THESIS PROPOSAL:

PROTECTING TIMBER SUPPLY ON PUBLIC LAND DURING CATASTROPHIC NATURAL DISTURBANCE:

Public desires and private response

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1. RESEARCH CONTEXT

Rarely, if ever, do forest jurisdictions take the full impact of natural disturbance into account when making decisions on timber supply. In forest planning, natural disturbances are considered to be too small to affect decisions regarding current and future timber supply, so deterministic planning readily accommodates such disturbances by permitting a small degree of flexibility in harvesting decisions. Where forestland within a jurisdiction is primarily privately held, forest holdings are generally small relative to the jurisdiction's entire timber base, so individual landowners will adapt quickly to threats of fire or disease, either by immediate fire suppression or harvest of the site before the disease strikes. In some cases, the landowner may lose his or her entire timber investment, but that is not something that concerns forest planning. Thus, if forestlands are privately held, it is likely that a massive disturbance, such as the mountain pine beetle (MPB) infestation in the interior of British Columbia, can be avoided, as timber is harvested before it can be attacked. The risk in this case is a potentially huge uplift in timber harvest as private holders liquidate their timber assets before the timber is struck by the outbreak. The cost is lower prices and a potentially large reduction in future timber supply.

The situation is different when a massive natural disturbance affects public timberlands and there is little in the way of privately held timber. In this case, political realities prevent the authority from harvesting 'ahead of the curve' because the public landowner must take into account environmental amenities, community stability and the even-flow of timber to mills, future timber availability for economic stability, revenues and timber prices (as public harvest decisions, unlike private ones, can affect prices), alternative mitigation strategies, et cetera. In other words, the public owner is less likely to increase harvests to avoid the spread of a pest like the MPB than if the same lands were privately held. The public owner is more likely to face the consequences of natural disturbance ex post rather than ex ante.

This is the situation with respect to the mountain pine beetle in British Columbia. The government did not increase harvest in anticipation of the MPB's spread, despite past experience with MPB, but must now deal with the ex post consequences. The current research focuses on this aspect of natural disturbance – the policies that the public authority undertakes to deal with massive disturbance after it has occurred.

British Columbia has the most productive forestland in Canada. With almost all of this forest under public ownership, the provincial government has a fiduciary responsibility to steward the multiple values in the forest through harvest policy, environmental standards, tenure provisions and timber pricing on behalf of the people of BC. The government relies on timber sales developed by government staff, and area-based tenures (or concessions) that tie a single company to an exclusive geographic area. However, 60% of the timber volume is managed through volume-based tenures, which are timber quotas entitling the holders to harvest an annual volume within a broad geographic area, referred to as a timber supply area (TSA). A TSA is shared among tenure holders, with each proposing an area to harvest (within government regulations) to obtain their allotted volume and paying the requisite stumpage fee. The company must regenerate the site with funds assigned via an allowance or credit against the stumpage fees paid to the government. While the government sets out the broad policy under which a tenure holder operates, it is the tenure holder that ultimately determines the location, type of harvesting action and silvicultural strategy. The tenure holder is operating to maximize an economic objective in a competitive business environment, and its objectives may not coincide with those of government.

As the resource owner, the government of BC has initiated a number of policies to address the MPB infestation and its consequences. However, it now appears that the outcomes are not the same as what the government expected. The reason is that the government does not chose the stands to harvest but has delegated management of the forest resource to private companies in exchange for stumpage royalties and a smaller government workforce, among other things. A forest company harvests stands of timber at company discretion to fulfill the legal requirements of their respective tenure, either a replaceable or non-replaceable forest licenses. The latter licenses are used primarily to salvage damaged timber and therefore carry some minimum expectation to deal with dead timber.

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 behaviour of the tenure holder. But how efficient is the volume-based tenure system when the forest resource contains mixed species and major natural disturbance is causing selective damage, as is happening in the interior of BC with the mountain pine beetle (MPB) epidemic?

The proposed research addresses the divergence between government policy and expected outcomes and actual, on-the-ground outcomes. In particular, the research proposes to answer the following questions:

1) What influence does the sporadic progressive pine beetle attack have on government's first best solution?

A mathematical programming model will be developed to create a representative first-best solution from the perspective of the public or government regulator. This assumes that, if the government were to have complete information and undertake action (say, harvesting in a mixed species forest characterized by a progressive irregular MPB-like disturbance), the outcomes would be ideal from the public perspective. This then constitutes a benchmark for comparing further outcomes.

2) What is the 'tenure effect' attributable to the tenure instruments government currently uses and what is the impact to the first best solution?

Our concern is the divergence between government desires and private actions – the public wants certain outcomes with respect to the MPB but lacks the information about how to achieve these outcomes, which is available only to the private forest companies. While the required information available to the private companies may not be complete, the companies have more information than the government regulator – information is asymmetrical. As a result, the model used to answer Question 1, which represents the outcomes if the government has full information and control, will need to be augmented by a second constrained optimization model to account for the actions of the private companies. The augmented model isolates the government's control variables from those of the forest company. Further, because there are two different types of tenure holders, replaceable and non-replaceable, there is the possibility that each tenure type introduces a different set of outcomes, termed the 'tenure effect.' This model will be used to explore the tenure effect and the government's best response to the asymmetry of information.

3) Does the theoretical model mirror reality or do other influences play a role?

Models are powerful tools to explore a range of possibilities, but their predictive 'power' requires that one is careful to calibrate a model before comparing it to the real world. Comparison can help identify other influences or possible variables not used within the model but important to explaining the outcome. The models constructed in this research will focus on a TSA in the BC interior, enabling us to examine expected outcomes with actual harvest choices.

2. MPB AND ECONOMIC TIMBER SUPPLY

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 2003a, British Columbia Ministry of Forests and Range 2007, British Columbia Ministry of Forests and Range 2006, 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 beetle damaged timber can be successfully logged.

Stennes and McBeath (Stennes and McBeath 2006) examined one aspect of the economic issues – 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 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, in order 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 to achieve 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 are examining, they 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 actions within the planning period of their license. This creates a conundrum in that government has a fuzzy objective function as outlined by its Mountain Pine Beetle Action Plan, while the two types of volume-based tenure holders, replaceable and non-replaceable, will each possess a different objective function. 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 framework. Under this 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 the principal controls (e.g. stumpage, silvicultural obligations, harvest level).

3. PRINCIPAL-AGENT APPROACH IN FOREST MANAGEMENT

Forest economists are keenly aware that the institutional framework will significantly influence both the policy choices available to the public land owner 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 beginning to examine the alternate arrangement, when economic behaviour influences the development of the institutions or rules. In British Columbia, it can be argued that volume-based tenure arrangements between the provincial government and forest companies are likely to have significant impacts on the timber supply outcome in times of catastrophic natural disturbance. With forest companies deciding where to harvest subject to immediate economic implications, government policy and timber supply goals will miss the mark without due consideration to the institutional framework, especially in the case of a perishable resource such as damaged timber.

And yet historically, timber supply in BC has not explicitly included forest economics, outside of the general provision that the biophysical supply be broadly considered as economic — stands should have reasonable transportation access, terrain should not be too expensive to develop, et cetera. Timber pricing and revenue projections generally use econometric approaches developed by timber pricing specialists to predict future government revenues based on lumber markets and assume the biophysical supply is representative of the profile of stands forest companies have harvested in the recent past. Timber pricing has been related more to lumber demand economics than to the forest management context. Since it has been shown that a public landlord can influence timber recovery by its stumpage policies (Amacher et al. 2001, Paarsch 1993), varying the stumpage price should influence the harvest choices of the forestry firms. Incorporating firm behaviour 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.

3.1 Principal-Agent theory

Principal-agent (PA) theory has its roots in the new institutional economics, which began with a description of the nature of the firm by Coase in 1937 (Coase 1998). While the primary coordination mechanism in economic theory had been the markets (prices), in many situations, the firm is the coordination mechanism that reduces the number of transactions and thus produces a more efficient outcome (Coase 1937). As long as the firm can coordinate a transaction at a lower cost than it can through the market, it pays to internalize the function. Once coordination becomes onerous, a firm may need to allocate the function to the market.

In its simplest form, the PA problem is one of delegated choice where the principal delegates management to another party, called the agent (Rees 1985). Delegation arises when tasks are "… too complicated or costly to carry out oneself" (Sappington 1991). As asset specificity or specialized skill increases and the duration of the activity decreases, it is clear that contracting an activity becomes more attractive. This explains, for example, the vertical integration that occurs as complex, possibly repeated, transactions in the market place are less efficient than retaining different specialists or functions within an organization. It is in this context that PA theory finds its basis.

Gray (2002) points out that governments typically do not have the internal capacity, the capital or the industry experience to operate logging operations and choose instead to contract this out to specialized forestry firms, creating the PA relationship. Contracting requires monitoring on the part of the principal. Gray warns that the use of volume-based tenures, also called timber quotas, can overlap and create significant complexity in monitoring the activities of the firms. An example of complexity based solely on silvicultural practice regulations in BC is found in Wang and van Kooten (2001). They suggest that PA theory is applicable because different levels of company effort to regenerate stands (used broadly to include financial costs) can prove problematic for the government (and even a private firm hiring independent silvicultural contractors) when there is ambiguity in the performance measure that defines success.

Government news releases can be seen as a signalling mechanism used by government to provide insights into how government views a certain situation. Prospective agents who ignore signals can miss the mark in written contract proposals by not using the vocabulary or subtle messaging that the principal reveals. During the 1990s, the term “timber supply” was regularly used in BC legislation and government policy and so research proposals often contained some connection to timber supply, no matter how tenuous, as a means to connect with the signal offered by the principal. Nowadays, the term “climate change” provides a similar vernacular. The provincial government signaled the catastrophic nature of the MPB epidemic by creating a geographic salvage area defined in Order-In-Council 661-08. This provided some valuable funding from the federal government but also put existing tenure holders on notice that salvage was a key priority.

Screening, on the other hand, is a more specific transfer of information. For example, in the past, provincial governments in Canada required appurtenancy, the need to operate a mill, in order to obtain a 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 2003b, Niquidet 2008).

An agent may reveal hidden information through the use of self-selection, whereby the agent chooses specific actions in response to the principal, thus informing the principal about the value of the activity. For example, British Columbia Timber Sales, the logging arm of the provincial government, regularly provides timber sales opportunities that receive no bidders, providing the government the characteristics of uneconomical timber types. The information could be extrapolated to the forested land base outside of the BCTS operating areas.

The asymmetry of information, whereby the agent is more knowledgeable than the principal, can introduce two important issues. The agent may choose actions that are not in the interest of the principal, termed adverse selection (Salanie 1997), or the agent may have hidden information or goals that are detrimental to the principal's endeavour, termed moral hazard (Holmstrom 1979). An example of the former is a forestry firm's ability to set cutblock boundaries to access the best damaged pine timber, while leaving more questionable areas untreated. By removing more valuable trees and not addressing proximate areas, the agent is reducing the value of the principal's resource base. As an example of hidden information, damaged trees that could be assigned to a specialty mill with optical scanners to extract all possible value from the timber may be harvested by a mill owner who has opted not to invest in the necessary technology. This results in wasteful practices that reduce the rent available from the forest resource. 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.

3.2 Forestry examples of the use of the principal-agent approach

Stiglitz (1974) produced one of the earliest examples of a unified description of a PA model applicable to the current problem, exploring the agriculture example of the landlord-labourer relationship. He concluded that, when direct supervision is either costly or ineffective, the use of sharecropping has an incentive and risk-sharing effect. There is a host of descriptive literature on the influence of forest tenure on reforestation efforts (Zhang and Pearse 1996), silvicultural investment (Luckert and Haley 1993), and rent distribution (Luckert 1991). It has long been held that the BC volume-based tenure system is in fact a deterrent to efficient timber management as there are no territorial rights, which leads frequently to the idea that privatization of the forest resource is the most efficient means of ensuring good forest management (Haley 1985). From a pure timber production and efficiency perspective this is probably true, as the agent becomes the principal and begins to internalize all the effects of their harvesting decisions. However, it can be questioned that, with the social expectations of a multiple-use forest, it is not likely that privatization will be "environmentally, socially or politically" acceptable and may not even be economically viable (Kant 2009). 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 forest lands.

There are many qualitative instances of forestry applications of PA theory due to its explanatory power. Kufuor (2004) uses PA theory to describe the policy failure that has plagued attempts to create sustainable forestry conditions in Ghana. Gray (2002) uses it to describe forestry concession policies with respect to government revenue systems. Karsenty et. al. (2008) apply the theory to the 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. In advising on policy instruments in a natural resource context, Sterner (2003) notes that information asymmetry between the principal and agent can be so severe that simple rental agreements may be the only appropriate tool. A number of qualitative studies have used the framework to describe forestry certification systems (Cousins 2006, Rametsteiner 2002, Kiker and Putz 1997). 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 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 forest land was dependent on whether tribal lands were managed internally (by the principal) or externally, by contract to 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 outcome for the tribe.

Vedel et. al. (2006) provide an elegant theoretical PA model to introduce differentiated contracts for forest advisory services to private forest owners. Piece-work enterprises commonly use PA theory and forestry is no exception. 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 PA theory in fields outside of piece-work contracting but this assertion has been challenged because the paradigm has such broad applicability as a construct even if a solution is difficult to provide (van Ackere 1993).

3.3 Bilevel programming formulation

To model the PA relationship in the volume-based tenure system of BC, a useful starting point is to define the decision variables that the government can use to influence the choices of the tenure holder. The key motivations, termed the objective functions, of the two parties should also be known. The mathematical method that will be used to describe this model is called bilevel or multilevel programming. Colson et. al. (2007) provide the following general formulation of the bilevel programming problem (BLPP):

Minimize or Maximize $\boldsymbol{F}$(x,y)

Subject to: $\mathbf{G}$(x,y) ≤ 0 ,

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Subject to: $\mathbf{g}$(x,y) ≤ 0

The mathematical program can be seen as a two stage process, representing the fact that there are different decision makers with different interests. There is the outer decision maker, or principal in our case, with its objective function ***F*** and a set of constraints, ***G***, plus, the optimal response function ***f*** of the inner decision maker (agent). The agent's decision is made subject to their own constraints. 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).

The technique of assigning decision variables to the appropriate decision maker is a key feature of bilevel programming. It makes very clear, in a formal mathematical construct, what variables the principal can explicitly control, the feasible range of these variables and how these variables enter the agent's decision criteria (Candler et al. 1981). Candler and Townsley (1978) define the variables as policy variables for the principal, behavioural variables for the agent, and a third class of variables, known as impact variables, that cannot be controlled by either the principal or the agent, such as the rate of stand damage by mountain pine beetle or lumber prices in global markets. Candler and Norton (1977) found that the policy-behavioural frontier was within a much narrower scope of the production possibilities or technological frontier than if the principal managed both sets of controllable variables. Not accounting for the policy-behavioural frontier will introduce policy failure. In their Mexican agriculture example, Candler and Norton (1977) found that even modifying an impact variable by an order of three did not affect the optimized behaviour of the farmers.

The method has seen use in agricultural settings to determine optimal government subsidies to farmers (Candler and Norton 1977, Ververidis 2008, Bard et al. 2000), decisions on pollution abatement measures (Amouzegar and Moshirvaziri 1999), and optimal allocations in various fisheries (Pan et al. 2001, Önal 1996, Meuriot and Gates 1983). Complete lists of examples can be found in any of the many bilevel bibliographies available (Colson et al. 2005, Dempe 2003, Vicente and Calamai 1994, Wen and Hsu 1991). Also a number of textbooks are available, exploring the various technical solution techniques (Dempe 2002, Bard 1998, Migdalas et al. 1998).

Using the general bilevel formulation, a useful starting point is defining the BC provincial government's objective function (G). An objective function that characterizes a portion of the BC government's mountain pine beetle action plan is one employed in Bogle and van Kooten (2009), namely to maximize the value of the standing forest at the end of the beetle salvage period. By harvesting any stand that will not have economic value in the future, there will not need to be expensive site rehabilitation to maintain forest productivity and the objective provides a reasonable justification for an increase in harvest in the short term to eliminate these stands. An economic justification is necessary to address the concerns of critics, especially those that would argue that natural resource capital is being depleted (Green 2000), or that opportunities are being eliminated with too aggressive a harvest allowance (Parfitt 2007, Hughes and Drever 2001). The objective function embodies a concern for the best possible future, while providing guidance to the short-term actions necessary to achieve that future.

An additional consideration is government revenue. Prior to the current infestation, harvested trees were an important source of government revenue. Revenues fell as the government encouraged harvest of MPB damaged timber via reduced sawlog stumpage rates. The absence of that revenue will have an impact on the choices available to the government if they are experiencing budget pressures (Amacher 1999, Amacher and Brazee 1997). Therefore, another term that will likely be part of the government's objective function is stumpage revenue. The government's objective function contains three components, stumpage revenue, the future value of the forest, and the cost of forest rehabilitation if stands are left unsalvaged. The government is able to control the stumpage payment or rent it receives from various timber types as well as the total amount of timber to be harvested.

Now consider the agents' objective functions. Historically, the holders of replaceable forest licenses (R) have treated wood supply from a minimum log cost perspective, subject to attaining enough volume to supply company sawmills. Stumpage, the resource rent paid for timber, is a cost. Therefore, the objective function for a replaceable tenure holder would likely be to minimize log cost subject to attaining the desired sawlog harvest with positive net revenue. This latter term reflects that *R* will be unlikely to harvest timber if its net value is negative. The firms will be profit maximizers but many of the factors influencing their profitability are unknown to the government.

On the other hand, the holders of non-replaceable forest licences (*N*), with their limited duration, are more likely to be profit maximizers. 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. Hence, their objective function will be to maximize net present value (NPV) subject to ensuring the harvest contains the timber types outlined in the contract, such as the amount of pine and dead material. Agent *N* will also be unlikely to harvest stands that have negative net value but will also be free from a constraint to supply a mill. This may allow agent *N* more harvest flexibility than a mill owner with ongoing mill costs.

In neither case is the forest left in an unharvested state going to be part of the agent's objective function, although some might argue that the renewability of the replaceable license creates the possibility that the tenure holder may have strategic plans for the future forest resource. Luckert and Haley (1993) indicate that tenures which 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.

To create a simple bilevel model, notation for the various decision variables is necessary. Appendix Table 1 contains a set of parameters that will be used to portray a conceptual model of the bilevel forestry problem. The bilevel model can be written mathematically as follows:

$$Maximize \ldots G = \sum_{t}^{T} \sum_{A} \sum_{S} \$_{gSt} h_{ASt} + \sum_{S} (V_{ST} - C) F_S - \varepsilon F_{DP}$$

Subject to:

Equation of non-pine motion	$I_{\eta t+1} = I_{\eta t} - h_{A\eta t}$	$t = 1, \ldots, T-1$
Equation of green-pine motion	$I_{\Phi t+1} = I_{\Phi t} - h_{A\Phi t} - \beta_t I_{\Phi t}$	$t = 1, \ldots, T-1$

Equation of dead pine motion $I_{\varphi t+1} = I_{\varphi t} - h_{A\varphi t} + \beta_t I_{\Phi t}$ $t = 1,\ldots,T-1$

Annual harvest $\sum_A \sum_S h_{Ast} = H_{gt}$ $t = 1,\ldots,T$

Firm R Minimize $\kappa = \sum_T \sum_S \left(C + \$_{gst}\right) h_{Rst} r^{-t}$

Firm N Maximize $Z = \sum_T \sum_S \left(V_{st} - C - \$_{gst}\right) h_{Nst} r^{-t}$

Economic annual harvest $\sum_S \left(V_{st} - C - \$_{gst}\right) h_{st} \geq 0$ $\forall A, t$

Pine component $h_{N\Phi t} + h_{N\varphi t} \geq \rho_g h_{St}$ $t = 1,\ldots,T$

DP component $h_{N\varphi t} \geq Đ_g h_{St}$ $t = 1,\ldots,T$

Using the terminology of Candler and Townsley (1978), the government policy variables are stumpage (\$) and annual harvest (*H*), while the agents' control their perspective stand harvests (*h*) subject to any economic or contractual restrictions. All parties are subject to the uncertainty created by the pine beetle damage (β) and the exogenous timber value *V* and harvesting costs *C*.

To solve the BLPP, we propose to use the grid search algorithm presented in Bard et al. (2000). The algorithm searches over the optimized agents' responses to the feasible range of government decision variables that produce the second-best solution to the government's problem. The government variables for harvest level (*H*) and stumpage price for dead pine (*\$*) are varied and then passed to the individual agent models. By considering the two agents' objective functions, it seems clear that government has to be more circumspect in its decision-making about non-replaceable licenses due to the likelihood of profit maximizing behaviour which may create a less desirable outcome than the minimizing cost behaviour of the replaceable license holder.

From this simple example, we see that the objectives of the license holders are likely to play a key role in the outcome the government can expect. Research into this area has been scant and will be valuable to understanding some of the implications and complications of the volume-based tenures used in BC during large-scale catastrophic natural disturbance.

4. DISSERTATION OUTLINE

Chapter 1 Research context

Chapter 1 provides a historical overview and research context of the volume-based tenure system in BC. It outlines the government response to MPB, forest company actions and highlights the complexity of the contractual relationship and thus the applicability of PA theory. BC has a rich forest management history and the provincial forest service has been diligently performing timber supply projections for several decades. The government response to natural disturbance has been to increase the harvest and create new licenses to harvest the damaged timber.

Chapter 2 Principal-agent theory in forest management

Exploring principal-agent theory, there are clear applications to the volume-based tenure system in BC. BC examples of aspects of the theory are developed as well as a literature review of its popular use qualitatively, and less so, quantitatively.

Chapter 3 Bilevel programming

This chapter explores the use of bilevel programming and its applicability in solving the PA forest management problem in BC. It will include an overview of the techniques to solve the bilevel programming problem, which includes the grid search algorithm introduced earlier.

Chapter 4 What makes the mountain pine beetle such a tricky pest?

The simple bilevel forest management model described earlier made a significant simplification from reality in that the tree species, non-pine, green pine and dead pine, were separable and dead trees retained their value fully until the final year of simulation. However, this is one of the elements of variability where the geography of the forest resource and the variability of mountain pine beetle attack may also influence the ultimate outcome. The dead pine resource is not compartmentalized or easily inventoried.

The research begins by obtaining sets of solutions incorporating the variability of the resource and the infestation as the government's first-best perspective, as if government controlled all of the decision variables in a forest estate representative of a pine-dominant area of BC, where pine is intermingled to varying degrees with non-pine, and the attack level varies for each stand. This will provide an economical backdrop for a PA bilevel model.

Chapter 5 Tenures and their influence on outcome

As has been outlined previously, the behavioural variables, specifically the stand types the agent harvests, are expected to affect the outcome. With a first best solution completed, the full bilevel model, using more realistic data for costs and timber values, can be developed to explore the influence of tenure on the outcome. As noted above, the response surface for the two types of tenures is likely to be different. This research will explore how the type of tenure influences the choices government must make and the eventual outcome the government can expect.

Chapter 6 Williams Lake case study

With a fully developed model, it will be tested in a specific geographic area in order to compare the development patterns that emerge in the model with those that occur on the landscape. The Williams Lake TSA will be used as a case study area for this research. It has been the location of previous beetle infestations and the license holders and government staff are familiar with salvage harvesting and should be the most aggressive in terms of managing dead pine.

Chapter 7 Conclusion

5. TIMELINE

Chapters 1, 2 and 3 are currently in draft form as part of the development of this research proposal.

Chapter four is based on an existing paper entitled "What Makes Mountain Pine Beetle a Tricky Pest? Optimal Harvest when Facing Beetle Attack in a Mixed Species Forest" delivered to the Third International Faustmann symposium. It will be submitted in the near future to a journal for publication.

Chapter five will take this model and provide a bilevel component, isolating the government's decision variables from those of the two types of agent. This work will culminate in a paper describing the model and preliminary results based on a hypothetical forest typical of the BC interior. The model and paper are expected to be completed by late spring of 2011.

Chapter six parameterizes the model more specifically to a geographic area with the geographic progression of the current MPB infestation as projected by the provincial MPB model. Data on the harvesting choices of the two types of tenures will need to be obtained from the Ministry and

Forests and Range for the Williams Lake TSA or alternatively from forest companies in the area. This data will be contrasted with a re-running of the bilevel model to simulate the choices the BC government made and the response of the license holders. The model will be used to explore whether the responses were predictable as suggested by the model formulation or whether external forces influenced the outcome (e.g. amount of pine harvested). A paper containing the revised bilevel model and a comparison with actual harvesting practice will be completed by the end of 2011.

Chapter 7 will summarize the findings for the developed models and provide conclusions about the influence of the volume-based tenure system on timber supply.

6. APPENDIX

Table 1. Parameters for a simple bilevel forest problem

Parameter	Value	Description
T	10 years	Planning horizon
t	Annual	Timestep
s	*ŋ*, Φ, *đ*	Species (non-pine, green pine, dead pine)
g		Government variable
A	*R*, *N*	Agent type (Replaceable, Non-replaceable)
H_g	Harvest	Feasible range set by government
h_{Ast}		Harvest of species s in time t by corresponding agent
p_g	0.7	Total Pine proportion of the harvest set by government
$Đ_g$	0.3	DP proportion of the harvest set by government
$\$_{gst}$	*ŋ*, Φ *=2* *đ=?*	Stumpage fee by species s per unit at time t
C	7	Harvest cost per unit
r	$1/(1+\delta)$	Discount factor (assume discount rate of 2.5%)
V_{st}	*ŋ*, Φ *=10* *đ=?*	Log value of species s in time *t*
ε	2	Rehabilitation charge per unit of dead pine
β_t		Proportion of pine damage in time t
I_{st}		Stock in units by species at time t
F_s		Final stock in units by species s at time T
G		Government objective function value
κ		Replaceable tenure holder objective function value
Z		Non-replaceable tenure holder objective function value

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