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

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Abstract

If logging on public forestlands is conducted by private forest companies under various tenure arrangements, attainment of the government’s objectives depends crucially on how companies respond to various incentives. This is a classic principal-agent (PA) problem. We employ bi-level programming to investigate the PA problem in the case of catastrophic natural disturbance caused by the mountain pine beetle. The principal (government) uses harvest levels and (lowered) stumpage fees to incentivize agents (forest companies) to harvest beetle-impacted pine while leaving sufficient living pine and non-pine species to ensure adequate future timber supply. We develop a canonical forest estate impacted by mountain pine beetle, and representative of the current situation in British Columbia’s interior. Bi-level programming results indicate that the government needs to understand and exploit agents’ objective functions if it is to achieve social objectives through its forest policy. As a response to catastrophic disturbance, the government must not only raise harvest levels and lower stumpage prices (reduce revenue) but must also pay attention to the underlying objectives of agents. In particular, even though no agent has a stake in the future forest estate, those agents with established mills are more likely to help achieve the government’s objectives pertaining to future timber supply than ones only interested in maximizing net returns from logging and selling logs on the open market.

Key words: principal-agent problem, salvage timber pricing, future timber supply, catastrophic disturbance

JEL Categories: Q23, Q15, Q28
Introduction

The extent of 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, namely, to maximize profit over the short and long term, which might lead to pre-emptive harvesting of susceptible pine stands for example. 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 provide adequate long-term timber supply 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 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 future of the province’s 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, 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.

Bogle and van Kooten (2012a) also examined the response to beetle attack, but focused on the benefits of greater flexibility in post-harvest silvicultural treatment compared to the regulated approach to regeneration employed by the government. They 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 with 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. Public forestlands on the BC coast are primarily allocated to area-based tenure holders as Tree Farm Licenses (TFLs), but public lands in the beetle-impacted interior of the province constitute mainly Timber Supply Areas (TSAs) that are directly managed by the principal. 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 them a specified harvest volume or quota. But harvests within a TSA are among various tenure holders, 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 if the government optimizes its objective function. But the principal-agent problem is unavoidable, because, as Nelson (2007) has shown, 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. 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 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 the 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 size of quotas, the PA problem is driven mainly by the volume-based tenure system. Yet, even with 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 or company that needs to supply a mill that they own. While supplying a 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 predisposed 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 licensee only tries to make the most money it can from harvesting and selling logs. It has no mill to supply and is only a seller of logs on the open market, compared to the replaceable licensee that might take part in both sides of the log market. Although neither license holder takes the future forest value into account, they have different objective functions as argued in the next section. This difference leads to different 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 volumes resulting from a harvest uplift caused by natural disturbance.

**Method**

We begin by assuming a canonical forest estate consisting of 50 units of pine and 50 units of non-pine (see Bogle and van Kooten 2012a). 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 1). Depending on how quickly green pine is harvested, the upper limit of damaged pine is 75%.

We also use simple ordinal values for a number of the parameters in the model. A
complete list of parameters is found in Table 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.\(^1\) Restoration of the damaged forest costs $2 per unit of damaged pine if it is not harvested within the assumed 10-year 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.

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 subsided value of –$2, with the latter representing the situation where the full burden of restoring a site falls on the principal, not the agents.\(^2\)

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

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\(^1\) 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.

\(^2\) Again the values do not represent actual stumpage values but ones meant to simulate the impact of government policy.
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 (1978) 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.

In the context of the mountain pine beetle infestation in British Columbia, Bogle and van Kooten (2012a) sought to define 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. 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. That is, if the agents behave exactly 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.

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

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3 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 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.
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.\(^4\)

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:

\[ \text{Maximize} \quad R = \sum_{t=1}^{T} \left( \sum_{s \in \{P, DP, NP\}} \tau_s \sum_{a \in \{R, N\}} h_{a,s,t} \right) - \delta^{T+1} w \sum_{t=1}^{T} l_{DP,t} \]

\[ + \delta^{T+1} \sum_{s \in \{P, NP\}} \left( v_{s,T+1} - c \right) l_{s,T+1} . \]

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; \( \tau_{s,t} \) is the stumpage fee per unit of harvest at time \( t \) 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 renewable and \( N \) to the non-renewable 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 \( t \); \( w \)

\(^4\) In the long run, the government can also control the tenure system, but that is something beyond the scope of the current paper.
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 \( \sigma_a \) 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):

\[(2) \quad I_{s,t+1} = (1 + g_s - \beta_{s,t}) I_{s,t} - \sum_a h_{a,s,t}, \quad \forall \ t = 1, \ldots, T; \ a \in \{R, N\}; \ s \in \{P, DP, NP\} \quad \text{(Inventory)}\]
\[(3) \quad I_{s,0} = \bar{I}_s, \forall s \in \{P, DP, NP\} \quad \text{(Starting inventory)}\]

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.

**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:

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

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

Subject to:

$$\sum_s h_{R,s,t} = H_{R,t}, \forall \ t = 1, ..., T$$ (Annual harvest)

$$\sum_s (v_{s,t} - c - \tau_s) h_{s,t} \geq 0, \forall \ t = 1, ..., T$$ (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 $R$, 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 (Bogle and van Kooten 2012b). 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 ($\pi$) 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:

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

Subject to

$$\sum_{s} h_{r,s,t} \leq H_{N,t}, \quad \forall \ t = 1, \ldots, T$$ \hspace{1cm} (Annual harvest)

$$h_{N,DP,t} \geq \mu \sum_{s} h_{r,s,t}, \quad \forall \ t = 1, \ldots, T$$ \hspace{1cm} (Dead pine harvest requirement)

where $\mu$ 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 $(\tau_s)$, annual harvest volumes $(H_a)$, and the proportions of pine and dead pine timber that can be harvested $(\sigma, \mu)$. 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 $(\beta)$, 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 $\tau_s, H_a$ and $\sigma$) 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.

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 results under five scenarios:

- #1 – The principal ignores the strategies of the agents (Figure 2).
- #2 & #3 – The principal takes into account the reactions of the renewable and non-renewable tenure holders (agents) for the case where dead pine values equal logging costs, with results presented in Figures 3 and 4, respectively.
- #4 & #5 – The principal takes into account the reactions of the renewable and non-renewable tenure holders for the case where dead pine values are less than logging costs, with results presented in Figures 5 and 6, respectively.

Recall that the government decides upon harvest rate $H$ and the stumpage rate $τ$. 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 (panels a) or the future forest value (panels b).
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 harvest level of 3.5 units per year, where all the dead trees are harvested. This is shown in Figure 2(b). 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 2(a), 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.
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 Figure 2 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. Figure 3 indicates 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 sites with dead timber that remain 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 Figure 4 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 4b). 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 chose 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.

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 3(b) and 5(b), 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 5b). From Figure 5(a), there appears to be a slight decline in government net revenues compared to Figure 3(b). 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.

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 6b). 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 6a). 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.

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.

**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.
References


Timberline Forest Inventory Consultants Ltd. 2006. Timber supply analysis: mountain pine beetle impact on interior timber supply areas. Council of Forest Industries,

Table 1. Parameters for a simple bilevel forest problem

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

Figure 1: Annual Proportion of Affected Timber Killed by Beetle after Initial Infestation
Figure 2: Government Revenue and the Future Value of the Forest, Solution to the Principal’s Problem
Figure 3: Government Revenue and Future Forest Value, Value of Dead Pine equals Logging Cost, Perspective of Agent R
Figure 4: Government Revenue and Future Forest Value, Value of Dead Pine equals Logging Cost, Perspective of Agent N
Figure 5: Government Revenue and Future Forest Value, Logging Cost exceeds Value of Dead Pine, Perspective of Agent R
Figure 6: Government Revenue and Future Forest Value, Logging Cost exceeds Value of Dead Pine, Perspective of Agent N