productivity information is significant and is the result of an increase in the average site index of 4 metres. This LRSY will be used as variable *G* – the minimum LRSY target for finding the minimum silvicultural cost to sustain regulation-based productivity.

Solving model I (minimize silvicultural cost) with the target LRSY indicates that the annual silvicultural cost can be reduced from \$1.57 million to \$1.24 million if none of the FFEP options are employed (scenario C). However, once the FFEP options are available, the total silvicultural cost drops to about half of that value, or to \$670,000 per year (scenario D). This indicates that many of the FFEP options are aimed at minimizing costs while retaining forest productivity (based on field experience of advanced pine regeneration in damaged pine stands). It is important to recognize that the regulation-based LRSY can be met while employing No Management in some areas. This is akin to leaving small portions of blocks untreated, which is unacceptable under the current Regulation regime.

Next model II is used to determine the maximum LRSY with the stipulation that there is a silvicultural budget equivalent to the Ministry of Forests appraisal allowance. Solving II returns a LRSY of about 610,000 m³ per year at an average cost of \$2.01 million per year (scenario E) and a CPM of \$3.30/m³. As this value is below the appraisal allowance, future FFEP options could explore additional silvicultural investments while remaining within the silvicultural budget. Although total spending is below target, it is important to note that spending at the landscape unit does not follow this pattern. There is more money supporting activities in certain landscape units than would be ‘earned’ via strict spending of an appraisal dollar on the hectare where it was derived. It is also important to note that, because silvicultural funding is not a constraint in this scenario, the FFEP regimes created to save money are not chosen while the more expensive Regulation-based planting regimes are chosen, as are the FFEP regimes that require additional funding, such as planting genetically-improved spruce and fir.

As a point of reference, the CPM for repressed pine treatment of thinning and fertilizing ranges from a low of \$10/m³ to a high of \$17/m³. While this is much more costly on a per unit basis than all of the other silvicultural treatments, it is important to remember that there is no volume contribution from the repressed pine strata unless it is treated.

As previously noted, current cost estimates are below the appraisal allowance in scenario E. This is a prelude to future MoFLNRO appraisal allowance reductions as cost-efficient company practices are reflected in cost surveys, thereby leading to a reduction of

MOFLNRO allowances. To simulate this, we reduce the silvicultural budget in each BEC variant by 20% (scenario F). Then the optimal solution reduces the LRSY to 606,000 m³ per year at a cost of \$1.79 million dollars, resulting in a CPM of \$2.95/m³. To offset the loss in funds, there is a reliance on the lower cost FFEP regimes.

Finally, the appraisal allowances are reduced by 40% below current levels and a new cost allocation constraint is maintained at the landscape unit level (scenario G). The silviculture budget is now \$1.34 million per year. Remarkably, the LRSY only declines to 575,000 m³ per year. However to achieve the silvicultural cost limits within certain landscape units (i.e., Horsefly and Black Creek), the No Management regime is used, while in areas like Bambrick and Bidwell Lava, the low-cost FFEP regimes are chosen.

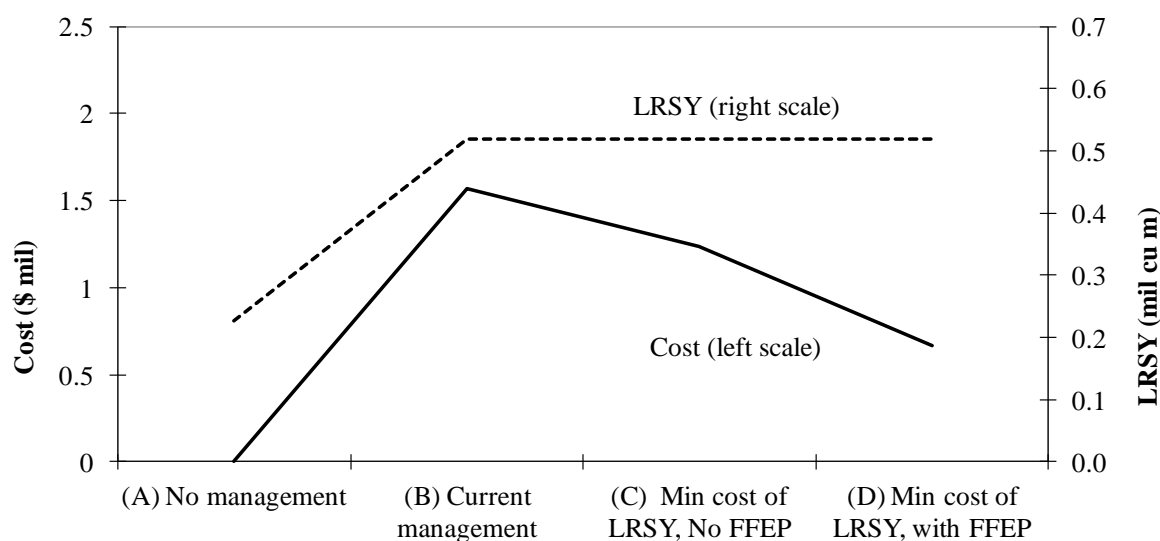


Figure 4.2: Comparison of Costs and LRSY by minimize silvicultural cost scenario

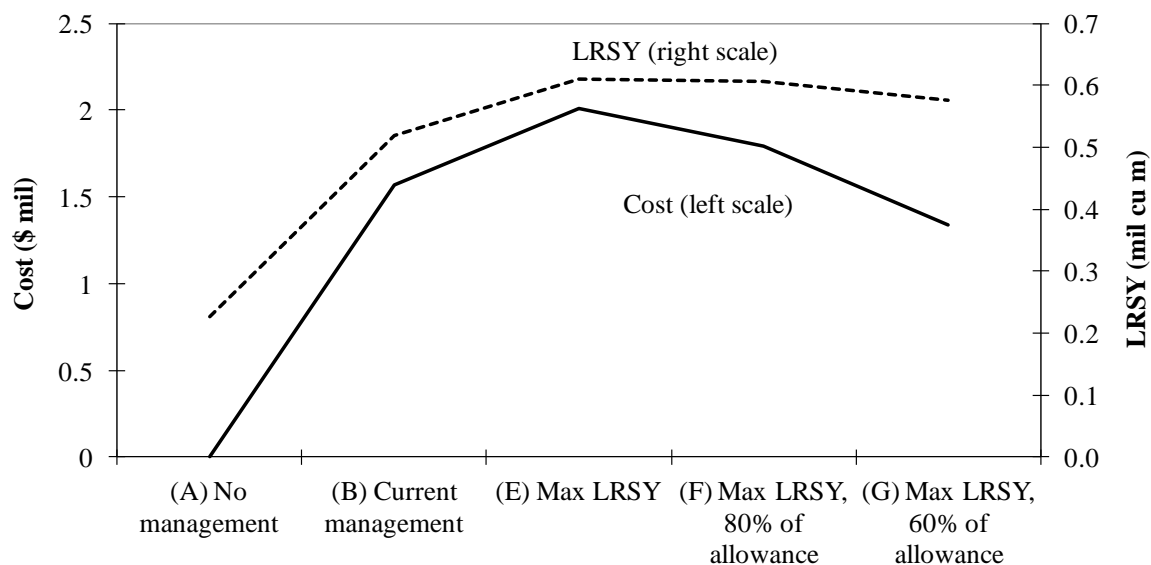


Figure 4.3: Comparison of Costs and LRSY by maximizing productivity scenario

4.6 Discussion

There is certainly merit in defining current mandatory practices for the rehabilitation of harvested sites and then examining outcomes under alternate silvicultural pathways. In this study, scenario analysis was used to demonstrate that economic efficiency could possibly be enhanced even when the budget for silviculture was severely constrained. Scenario analysis was also used to show that increased flexibility in silvicultural practices could reduce silvicultural costs while continuing to meet mandated outcomes. This is an important consideration if forest revenues provide agents with insufficient funds to meet the principal's silvicultural obligations when harvest sites have been hit hard by natural disturbance.

Given the underlying yield tables and site productivity estimates employed in this study, we find that there is about a 20% difference between the long-run sustainable yield outcome likely to accompany current management and that potentially provided by the silvicultural treatments we examined. However, costs changed by a much larger order of magnitude. This is shown in Figure 4.2. The graph indicates that there are vastly different costs associated with nearly the same forest productivity (for any given LRSY). However, if harvesting is to continue in negatively valued stands, where company funding is required to meet the silvicultural liabilities, it is anticipated that there will be

an inevitable ‘collapse.’ At first firms will adopt more flexible silvicultural regimes to maintain TSA productivity targets, thereby reducing costs as seen in scenarios B through D in Figure 4.2. But unless there is a change in the principal’s policies, firms will be unable to continue harvesting dead pine if they are to avoid continued loss of quasi-rent (needed to offset fixed costs), or they will need to reduce silvicultural expenditures to the point where mandated targets can no longer be achieved.

It is clear that, if companies are to maximize the principal’s productivity objective, which is meant to address employment and community stability, silvicultural costs will be much higher as is evident upon comparing Figures 4.2 and 4.3. As the government reduces the extent to which companies can charge silvicultural expenses against royalties (i.e., against stumpage), companies will seek to move away from a focus on inputs to outcomes. They will approach silviculture more flexibly, relying more on natural regeneration and FFEP treatment options to meet outcomes. However, with a negative value index and no royalty payment against which to charge silvicultural costs, companies will eventually halt forest regeneration activities, and stop harvesting beetle-damaged sites, with LRSY falling to its minimum (No Management) level given by alternative A.

As a response to the mountain pine beetle infestation, the policy regulating outcomes along with the silvicultural funding mechanism place the aggregate productivity of the future forest at risk. The British Columbia government has recognized this and has therefore solicited input into the development of a silvicultural strategy. Responses indicated that the government needed to modify the tenure and appraisal arrangements in order to create appropriate incentives for license holders (MoFLNRO 2011). With no explicit silviculture budget and no ability of firms to charge costs against stumpage (royalty) payments, it is hard to imagine how resources can be efficiently allocated to maintain socially desired timber growth targets on public forestlands.

The stand-level prescriptions employed in this study could be extended to determine forest-level outcomes, and then modified to incorporate other values or indicators, which themselves could become useful objectives. The method could then be used to examine the tradeoffs between various sustainable forest management goals (e.g., using compromise programming). Providing a richer set of silvicultural pathways with

associated costs and benefits would aid in developing the range of activities that might benefit the broad range of stakeholders in the public forest.

In 2004, the BC government moved away from the prescriptive forest management model of the Forest Practices Code to the ‘outcomes-based’ forest management model embodied in that year’s Forest and Range Practices Act. The success of this shift depends on the professional judgements of foresters prescribing silvicultural activities throughout the province. Even so, operational foresters are prevented by the institutional framework from managing the forest to its productive potential. Perhaps it is time to remove silvicultural cost as an appraisal allowance and come up with a separate funding mechanism that also rewards efficiency in achieving forest growth targets.

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Chapter 5: Bi-level Timber Supply model of the PA Problem¹²

5.1 Introduction

Public ownership of timber lands in British Columbia is among the highest of any jurisdiction in the world, with 96 percent of commercial forestland owned by the provincial government (Wilson et al. 1998, p.13). Managing public forestland in the face of catastrophic natural disturbance presents a more complex operating environment than management of private forestland. For the private forestland owner, response to natural disturbance can be swift and singular in purpose; for example, in response to the threat of possible catastrophic disturbance, she could pre-emptively harvest all threatened stands of timber. The public landowner, however, has a fiduciary responsibility to be a steward, taking into account the multiple values of the forest through its harvest policies, environmental standards, tenure provisions and timber pricing; the public owner also has an obligation to ensure an adequate long-term supply of timber to sustain forest dependent communities.

Both the government forestland owner (principal) and the private forest companies (agents) are concerned with the implications that natural disturbance has on the future supply of timber from public lands. The government of British Columbia has generally focused on biophysical timber supply in its efforts to mitigate the harm from large-scale damage to pine trees (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) as a result of the mountain pine beetle (*Dendroctonus ponderosae* Hopk. [Coleoptera: Scolytidae]) (British Columbia Ministry of Forests and Range 2003, 2007). The province's forest industry has also expressed similar concerns about the beetle's impact on future timber supply (Timberline Forest Inventory Consultants Ltd 2006).

For the most part, researchers have tended to focus on certain short-term outcomes related to natural disturbance. Thus, Prestemon et al. (2006) studied the economic impacts of delaying salvage activities on lands managed directly by the public landowner,

¹² A version of this chapter has been submitted for potential publication.

while Cumming and Armstrong (2004) explored the efficiency of joint planning when area-based tenures on public land overlap, thereby highlighting the importance of reducing competitive inefficiencies. Mathey and Nelson (2010) considered optimal decision-making within an area-based tenure when mountain pine beetle struck, concluding that the tenure-holder's most profitable strategy would actually achieve the government's risk reduction strategy on public land. Schwab et al. (2009) developed an elaborate agent-based forest sector model to explore likely outcomes when BC forest companies employed competitive harvest strategies within their allowed quota.

Chapter 3 explored the government response to the beetle attack by focussing only on the principal's problem. It addressed the question: What is the optimal strategy for the principal to pursue if it wishes to maximize the amount of timber available after the mountain pine beetle has run its course? The first-best timber supply strategy turned out to be one that incentivizes the agents to harvest those damaged stands that deteriorate quickest and are economically worthless by the end of a 10-year time horizon. This, then, provides justification for a short-term uplift in harvest levels. However, the research failed to consider the effect of government intervention on the behavior of forest firms, which responded by increasing harvests of living pine and non-pine species in addition to harvests of damaged pine.

According to Mathey and Nelson (2010), the behavioral response by forest firms to incentives is the key issue facing the public policy maker. However, the government has recently begun to recognize the need to proceed cautiously and better understand agents' actions (BC Ministry of Forests and Range 2006). It has also indicated it should expend more effort actively monitoring harvesting operations (Forest Analysis and Inventory Branch 2009).

When confronted by a natural disturbance such as the mountain pine beetle, one can reasonably assume that the area-based tenure holder's objective function will include both harvests and standing timber, because no other agent can expropriate the investments made by an area-based tenure holder. The same is not true for volume-based tenure holders in BC, who account for 60% of the harvesting rights. Use of area-based tenures, in the form of Tree Farm Licenses (TFLs), is primarily confined to the BC coast, where there has been little beetle damage. The beetle has mainly impacted the interior of

the province, where public forestland constitutes mainly Timber Supply Areas (TSAs) that are indirectly managed by the principal through volume-based tenures.

Unlike the area-based license, the volume-based license provides forest companies operating within the broad geographic area of a TSA with short-term cutting rights, allocating the licensee or agent a specified harvest volume or quota. But harvests within a TSA are allocated to various agents, with each proposing an area to harvest within government regulation to obtain their allotted volume, while paying the requisite stumpage fee. With no area-based exclusivity, volume-based tenure holders will not include the value of future forest inventory in making decisions as they possess no specific timber rights to areas outside of their government-approved cutting permits, which represent no more than two years of projected harvest. Instead, they focus on maximizing the net value of harvest activities within the planning period of their license, with the silvicultural liability included simply as another cost of harvesting. Further, as Nelson (2007) suggests, the lack of clear direction in the government's Mountain Pine Beetle Action Plan (Government of British Columbia 2006) leaves little flexibility for forest managers to respond to natural disturbance.

If the forest were fully homogenous, with stands of equal value, the future state of the forest would not be adversely impacted by the profit-maximizing behavior of tenure holders. If the government was the sole harvester or a forest company could fully manage its future timber supply through area-based exclusivity, there is no principal-agent problem, and the optimal outcome could be achieved by government optimizing its objective function. But the principal-agent problem is unavoidable, because the forest industry feels that the government's response to natural disturbance has been insufficiently aggressive, while public decision makers view the forest industry as simply too focused on accessing adequate fiber at least cost, even to the detriment of public values (Nelson 2007). The goals of the principal (government) are clearly different from those of the agents (private forest companies), which might lead to outcomes that are unanticipated and perhaps even undesirable, causing some to suggest that public forestland owners should avoid volume- or quota-based tenure systems (Haley 1985; Gray 2002). Principal-agent (PA) theory provides a framework for analyzing the incompatibility that occurs when responsibility for forest management in a volume-based

tenure system is delegated by government to the forest companies. We use PA theory to explore the efficiency of the volume-based tenure system in a mixed species forest when major natural disturbance occurs. Our research addresses the divergence between government objectives and expected and realized outcomes, and offers a programming approach to bring incentives into line.

Because the government's response to the beetle disturbance has been to increase the total harvest and create additional quotas, the PA problem is driven mainly by the volume-based tenure system. Yet, even within such a tenure system, two types of distinct tenures can be identified and, as we demonstrate in this study, the allocation of quota to a given type may be important. First, we identify a replaceable tenure holder that owns a mill it needs to supply and whose license can be renewed. To supply its mill, the replaceable tenure holder can purchase or sell logs on the open market and, because it has a mill, has some affinity towards ensuring that there might be sufficient timber in the intermediate term of 10 to 15 years; the principal is generally pre-disposed to guaranteeing that such an agent is able to supply its mill regardless of where the logs come from.

Second is the non-replaceable tenure holder, which might be a company, First Nation or market logger. This agent only tries to make the most money it can from harvesting and selling logs for the duration of the license. This type of license has traditionally been used for short-term salvage operations, which explains the non-replaceable nature of the license. The agent has no mill to supply and is only a seller of logs on the open market, compared to the replaceable licensee who might take part in both sides of the log market.

Although neither the replaceable nor non-replaceable license holder takes the future forest value into explicit account, they have different objective functions as argued in the next section. This difference leads to divergent outcomes from the perspective of the principal, and therefore has an important policy implication, namely, that the government needs to be careful in choosing to allow new agents to access timber volumes resulting from a harvest uplift caused by natural disturbance.

5.2 Method

We begin by assuming a canonical forest estate consisting of 50 units of pine and 50 units of non-pine (see Chapter 3). After initial infestation, pine beetle damage is assumed to occur over a five year period, rising from 10% in the first year, achieving a maximum of 45% in the third year, and then declining to zero by year six (see Figure 5.1). Depending on how quickly green pine is harvested the upper limit of damaged pine is 75%.

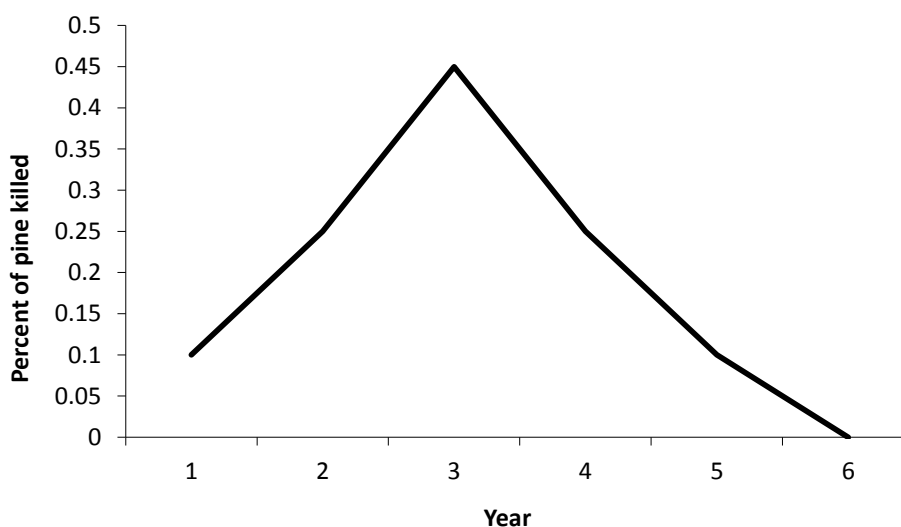


Figure 5.1: Annual Proportion of Affected Timber Killed by Beetle after Initial Infestation

We also use simple ordinal values for a number of the parameters in the model. A complete list of parameters is found in Table 5.1. It is assumed that the forest is harvested at a rate of two units per year, and we wish to simulate the best possible short-term decision-making to be implemented by the principal in managing the forest over the next decade. Further, the historical stumpage price for this forest is assumed to have been \$2, timber value has been \$10 and logging cost is \$7.¹³ Restoration of the damaged forest costs \$2 per unit of damaged pine if it is not harvested within the assumed 10-year

¹³ For convenience and since we employ simulated forests that represent those of the BC interior, which has been impacted by mountain pine beetle, we do not assign a specific unit of measurement to biomass and use \$ simply to denote a monetary value.

planning horizon. Thus, with a cost of \$2, the principal is responsible for the full cost of silviculture on unharvested, denuded stands at the end of the 10 years, but without the stumpage revenue necessary to offset it.

Table 5.1: Parameters for a simple bi-level forest problem

Parameter	Value	Description
T	10 years	Planning horizon
t	Annual	Timestep
s	(P, DP, NP)	Species (green pine, dead pine, non-pine)
a	(R, N)	Agent type (Replaceable, Non-replaceable)
$H_{a,t}$		Government total harvest assigned to agent a in year t
$h_{a,s,t}$		Harvest by agent a of species s in year t
σ_a	$\{0.5, 0.7\}$	Pine proportion of total harvest set for agents $\{R, N\}$
μ	0.3	DP proportion of the harvest set by government for agent N
τ_s	$[-\$2, +\$2]$	Stumpage fee by species s per unit at time t
δ	$1/(1+r)$	Discount factor where r is the discount rate (assumed 2.5%)
w	\$2	Rehabilitation cost per unit of dead pine inventory charged in year $T+1$
$v_{s,t}$	\$10	Per unit gross value of standing timber of species s at time t
c	\$7	Per unit harvest cost of timber
$I_{s,t}$		Inventory of standing timber of species s at time t
$\beta_{s,t}$		Proportion of timber attacked by pine beetle in year t

The public landowner's stumpage policies influence timber recovery, so that varying the stumpage price influences the harvest choices of the agents (Amacher et al. 2001; Amacher 1999; Paarsch 1993). Incorporating firm behavior into a short-term timber supply context would seem a necessary component to understanding the ultimate impact of the beetle infestation on the provincial forest resource. Not adequately accounting for the decision variables and the responses of the agent may call into question the explanatory power of an economic model (Angelsen and Kaimowitz 1999). Thus we test a range of stumpage values from the current value of \$2 to a subsidized value

of -\$2, with the latter representing the situation where the full burden of restoring a site falls on the principal, not the agents.¹⁴

The technique of assigning decision variables to the appropriate decision maker is a key feature of bi-level programming (BLP). It clarifies in a formal mathematical construct those variables under the control of the principal, their feasible range, and how these variables enter into the agent's decision criterion (Candler et al. 1981). Candler and Townsley (1982) define variables as to whether they are the principal's policy variables, the agents' behavioral variables, or impact variables that are not be controlled by either the principal or the agent. The latter are also known as state variables as they describe the state of nature; they include such things as the rate of mountain pine beetle attack, the shelf-life of damaged timber, the deterioration of recovery rates of timber products from beetle-impacted logs, or economic factors such as lumber prices. Candler and Norton (1977) found that, if the agents' behavior was explicitly taken into account by the principal, the policy-behavior frontier was within a much narrower scope of the production possibilities (technological) frontier than if the principal took into account only those variables under its control. This is not surprising because, whenever constraints are added to a constrained optimization problem, the set of solutions is diminished. As Candler and Norton (1977) found in an application to farmers in Mexico, ignoring the policy-behavior frontier introduces policy failure.

Chapter 3 describes a novel approach to capture the government's objective function by assuming the principal seeks to maximize the value of the standing forest at the end of the beetle salvage period, in other words, long term forest stewardship. If it can be assumed that agents harvest only sites that will have no future economic value because of beetle damage, the requirement that harvested stands be restored to 'free-to-grow' stage ensures that the principal will not, in these circumstances, need to incur expensive site rehabilitation to maintain forest productivity.¹⁵ That is, if the agents behave exactly

¹⁴ Again the values do not represent actual stumpage values but ones meant to simulate the impact of government policy.

¹⁵ The assumption that agents will harvest only stands that will be uneconomic in the future is only a starting point for defining the best possible future forest scenario. The Association of BC Forest Professional's Professional Practice Committee (2009) discusses the ethical dilemma facing professional foresters who
Continued

as desired, the objective of maximizing future stand value provides a reasonable justification for an increase in short-term harvests (an ‘uplift’) to eliminate these heavily beetle-damaged stands. This approach to the PA problem formed the economic justification needed to address the concerns of critics, especially those who argued that natural resource capital was being depleted (Green 2000) or that opportunities were eliminated by overly aggressive harvest allowances (Parfitt 2007; Hughes and Drever 2001). The objective of ‘maximizing the future value of the standing forest’ simply embodies a concern for the best possible future, while providing guidance for the short-term actions needed to attain that future.

5.3 Modeling the Principal’s Decision Making

The government is not only interested in ensuring future timber harvests and, supposedly thereby, economic and rural community stability, but it is also interested in the rents it can extract from the forest sector, the rehabilitation costs that it might have to incur if beetle-impacted stands are left unharvested, and the environmental values that are associated with the forest ecosystem more generally (e.g., carbon sequestration, visual and wildlife values), many of which are identified by environmental groups. Prior to the mountain pine beetle infestation and more recent financial crisis, timber harvests were an important source of provincial revenue. Revenues fell as the government encouraged harvests of beetle damaged timber through the use of reduced sawlog stumpage rates and use of waste fiber from affected trees deemed unfit for milling. The reduction in forest rents impacts the choices available to the government as it experiences budget pressures (Amacher 1999; Amacher and Brazee 1997). The government’s objective includes all of the forgoing considerations, but it can only control the stumpage fees it charges for various types of timber, the total timber harvest and, to a much lesser degree, the species composition of the harvest.¹⁶

prescribe the “harvesting of green wood in a sea of dead pine.” Clearly, other factors play a role in the agents’ ability to meet the principal’s objectives.

¹⁶ In the long run, the government can also control the tenure system, but that is something beyond the scope of the current paper.

We assume that the principal (the public forestland owner) seeks to maximize the rents it extracts from the forestlands it owns, subject to biophysical constraints related to disturbance on standing timber inventory and its desire to address damages caused by the mountain pine beetle infestation. The principal's objective is specified as follows:

$$(1) \quad \begin{aligned} \text{Maximize} \\ \tau_{s,t}, H_{a,t}, \sigma_a \quad R = & \sum_{t=1}^T \delta^t \left(\sum_{s \in \{P, DP, NP\}} \tau_s \sum_{a \in \{R, N\}} h_{a,s,t} \right) - \delta^{T+1} w \sum_{t=1}^T I_{DP,t} \\ & + \delta^{T+1} \sum_{s \in \{P, NP\}} (v_{s,T+1} - c) I_{s,T+1}. \end{aligned}$$

In the above, t refers to year and T to the number of years in the planning horizon; $\delta = 1/(1+r)$ is the discount factor, with r the principal's discount rate; τ_s is the stumpage fee per unit of harvest of species $s \in \{P, DP, NP\}$, where P refers to green or living pine, DP to dead or severely damaged pine and NP to non-pine species; $h_{a,s,t}$ is the harvest in year t of species s by agent $a \in \{R, N\}$, where R refers to the replaceable and N to the non-replaceable tenure holders (discussed below); $H_{a,t} = \sum_a h_{a,s,t}$ is the harvest assigned by the principal to agent a at time t ; w is the average cost of rehabilitating dead pine inventory $\sum_t I_{DP,t}$, which is assumed to occur instantaneously at the end of the time horizon; $(v_{s,T+1} - c)I_{s,T+1}$ is the net salvage value of the timber inventory of species s , where $v_{s,T+1}$ refers to the standing value of timber per unit of inventory at $T+1$ and c is the per unit harvest cost; and σ_a is the proportion of agent a 's total harvest that constitutes pine timber.

When the agents are treated as if they behave in accordance with the wishes of the principal, the optimization problem (1) is solved subject to inventory constraints on each of the three species (equations 2 and 3):

$$(2) \quad I_{s,t+1} = (1 + g_s - \beta_{s,t}) I_{s,t} - \sum_a h_{a,s,t}, \quad \forall t = 1, \dots, T; \quad a \in \{R, N\}; \quad s \in \{P, DP, NP\} \quad (\text{Inventory})$$

$$(3) \quad I_{s,0} = I_s^*, \quad \forall s \in \{P, DP, NP\} \quad (\text{Starting inventory})$$

In the inventory constraint (2), g_s refers to growth rates; clearly, the growth rate of dead pine is zero, but the growth rates of non-pine and pine timber are also assumed to be zero for convenience, because the time horizon is short and growth has no impact on our story. Also, $\beta_{s,t}$ refers to the proportion of living pine that is attacked by the mountain pine beetle in year t ; therefore, $\beta_{NP,t}=0$, $\beta_{P,t}>0$ and $\beta_{DP,t}<0$.

As indicated by the last term in objective function (1), the principal is concerned with biophysical timber supply projections as well as immediate revenue. The public landowner is also interested in making sure that the future species balance does not tilt too far towards pine, which would then be vulnerable to future beetle outbreaks. Therefore, an additional constraint (4), discussed in the next subsection, needs to be added to complete the principal's problem and ensure that agents do not harvest too little pine. While the principal may ignore economics in its policy analysis, the agents will, however, adhere to economic criteria to stay in business.

5.4 Modeling Agent Behavior

Now consider the objectives of the agents and the constraints they face. We consider two types of tenure holders – those with replaceable forest licenses (denoted R) and those with non-replaceable forest licenses (N). We will begin with an additional constraint (4) that applies for both agents, namely, a minimum proportion of pine in the total harvest:

$$(4) \quad \sum_{a \in \{R, N\}} (h_{a,P,t} + h_{a,DP,t}) \geq \sigma \sum_s h_{a,s,t} ; \forall t = 1, \dots, T \quad (\text{Pine harvest constraint})$$

where σ is the proportion of the total harvest that must constitute pine. This proportion may be the same for both agents, or the principal may specify different proportions for each. The components of σ will be assumed to be proportional to the species portfolio for agent R (50%). We set a higher percentage pine harvest for agent N (70%) to reflect that the principal has the opportunity to place more stringent requirements on a new non-replaceable contract holder.

Historically, the holders of replaceable forest licenses have sought to minimize the costs of procuring the wood supply required for company sawmills. Stumpage fees that the resource owner collects and the silvicultural liabilities incurred to regenerate harvested stands were considered part of the costs of obtaining logs. Therefore, the situation facing agent R could be represented mathematically by the following constrained optimization problem:

$$(5) \text{ Minimize Cost} = \sum_{t=1}^T \delta^t \sum_s (c + \tau_s) h_{R,s,t}$$

Subject to:

$$\mathbf{R}: \quad (6) \sum_s h_{R,s,t} = H_{R,t}, \forall t = 1, \dots, T \quad (\text{Annual harvest})$$

$$(7) \sum_s (v_{s,t} - c - \tau_s) h_{s,t} \geq 0, \forall t = 1, \dots, T \quad (\text{Positive annual revenue})$$

In this specification, the variables are the same as described above, although the discount rate r might be the same for the agents as for the principal, or it might be higher. $H_{R,t}$ is the government determined allowable harvest by agent R at time t .

When it comes to forest-level operations, the objective for a replaceable tenure holder is to minimize log costs rather than profit, because agent R needs to supply a downstream mill with logs. This also partially accounts for the ‘annual harvest’ constraint in program \mathbf{R} , as the agent wants to ensure that there is an adequate supply of logs to the downstream mill. However, since the annual harvest level, $H_{R,t}$, is set by the principal and because deviation from this harvest level could impact future harvest levels when the tenure is renewed, the agent seeks not to deviate from the timber harvest level it is given. However, agent R is unwilling to harvest timber if its net value is negative, preferring to buy logs from other sources (perhaps from agent N) to supply its mill. The positive annual revenue constraint ensures that log value exceeds log cost – that the government does not capture quasi rent rather than resource rent as noted in Chapter 4. To ensure positive annual revenue and meet the annual harvest constraint, the agent will shift from

salvage harvesting of beetle impacted timber to more valuable living pine and non-pine timber.

The holders of non-replaceable forest licenses (N), on the other hand, maximize profits from harvesting timber, because it is assumed they have no production facility. Profit is derived by directly maximizing the difference between log value and log cost on the portfolio of stands the government has assigned in the license contract. The non-replaceable license affords the principal the ability to tailor the contractual arrangement to incorporate a salvage focus. We assume agent N will have an annual minimum dead pine harvest to simulate a minimum salvage component. Yet, the principal must permit the agent sufficient flexibility so that harvest actually takes place.

Agent N 's objective function is to maximize net discounted value (π) subject to ensuring the harvest contains the timber types outlined in the contract, such as the amount of living and dead pine material. Agent N will also avoid harvesting stands that have negative net value, although she is constrained by the principal to address specific stand types, something not necessarily required of agent R . However, as indicated by the inequality in the first constraint in the following program, N does not have to meet the principal's upper limit on harvest – agent N can simply reduce total harvest to avoid a loss.

Agent N 's problem is specified as follows:

$$(8) \text{ Maximize} \quad \pi = \sum_{t=1}^T \delta^t \sum_s (v_{s,t} - c - \tau_s) h_{N,s,t}$$

Subject to

$$\mathbf{N:} \quad (9) \quad \sum_s h_{N,s,t} \leq H_{N,t}, \forall t = 1, \dots, T \quad (\text{Annual harvest})$$

$$(10) \quad h_{N,DP,t} \geq \mu \sum_s h_{R,s,t}, \forall t = 1, \dots, T \quad (\text{Dead pine harvest requirement})$$

where μ is the proportion of agent N 's annual harvest that must include dead or severely damaged pine.

It is unlikely that any unharvested timber will interest either agents R or N , although some might argue that the renewability of the replaceable license creates an incentive for

agent R to harvest dead pine as a strategic means of accessing future forest resources. However, Luckert and Haley (1993) indicate that tenures that treat silvicultural activities solely as costs with respect to current harvest will not encourage firms to internalize the outcome of their harvesting actions against the future value of the forest resource. Thus, neither agent has an incentive to harvest timber that yields negative returns.

As noted, the government's policy variables consist of stumpage fees (τ_s), annual harvest volumes (H_a), and the proportions of pine and dead pine timber that can be harvested (σ , μ). The agents control their harvests (h) subject to any economic or contractual restrictions, such as the annual harvest constraints in programs **R** and **N**. All parties are affected by uncertainty from the pine beetle (β), and the exogenous timber values $v_{s,t}$ and harvesting costs c . We assume that agent R is a vertically integrated forest company with a mill designed to absorb the government's assigned harvest level, while agent N enjoys the freedom to harvest below the government's assigned harvest level if this is in their best interests.

When the principal fails to take into account the actions of the agents, its problem is represented by equations (1) through (4). That is, the government chooses a strategy (values of τ_s , H_a and σ) that maximizes the rent to the forest resource (equation 1) subject to biophysical and other constraints given by equations (2), (3) and (4). The solution to this problem is different than if the government were to take into account the actions of the agents, to the extent that these are knowable. To do so, we explicitly include the agent's problem, either program **R** or **N**, as additional considerations in solving the constrained optimization problem given by equations (1) through (4). To do so, we solve the bi-level programming problem using a grid search algorithm outlined in Bard et al. (2000). This algorithm searches over the agents' responses to the feasible range of the government decision variables, thereby producing a second-best solution to the principal's problem. The principal's strategy is then varied and again passed to the individual agent models. In this way, we create 35 different scenarios per agent. We also test the impact variable log value by reducing the log value from \$7 to \$6 to reflect the situation where the value of damaged trees does not cover harvesting costs.

5.5 Results

Our results focus on the variables of interest from the principal's perspective, namely, the government's net revenue and the future value of the forest. We examine five scenarios:

#1 – The principal ignores the strategies of the agents (Figures 5.2 & 5.3).

#2 & #3 – The principal takes into account the responses of the replaceable and non-replaceable tenure holders (agents) for the case where dead pine values equal logging costs, with results presented in Figures 5.4, through 5.7, respectively.

#4 & #5 – The principal takes into account the reactions of the replaceable and non-replaceable tenure holders for the case where dead pine values are less than logging costs, with results presented in Figures 5.8 through 5.11, respectively.

Recall that the government decides upon the harvest rate H and stumpage fee τ . The horizontal axis on the graphs presents the stumpage value to the principal in each case, while the vertical axis is either discounted net revenue or the future forest value. The government's assigned harvest levels (H_t) are given in the legend in increments of one half units from 2 units to a maximum of 5 units; assigned harvests are assumed not to vary across the 10-year time horizon.

The BC government's timber supply forecasts in response to the mountain pine beetle have focused mainly on the need to maintain future timber supply (e.g., British Columbia Ministry of Forests and Range 2007). Therefore, the principal's policy evaluation process begins by examining the future forest value and extrapolating net revenues to the treasury. However, in BC forest planning the process for determining stumpage value (what to charge agents for harvesting timber on public lands) does not currently relate to the process for determining the harvest level. If the principal ignores agents' responses, the maximum future forest condition occurs at a harvest level of 3.5 units per year, where all the dead trees are harvested. This is shown in Figure 5.3. Harvesting less than this level means dead trees are relegated to rehabilitation and harvesting more leads to harvests of green (live) trees.

As noted earlier, assuming a pre-beetle harvest level of 2 units per year and stumpage of \$2 per unit, the government would have no impact on its short-term

revenues as long as stumpage payments are at least \$4 per year, or discounted net revenue of about \$36 for our case study. From Figure 5.2, the government's net revenue increases with higher harvest levels, and the government anticipates receiving a linear increase in revenue as stumpage rates move from subsidy to income. However, even here it is obvious that, in order to maintain the revenue stream, the harvest must remain at or above 3 units per year if dead pine provides normal stumpage of \$2 per unit. If damaged pine has less value and cannot return \$2, an increase in harvest is necessary to sustain the pre-beetle government revenue.

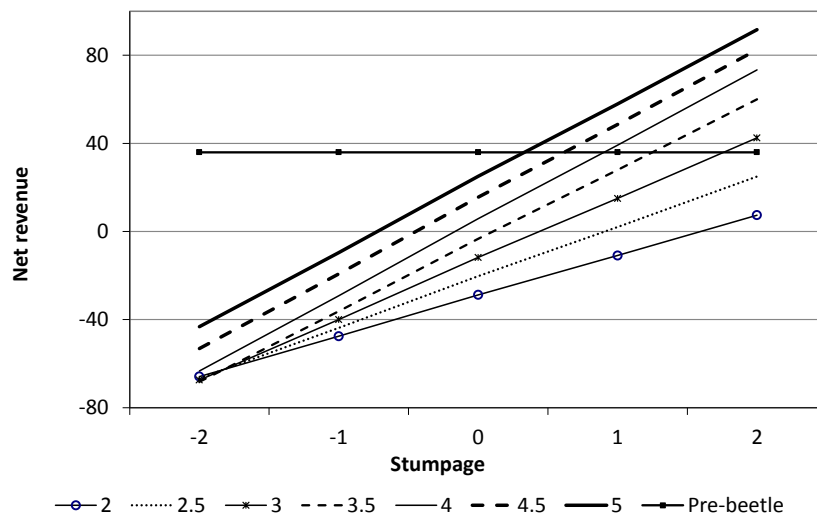


Figure 5.2: Government revenue solution by harvest rate to the Principal's Problem

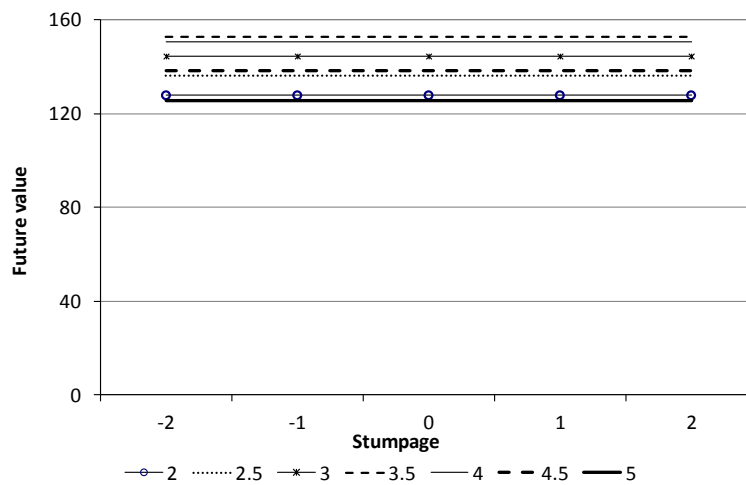


Figure 5.3: Future value of the forest solution by harvest rate to the Principal's Problem

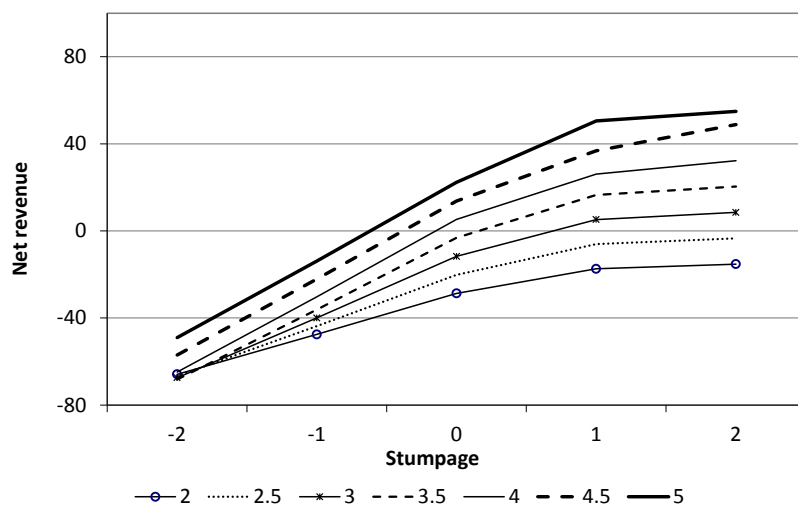


Figure 5.4: Government revenue by harvest rate when value of dead pine equals logging cost, perspective of Agent R

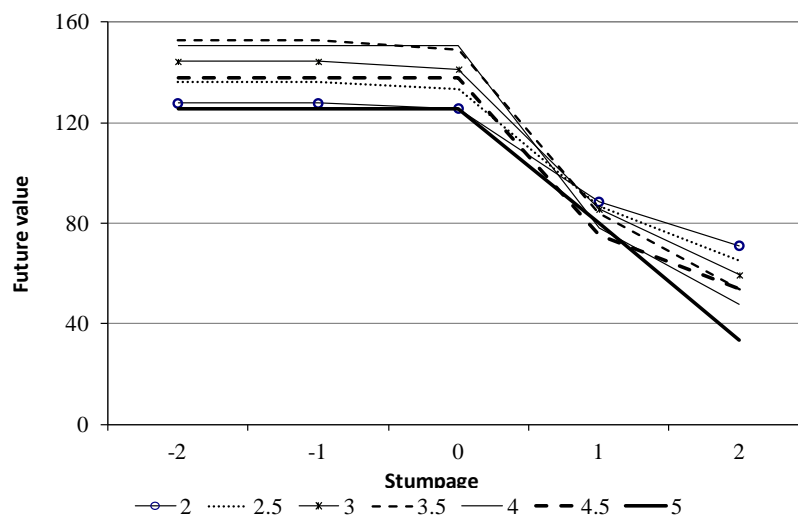


Figure 5.5: Future forest value by harvest rate when value of dead pine equals logging cost, perspective of Agent R

Notice that logging cost does not play directly into the principal's constrained optimization problem, given by equations (1) through (4), except in determining the value of end-of-period standing inventory. Therefore, the principal's biophysical timber supply outlook does not change if logging cost exceeds dead pine value, which implies that the results in Figures 5.2 and 5.3 are invariant to changes in the circumstances faced by the agents – scenarios #2 through #5. Consider first scenarios #2 and #3 where the value of dead pine equals the cost to harvest it. Figures 5.4 and 5.5 indicate what happens when

the response of Agent R to a harvest allotment H and stumpage price for pine is taken into consideration.

Government revenue is highest at positive stumpage rates, but this reduces the future forest condition. If the government accepts a nominal or zero stumpage (which in practice is set at \$0.25 per cubic meter), the outcome is a future forest approximately equivalent to what the government expects. Clearly, if the government does not adjust stumpage rates downwards, the result is quite a low future forest value as green timber is harvested (instead of dead and damaged pine) and remaining sites with dead timber must be restored. The principal can see that negative stumpage – namely, a subsidy – is not necessary as subsidies result in no gain to the future forest value over zero stumpage. Regardless of the harvest rate, there is a convergence point if stumpage is set at \$1.

The outcome is entirely different if the government is dealing with agent N. Results shown in Figures 5.6 and 5.7 provide the range of future forest outcomes from the 35 different scenarios. In this case, only a subsidy of \$2 (stumpage value of -\$2) will result in the future forest outcome the principal desires; anything less than a \$2 subsidy results in a less valuable future forest (Figure 5.7). The future forest value is largely flat in the positive stumpage range as agent N is constrained by the principal from harvesting too much non-pine, thus capping the possible negative influence of this agent's harvest choices.

In the case where the value of dead pine equals the cost of logging it, the government should choose to use agent R rather than N in carrying out harvests. Even so, the government needs to set the harvest rate at 4 units per year and charge the agent a nominal or effective stumpage of \$0 for harvesting dead pine. This produces the highest combined result of future forest value and government net revenue.

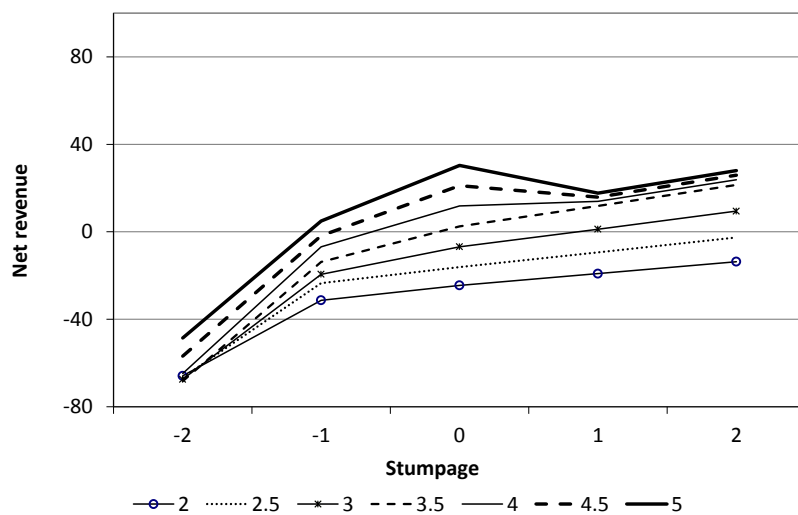


Figure 5.6: Government revenue by harvest rate when value of dead pine equals logging cost, perspective of Agent N

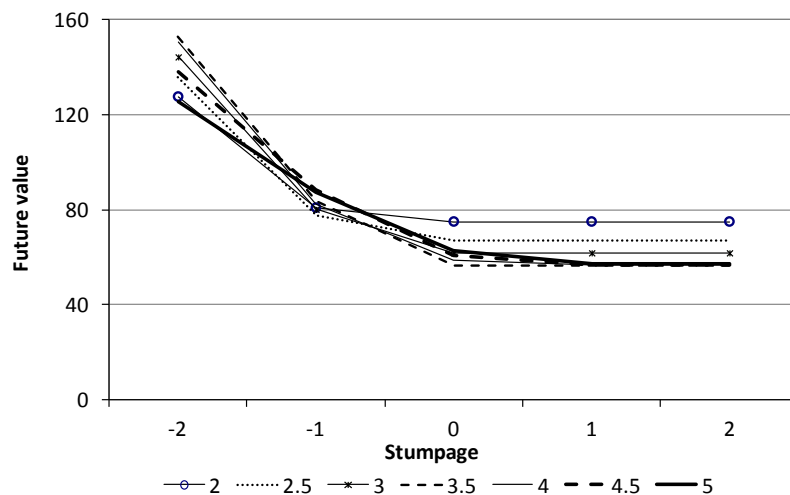


Figure 5.7: Future forest value by harvest rate when value of dead pine equals logging cost, perspective of Agent N

Now consider how agents respond if the value of dead pine is below the cost to harvest it – scenarios #4 and #5. Upon comparing Figures 5.5 and 5.8, we find that agent R responds in such a way that the isolines shift to the left by one unit on the horizontal axis, and there is more differentiation between the future forest value at the various harvest rates for positive stumpage values. The convergence of outcomes for the future forest value now occurs at the nominal stumpage (effectively \$0). The future forest value will only be sustained, regardless of harvest level, by a subsidy of \$1 for dead pine (-\$1

on the horizontal axis in Figure 5.9). From Figure 5.8, there appears to be a slight decline in government net revenues compared to Figure 5.4. However, if the government were to implement a subsidy, it would need to decide the tradeoff between the short term, as represented by net revenue, with the longer term as represented by future forest value.

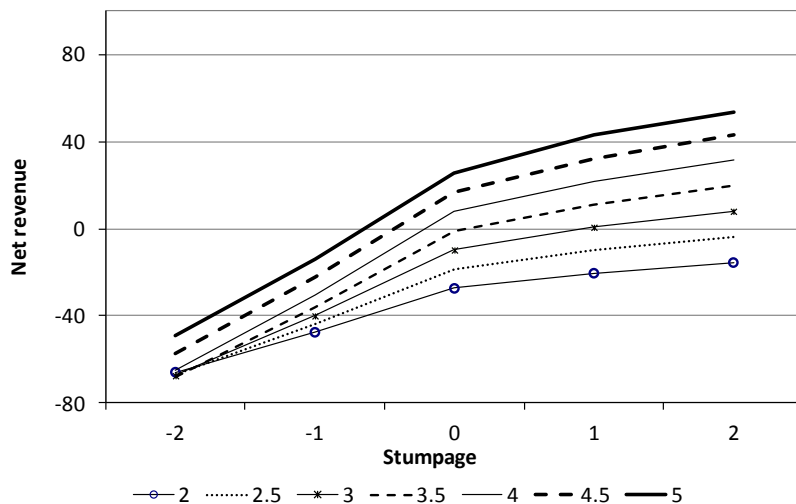


Figure 5.8: Government revenue by harvest rate when logging cost exceeds value of dead pine, perspective of Agent R

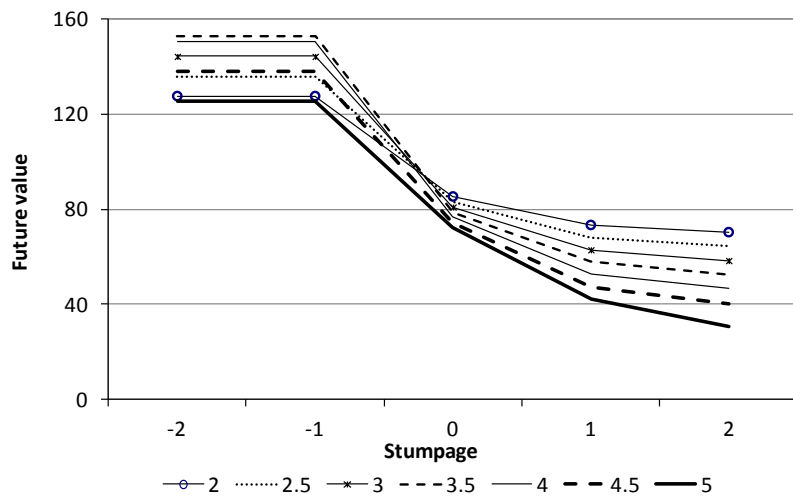


Figure 5.9: Future forest value by harvest rate when logging cost exceeds value of dead pine, perspective of Agent R

If the impact variable dead log value is below harvest costs, the principal would encounter an even greater challenge in choosing to employ a tenure holder represented by agent N. The future forest outcome shown in Figure 6 is less than half the level the

principal desires. Even a subsidy of \$2 per unit does not significantly improve the future forest outcome, regardless of the harvest level (Figure 5.11). If the principal attempts to maintain stumpage rate at \$2, the net revenue in this scenario is negative regardless of what harvest rate is implemented (Figure 5.10). In fact, the expected government net revenue is negative for most scenarios, unless harvesting is set at a high enough rate that green timber produces some revenue; however, this is achieved at the expense of a future forest value of about \$60 between stumpage values of -\$1 and +\$1.

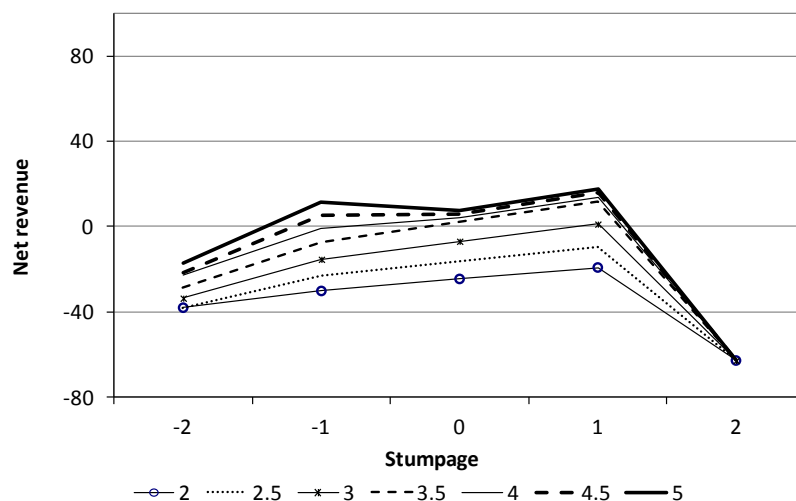


Figure 5.10: Government revenue by harvest rate when logging cost exceeds value of dead pine, perspective of Agent N

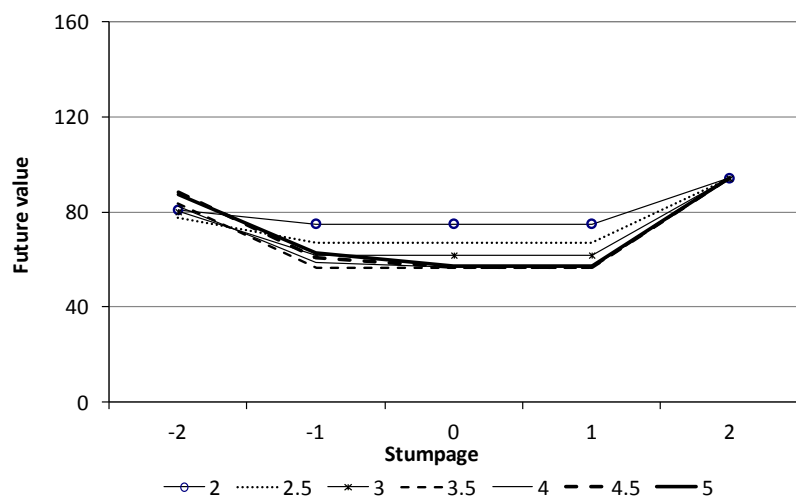


Figure 5.11: Future forest value by harvest rate when logging cost exceeds value of dead pine, perspective of Agent N

In the situation where dead pine value is less than logging cost, the optimal strategy for the principal is to rely on an established tenure holder (agent R) while leaving the harvest level at 4 units per year, but subsidizing the harvest of dead pine to the tune of \$1 per unit. A direct subsidy is anathema to BC forest policy, however, because it will undoubtedly lead to countervailing grievances under the Canada-U.S. Softwood Lumber Agreement (see Yin and Baek 2004). To get around this problem, BC has made use of indirect methods, such as relying on the results of ‘timber cruising’ rather than more detailed and costly appraisal-based methods for determining stumpage values, to reduce the costs of harvesting damaged timber, but this might not be sufficient. Nonetheless, it is clearly necessary that the public landowner come up with ways to reduce the costs to logging companies of conducting risky timber salvage operations as a response to catastrophic natural disturbance.

5.6 Conclusions

Although we relied on a conceptual forest model, we were able to demonstrate that the management of public forestlands provides difficult challenges for the authority because of the principal-agent relationship. An important observation is that, regardless of the harvest level set by the principal, the future forest estate condition is dictated by the harvesting choices of the agents. Setting a low or a high harvest level alone does not dictate the future forest condition. Even tightly dictating the conditions under which a non-replaceable agent can remove timber from public lands may yield less than desirable outcomes. The main conclusion of the research is that decisions regarding harvest levels do not necessarily ensure either positive government revenues or a future forest estate that is adequate to support a forest industry. It is also clear that, if logging costs meet or exceed dead pine value, government must prepare for a time of reduced revenues or even outlays if the future forest is to retain the highest possible value and thus the highest possible future economic timber supply.

The research also highlights the need for government to be very circumspect in using the three primary tools in its tool-kit – harvest level, stumpage price and tenure arrangement. In our simple example, employing the replaceable license holder creates a

result more in line with the desires of the principal. However, the direct allocation of an uplift in timber volume (brought about by the mountain pine beetle disturbance) to an existing replaceable tenure holder leads to the appearance of favoritism and requires analysis and justification to communicate the decision choice to the public and other stakeholders.

It is clear that the objectives of license holders play a key role in the outcomes that the government can expect. In the forestry context, research into this issue has been scant, but it is nonetheless crucial to understanding some of the implications and complications of relying on replaceable and non-replaceable volume-based tenures to address large-scale catastrophic natural disturbance in forestry. Until the government employs an incentive mechanism that brings the entire forest estate into the objective function of a license holder, careful consideration of the implementation of the harvest is vital to preserving timber supply options for the future.

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Chapter 6: Summary and Conclusions

6.1 Summary

The management of public forest often leads to a principal-agent relationship, where the government as the principal may have desires in terms of revenue or forest restoration that must be achieved through the actions of private agents. These agents possess their own motivations and constraints, often financial, which the principal must take into account when developing good forest policy. To date, principal-agent theory has been used primarily in a qualitative way in forest management. The research presented here supplies much needed numerical results, which are especially useful when governments manage forests ravaged by catastrophic natural disturbance and employ volume-based tenures.

In Chapter 2, the PA theory is described within the broader context of the New Institutional Economics and discussed from the perspective of forest management, with particular emphasis on the timber allocation mechanism used in British Columbia. The various forms of tenure are juxtaposed in terms of duration and exclusivity in order to show how the volume-based tenure system appears to create the highest degree of risk for the principal and thus requires special attention when forest policy is being developed. The importance of understanding the PA relationship in forest management was highlighted by the financial penalty applied by the Supreme Court to the BC government for changing the rules of the game without considering the legal ramifications. Understanding the PA relationship does not entail creating inflexible solutions or responses but in creating and maintaining mechanisms that the principal may employ to use the agent's skills and self-interest to the principal's advantage.

The focus in chapter 3 was on exploring the implications of sporadic progressive pine beetle attack in a mixed species forest and the implications on government's first-best forest management strategy. The PA relationship introduces a complication to formulation of a strategy, but in this chapter the analysis examined primarily the management of a damaged forest resource from the principal's perspective. A novel

objective, maximizing the future forest value rather than discounted net present value, provides a means for the principal to justify the necessity for an increase or ‘uplift’ in harvest level to stakeholders and the global community. In the specific set of circumstances examined in this case study, the principal must explicitly decide whether to choose revenue generation or a sustainable supply of forest products. The results indicate that a quarter of the forest would be better left for future harvesting, creating a useful agent monitoring rule whereby harvest should be sustained in stands with at least 70 percent pine for as long as possible to achieve the best future forest condition. The results in this chapter emulate, to a certain degree, the biophysical timber supply methods used by the BC government in timber supply projections and, while useful for providing a first-best outcome, cannot be seen as providing anything but a necessary reference point due to the failure to integrate the principal-agent relationship into the analysis.

The nature of the principal-agent paradigm affects the silvicultural regime available to the agents, the resulting forest productivity and the ability of the agents to carry out salvage in beetle damaged stands. Chapter 4 introduces one of the inefficiencies of the silvicultural allowance system used in BC, namely, that silvicultural funding through harvest depletions does not create an incentive for the agents actively to manage the future forest. The study is based on actual agent data and forest management philosophies and highlights the fact that the regulated silvicultural regime may be negatively impacting forest productivity, as forest companies will not invest their own funds to access stands that possess a negative return due to beetle damage. However, given an appropriate metric and financial incentive, the technical expertise of the agent could be used by the principal to efficiently achieve the productive capacity of public forestland. Results based on forest company data indicate that the government is currently foregoing 20 percent forest growth in the study area merely because the agents are constrained to operate primarily in a regulation-based stand management model of silviculture, rather than a forest-based model. The principal is not obtaining all of the benefits that an agent acting efficiently could provide.

Having shown a clear effect on forest productivity of the principal-agent relationship in Chapter 4, Chapter 5 integrates the principal-agent paradigm into the short-term timber supply context of Chapter 3. We sought to understand the ‘tenure

effect' attributable to the tenure instruments government currently uses and illustrate the impact relative to a first-best management strategy. In Chapter 5, the bi-level nature of the problem in volume-based tenure management, where the principal controls some things and the agent responds, is emphasized. The mathematical formulation separates the policy variables of government – timber price, harvest level and tenure type – from the harvest choice of the agent. Both actors are faced with the same state of nature, the mountain pine beetle infestation. In the model, the principal may possess one objective for protecting future timber supply, while the agents possess short-term financial objectives and constraints. In the scenarios examined, the safest course of action for the principal is to use the agent with the strongest ties to future forest harvesting possibilities, namely, the replaceable tenure holder rather than the non-replaceable one. This has not been the approach of the BC government, as salvage has traditionally been dealt with through non-replaceable salvage licenses. The research suggests that, if the principal decided to choose the replaceable tenure holder to deal with salvage operations, the principal still needs to understand the response to timber pricing, not just harvest level, in order to safeguard future forest opportunities.

Exploration of the PA relationship in BC during natural disturbance illustrates the influence that the volume-based tenure system has on managing the public forest resource. While there has been continued government reliance on biophysical timber supply projections in British Columbia, PA theory suggests, both qualitatively and quantitatively, that these projections are unlikely to come to fruition. Harvesting and regeneration actions performed by the various forest agents will not lead to the desired forest estate that the BC government desires unless the principal creates the right operating environment.

6.2 Limitations and Application Potential

The research described in this dissertation uses PA theory as an integral basis to provide recommendations that might reduce the chances of policy failure. In Chapters 3 and 5 simulated rather than actual data are employed, leaving critics to suggest that the problems described in this dissertation are too simplistic. The numerical results are driven

primarily by shifting economic values that may yield successful policy while the values hold but policy failure if the government does not pay close attention to the parameters. The research also fails to consider issues related to First Nations' tenures or forest certification, for example, nor does it go into significant detail about the Canada-U.S. softwood lumber agreement. All of these policy issues affect the decision-making freedom and power of the BC government.

The lack of inclusion of these important issues could be viewed as a serious drawback of the research. However, as Miller (2005) points out, it is the juxtaposition of the two parties' beliefs, goals and willingness to deal with risk that produces the necessary blend of actions between them rather than a definitive solution to the principal-agent problem. In that light, the research provides an important numerical evaluation of aspects of the principal-agent relationship in public forestland management that has not been examined previously. The research can also be seen as providing not a definitive answer, but, rather, an important reference point for policy analysts who may ignore the institutional arrangements underpinning forest management in the province.

The PA framework and the bi-level programming application are vital to ensuring that policy analysis adequately expresses the factors that government controls, while providing bounds on the feasible responses of the forest companies. The research is directly applicable to the principal, the BC government, it provides guidance for crafting communications materials to stakeholder groups and developing feasible forest outcomes. For example, Chapter 3 provided evidence to enable the BC government to justify uplifts in harvest level without being accused of having only a short-term salvage focus. The results in Chapter 4 encourage the government to embrace its own professional reliance model by allowing professional foresters to grow the forest rather than the trees. And, finally, Chapter 5 highlighted the pitfalls for the forest resource if government is not wisely combining policy instruments to produce an operating policy environment that will encourage the agents, the forest companies, to produce the desired forest outcome.

Combining the findings of this research to provincially available data should lead to valuable improvements in timber supply projections used by the province's chief forester to determine the annual allowable cut and in managing the forest for multiple values. The current focus on biophysical timber supply belies the importance the agents place on

achieving the necessary economic conditions in order to remain viable as companies in a competitive market. Understanding the required economics could also limit the use of ineffective tenure instruments, particularly if the tenure instrument has not fully addressed the agent's underlying objectives. The reflection of Chapter 5, that timber price influences behaviour, completes the triad of different arms within the BC government responsible for managing the outcome of the catastrophic damage caused by the mountain pine beetle. To date, these business areas, namely Forest Analysis, Tenures and Pricing, have been operating independently, as evidenced by the focus on biophysical timber supply, allowable annual cut uplifts being sold as non-replaceable forest licenses primarily to market loggers and timber pricing creating strange practices such as kiln-drying of logs to obtain favourable stumpage conditions. The research found in Chapter 5 suggests that the best forest outcome would have been created by combining the decisions made by these separate business areas, into a coordinated decision process which allowed for feedback on the economic conditions as they changed. While treating the three areas as separate entities may not have created policy failure, the BC government did not create a cohesive strategic response that recognized the PA relationship at the root of its tenure system.

6.3 Future Research

A useful next step in principal-agent research would be to calibrate the modelling on a timber supply area such as Williams Lake. A case study showing an expected or modelled outcome compared with actual harvest and regeneration operations of the various forest companies would be a valuable confirmation that the theoretical expectation is matched by operational reality.

Another avenue to pursue within the PA framework could be research into the ramifications of emerging forest products, which creates new agents with a desire for a sustainable supply of feedstock. Currently, lumber manufacturing represents the single largest driver of economic activities in BC forestry. However, even as the government wished to create a bio-energy industry, the issue of balancing multiple tenure holders in a single geographic area – a timber supply area – will further challenge the volume-based

tenure system. Research may inform whether government is wiser to regulate the relationships through tenure or explore other measures to encourage the diversification of products extracted from the forest resource.

Taking an inter-disciplinary view, there is increasing interest by the principal, the BC government in this dissertation, to begin to act as a single land manager who understands the cumulative effects of multiple resource uses on land values. Currently different legislation guides the different agents on the public land, creating an uneven operating environment. Combining the various proponents of resource use such as independent power producers, oil and gas companies, forest companies, and recreation service providers, will need careful consideration of the economic objectives of the various agents in order to manage and steward the public land wisely. It will also require the BC government to be explicit about the objective function that it is managing for, something that remains fuzzy and decidedly politically acceptable rather than economically achievable.

6.4 References

Miller, G.J. 2005. Solutions to Principal-Agent Problems in Firms. In *Handbook of New Institutional Economics*. Springer-Verlag, Netherlands pp. 349-370.