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AN OPTIMAL CONTROL MODEL OF ILLEGAL LOGGING BY COMMERCIAL LOGGING CONTRACTORS IN LAOS PDR

by

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Abstract

Laos is an income poor but resource-rich country heavily dependant upon its natural forest resources. This paper uses an optimal control model to analyse deforestation in Laos. Specifically, this paper analyses illegal logging by a sole commercial logging contractor within a single region in Laos. The commercial contractor aims to maximise discounted profits from commercial contracts to log government quotas and from illegal logging.

Policy implications for a government wishing to sustain a target level of forest stock are derived from the model. Results show that it is likely that the steady state level of forest stock will be lower than the government's target. In order to minimise the difference between the target and actual levels of remnant native forest the government can consider increasing the value of contracts awarded, the duration of contracts awarded or the level of fines imposed on detected illegal loggers.

The model, however, simplifies what is an extremely complex problem. Game-theoretic extensions to the modelling framework are suggested as avenues that may help the model better reflect the complexity of illegal logging and deforestation in Laos.

1 Introduction

Laos, unlike many other Asian countries, has so far escaped the severe pressures of over population. In the absence of such pressures, Laos has maintained around 47 percent of its natural forests. While Laos remains highly forested relative to other Asian countries, it is certainly experiencing deforestation pressures (Domoto 1997). In 1940 Laos had 17 million hectares of natural forest. This had fallen to 12.7 million hectares in 1973, to 11.2 by 1981 and now remains at around 11 million hectares. Apart from concerns regarding the efficient management of the forest as a valuable source of timber revenue, deforestation has caused: erosion; siltation of reservoirs and irrigation systems; loss of biodiversity; and reduced groundwater levels (Library of Congress 1995, Stuart-Fox 1997). In Laos, the government and residents rely heavily on revenue generated through forestry operations (MAF 1992, Domoto 1997) and non-timber forest products such as traditional medicines and wild foods (Library of Congress 1995). As such, all Lao environmental concerns take on economic importance.

Economic and political history have played central roles in the evolution of the timber industry in Laos. As a poor but resource rich country, Lao forests have always been considered a ready source of foreign revenue. In 1988 wood products accounted for more than one half of export earnings while in 1992 wood products accounted for almost one-third of total principal exports (Library of Congress 1995). However, as a poor country, Laos has had inadequate wealth to develop the infrastructure or timber processing technologies needed to gain full benefit from their timber exploits. Inadequate staff training has also hindered the timber industry's efficiency. On top of institutional problems, Laos has a long entrenched illegal timber market. The illegal timber industry, apart from suffering the same efficiency problems as the legal sector, acts to undermine government attempts to plan and implement sustainable forestry use.

The Lao timber industry is still in its infancy. Government forestry policy between 1985 and 1992 saw cut rates controlled by autonomous forestry regions while log exports were highly taxed to encourage secondary production within Laos. The autonomy, however, was believed to be leading to overexpoltation of forest resources (Library of Congress 1995) while the high export taxes seemed to encourage log smuggling.

In the face of policy failures the Lao Ministry of Agriculture and Forests (MAF) introduced the *New System of Resource Management* (NSRM) in 1992. The new institutional framework introduced a centrally determined quota system controlled by the Department of Forestry (DOF). The DOF now act through *regional management centres* (RMC) to engage commercial contractors to log within allocated sub-regions within each RMC known as *regional management areas* (RMA) (varying between 20,000 and 50,000 hectares in area). The commercial contractors enter contracts *"that stipulate the precise scope of works prescribed in sustained yield management plans prepared by the DOF"* (MAF 1992 p8). The

NSRM states that in order for contractors to be paid, they must demonstrate compliance with the management plans. Ownership of cut logs passes from the government to the sawmill on delivery. At no time does the commercial contractor have ownership of the logs (MAF 1992). The NSRM also stipulates that log prices are set by the DOF. The DOF set log prices, categorised by species, at levels that maximise rent capture and reflect regional market values.

Based on current policies it appears that the Lao government has adopted a relatively sustainable approach to forestry management (Tookey 1997). AusAid (1996) reported that annual quotas stabilised at around 275,000m^3, while the World Bank estimated the sustainable extraction rate at 288,000m^3. Illegal logging, however, was estimated at between 100,000m^3 and 150,000m^3 and therefore undermined the sustainability of the quota system.

This paper defines illegal timber extractions as those that contradict NSRM's newly defined property rights officially recognised by the MAF. Illegal logging therefore includes timber usage by communities who build houses with illegally extracted timber and collect and sell illegally extracted firewood. While such activities contradict MAF property rights, they may be based on well defined traditional property rights. With the exception of slash and burn agriculture (practiced by 257,000 Lao families (Tookey 1997)) traditional forest usage causes comparatively few environmental problems[1].

[1]Ireson's (1995) work with Lao Hmong indicates that slash and burn agriculture can some-

Illegal logging is also engaged by commercial contract operators acting illegally and domestic and foreign illegal operators. Contract operators are those who are engaged to log on behalf of the government. Logging that exceeds the scope stipulated by their contracts is defined as illegal logging. Domestic illegal operators are Lao who log regardless of property rights and sell logs either locally or in foreign markets. The NSRM makes explicit mention of such operators (MAF 1992) when they claim that illegal operators contribute to rent dissipation. Foreign illegal loggers are non-Lao, most likely from neighbouring countries, who cross into Laos and extract logs. The 1987 Laos-Thailand boarder dispute, which was apparently triggered by illegal Thai teak logging, provides an example of such activities (Stuart-Fox 1997).

A final category of illegal timber harvesters is unclassified harvesting by the Lao military. As of 1985 the Lao People's Army was awarded rights to exploit important timber reserves and negotiate it's own contracts with foreign buyers (Stuart-Fox 1997). The move was designed to give the military some degree of self-sufficiency. However, the move also provided enhanced opportunities for corruption and log smuggling. Stuart-Fox (1997) suggested that continued unofficial government support for the army's logging operations may reflect factional political deals to win army support, who hold an increasing number of votes within the Lao government. While Lao military timber operations appear well

times be sustainable if population densities remain sufficiently low.

recognised, the details of such operations remain undocumented and disregarded by official statistics.

This paper uses optimal control theory to analyse deforestation and timber harvesting in Laos. Given the high level of dependance on forestry exports, the significant non-timber usage and the persistence of illegal logging, forestry management in Laos represents a complex problem. This paper begins to examine the problem by narrowing it down to that of logging by a sole commercial contractor in a single region within Laos.

2 Dynamic Analysis of Natural Forests

Optimal control models have been extensively applied to problems of renewable resources. The two main areas of such research are ocean and forest resource exploitation. Forest resource exploitation models have tended to examine plantation timber. Such models examine optimal rotation and harvest ages (Heaps 1984) and commonly examine the trade-off between other uses such as agriculture (Swallow *et al.* 1990) or forage (Stienkamp and Betters 1991).

Models analysing deforestation are less common. Hassan and Hertzler (1988) use optimal control to examine deforestation in Sudan, and more generally arid and semi-arid regions. In Hassan and Hertzler's model the primary reason for deforestation is cutting wood for use as firewood. The paper argues that the common property nature of Sudan's forests lead to firewood being undervalued and over consumed.

Ehui *et al.* (1990) propose a two-sector control model analysing agricultural productivity and deforestation in the tropics. In this model, once natural forests are harvested they are converted to agricultural land and never allowed to regenerate. Ehui's theoretical model maximises discounted utility over an infinite time frame. A motive to deforest is provided by agricultural yields while non-timber forest usage provides a conservation motive. The model concludes that higher agricultural yields result in greater deforestation early in the process of deforestation and less later. Ehui and Hertel (1989) apply a similar model to Côte d'Ivoire. However, they do not attempt to quantify non-timber forest usage. An important assumption used in Ehui and Hertel (1989) and Ehui *et al.* (1990) is that there are either little or no property rights, or enforcement of property rights. In others words the forests are effectively exploited as an open access resource. This assumption is certainly appropriate in Laos (Tookey 1997).

Clarke *et al.* (1993) analyse the role of property rights enforcement in managing forests. They develop a model where forest managers choose legal harvest rates and expenditure on enforcing property rights. In the model illegal harvest rates are determined by an illegal timber supply curve that depends on enforcement expenditure. Clarke *et al.* derive the supply curve by endogenising the probability of detection of illegal logging.

3 Analytical Framework

This paper uses an optimal control model to analyse deforestation and timber harvesting by a sole commercial contractor in a single region in Laos. The region is meant to represent a RMA. This allows for the assumption that the only logging in the region is carried out by the sole commercial contractor. The contractor logs government quotas but may also log illegally. The contractor chooses illegal harvest rates throughout time, while quotas are determined endogenously as a function of remaining forest stock and some exogenous government target level of forest stock. The exogenous target level is assumed to be some level determined by the government that maximises Lao utility. The model is solved over infinite and continuous time. A discount factor is used to represent both the time preference for money and the uncertainty and time frame of contractual arrangements.

The model presented in this paper maximises the discounted profits of the commercial contract logger. Profits are generated by commercial contracts to log for the government and illegal logging. The contractors face a chance of getting caught and fined for illegal logging[2]. The function determining this *chance* is defined as $G(h)$, where h refers to the level of illegal log harvesting. The more logs poached the greater the chance of being caught and fined. The function $G(h)$

[2]Introducing the a chance of being caught and fined for illegal logging ($G(h)$) introduces problems associated with probabilities in a control problem. To simplify this introduction, let the level of the fine imposed be represented by Ψ. The term $\Psi G(h)$ can therefore be viewed as an expected cost associated with illegal harvesting. As illegal harvests increase, there is an increasely large expected cost - that being the payment of Ψ. The term $\Psi G(h)$ may therefore be viewed as similar to an endogenous cost function.

is assumed to be logistic and to lie between 0 and 1. Government expenditure on policing commercial contractors also effects the chance of being caught and fined. However, given the region considered in only one small area within the Government's forest management plan, the level of enforcement expenditure can be assumed to be exogenous to the model. The contractors are also assumed to be risk neutral. Therefore any chance of getting caught and fined is viewed by commercial contractors purely as a financial consideration. The assumed nature of the function $G(h)$ is graphically summarised in Figure 1.

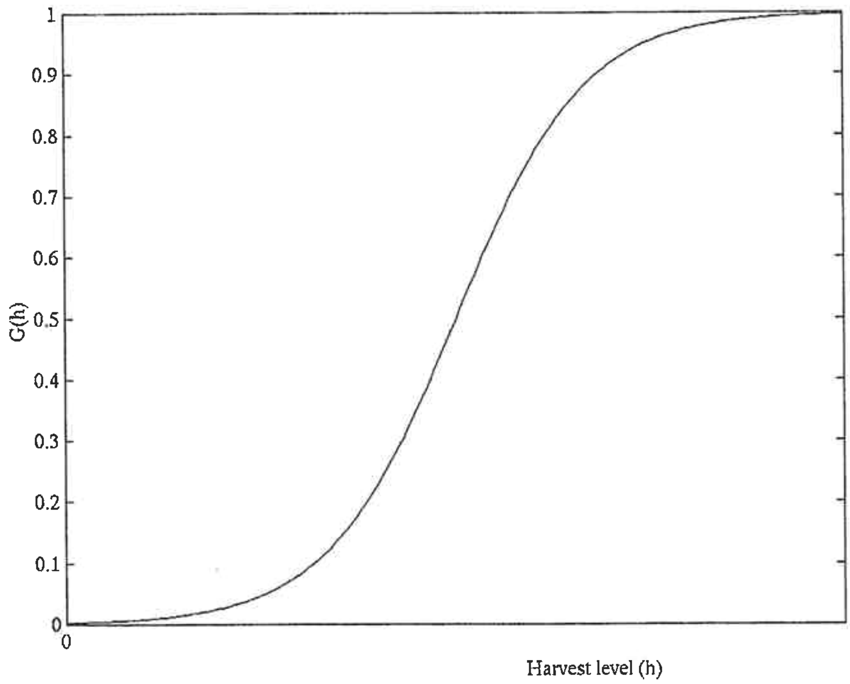

Figure 1: Chance of getting caught fined for illegal logging $G(h)$

Forest regrowth is determined endogenously as a function of forest stock. Forest regrowth is assumed to follow a standard logistic growth function such that regrowth is zero when either forest stock is zero or at its maximum capacity (K). The level of legal logging is also determined endogenously as a function of the remaining forest stock. As mentioned above, the government is assumed to have a target level of forest stock (Υ). If the forest stock falls below the target level, then the government will issue quotas totalling less than expected regrowth. Alternatively, if the forest stock is greater than the target level, then quotas are assumed to exceed forest regrowth. Assumed regrowth and quota functions are depicted in Figure 2 below.

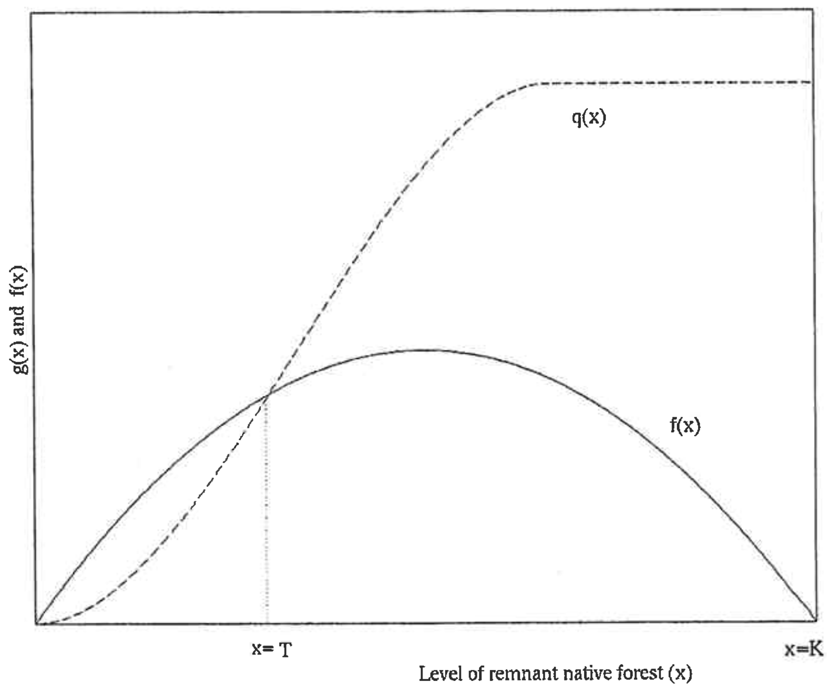

Figure 2: Forest regrowth $f(x)$ and logging quotas $q(x)$

The analytical framework specified above can be expressed as the following dynamic optimisation problem:

$$\max_h \int_0^\infty \left\{ h \left((p^h - c) - \Psi G(h) \right) + (p^c - c) q(x) \right\} e^{-\delta t} dt \tag{1}$$

subject to,

$$\dot{x} = f(x) - h - q(x) \tag{2}$$

$$x(0) = x_0$$

$$x \geq 0$$

$$h \geq 0$$

where h refers to the quantity of timber illegally harvested in hectares, $(p^h - c)$ the average price received for illegally harvested timber less a constant per hectare cost of harvesting, $G(h)$ the chance of being caught and fined for illegal logging, x the remaining stock of natural forest in hectares, Ψ a fine levied per hectare of illegal harvests detected by authorities, $(p^c - c)$ the average per hectare contract value received by contractors to log state timber less a constant per hectare cost of harvesting, $f(x)$ the function determining forest regrowth, $q(x)$ the function determining government quota levels, and δ the discount rate used by contractors in their decision process. All variables have an implicit time subscript (t). The subscript has been ignored for ease of notation.

3.1 Optimal control model

The problem described above can be solved analytically as an optimal control model. Given the equations outlined above, the current value Hamiltonian becomes:

$$H = h\Big((p^h - c) - \Psi G(h)\Big) + (p^c - c)q(x) + \lambda\left(f(x) - h - q(x)\right) \tag{3}$$

According to the maximum principle, the necessary conditions associated with the problem are the first order condition (4) and the costate equation (5):

$$(p^h - c) - \Psi(G(h) + hG_h) - \lambda = 0 \tag{4}$$

$$\lambda\left(\delta - f_x + q_x\right) - (p^c - c)q_x = \dot{\lambda} \tag{5}$$

Solving the first order condition for λ, then totally differentiating with respect to time gives:

$$\dot{\lambda} = -\Psi\left(2G_h + hG_{hh}\right)\dot{h} \tag{6}$$

Equating (5) to (6) and solving for $\dot{h}$ gives:

$$\dot{h} = \frac{\left((p^h - c) - \Psi(G(h) + hG_h)\right)(\delta - f_x + q_x) - (p^c - c)q_x}{-\Psi\left(2G_h + hG_{hh}\right)} \tag{7}$$

The system can now be analysed using the equation of motion of illegal harvests (7) and the equation of motion of forest stock (2). Figure 3 shows the system as a phase diagram[3].

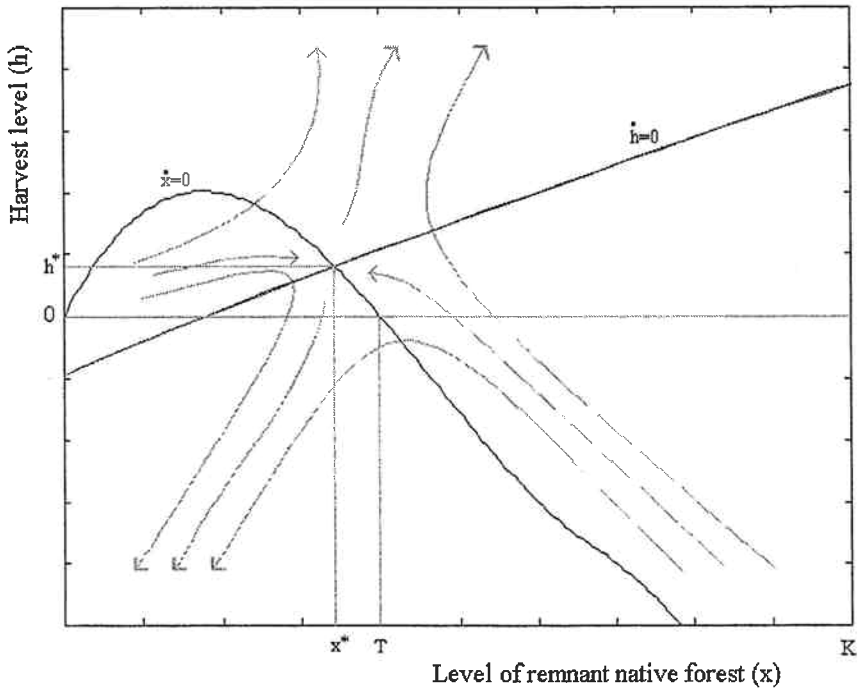

Figure 3: Phase Diagram

The intersection of demarkation lines $\dot{x}= 0$ and $\dot{h}= 0$ in Figure 3 show a steady-state of (x^*, h^*). Notably this solution implies a level of forest stock less than the government target Υ. This however, is just one possible outcome.

[3]The saddle point nature of the problem is assumed. For justification see Léonard and Long (1992) .

To analyse the problem more carefully consider the range of possible steady-state solutions. Any steady-state solution must lie on $\dot{x}= 0$. Given h is constrained to be positive, then moving to the right of the government target Υ would invoke the constraint binding h. Therefore any steady-state solution would require x^* to fall between 0 and Υ.

Now considered an example where x^* equals the target rate Υ. Again the solution must lie on $\dot{x}= 0$. Equation (2) reminds us that along $\dot{x}= 0$, x will equal Υ only when government logging quotas equal forest regrowth (that is, $f(\Upsilon) = q(\Upsilon)$). At this point, not only would x equal Υ, but h would equal zero. The chance of getting caught and fined for illegal logging is zero when there are no illegal harvests (i.e. if $h = 0$ then $G(h) = 0$). Substituting $G(h) = 0$ and $h = 0$ into equation (7) yields an equation of motion of illegal harvest where the forest stock has reached the government target:

$$\dot{h}= \left[\frac{1}{-\Psi 2G_h}\right]\left[\frac{(p^h - c)\,(\delta - f_x + q_x) - (p^c - c)q_x}{1}\right] \tag{8}$$

Given $\dot{x}= 0$, then if $\dot{h}$ from equation (8) equals zero the system represents a steady state. This is significant because if the equations (8) and (2) do represent a steady state then the solution is one that sees the government's target Υ being realised. For $\dot{h}$ from equation (8) to equal zero, either $\{-1/\Psi 2G_h\}$ or $\left\{(p^h - c)(\delta - f_x + q_x) - (p^c - c)q_x\right\}$ must equal zero. The first term will approach zero if G_h equals infinity. This, however, is unlikely given the assumptions made regarding $G(h)$. The second term can be set to zero and re-arranged to assist in the analysis. Equation (9) shows that the system will represent a steady state solution only when the ratio of the gross margin for contracts $(p^c - c)$ to the gross margin for illegally logged timber $(p^h - c)$ equals $(\delta - f_x + q_x)/q_x$.

$$\frac{\delta - f_x + q_x}{q_x} = \frac{(p^c - c)}{(p^h - c)} \tag{9}$$

If the condition (9) does not hold, $\dot{h}= 0$ will either intersect $\dot{x}= 0$ to the left or right of Υ. If condition (9) fails because the left hand side is too high, $\dot{h}= 0$ will intersect $\dot{x}= 0$ to the right of Υ. The constraint holding h positive will then bind leaving the steady-state at $(x^* = \Upsilon, h^* = 0)$. If the condition (9) fails because the left hand side is too small, $\dot{h}= 0$ will intersect $\dot{x}= 0$ to the left of Υ, and a steady-state will be implied combining a level of forest stock between 0 and Υ and some positive level of illegal harvesting $(x^* < \Upsilon, h^* > 0)$.

4 Policy Implications

The problem of logging contractors exceeding their contractual arrangements in given management areas is just one of many complex issues facing the Lao environment and its natural resource based economy. Modelling this problem in isolation, however, indicates that if the government wishes to maintain a target level of native forest then they need only pay contractors *adequate* compensation. In reality though, paying contractors adequately may well be beyond the financially constrained Lao government. A more likely scenario is that the level of remaining forest will be allowed to fall below the target level and some illegal logging tolerated. The state will lose some timber harvesting revenue but will gain by paying contractors less.

In the model presented above the level of forest stock that the government ultimately accepts will depend on fines charged, contract payments and an exogenous level of enforcement. Assuming the government wishes to narrow the gap between the target and actual levels of forest stock, the best policy option appears to be to increase the fine level. However, this is complicated by two factors. Firstly there may be a financial cost of enforcing the fines. Both legal and institutional systems in Laos are underdeveloped. In 1992 the NSRM declared intentions to introduce "*an effective sector financing mechanism to provide [an] effective national program of regulation and control*" (MAF 1992 p7). It appears however that financial constraints have prevented the satisfactory completion of this objective. Consequently, increasing fines on a policy level is unlikely to impact on the grass-roots level. Secondly, while the fines are modelled as penalties, in reality the corruption associated with the timber felling industry (Stuart-Fox 1997) means that the fines modeled in this paper are more likely to represent bribe payments. Even if fines were increased to some prohibitive level, actual fine payments may well be in the form of negotiated payments at a much lower rate - one that gives the bribe receiver sufficient profits for turning a blind eye, but one that doesn't discourage future illegal harvests and therefore future bribe payments.

As with the model presented in this paper, when Clarke *et al.* (1992) analysed property rights enforcement their modelling work also implicated increasing fines as an easy solution to controlling illegal logging. They too, however, reasoned that this conclusion was essentially a weakness in the modelling framework. Clarke *et al.* proposed that enforcing heavy fines may not be optimal as doing so may impose excessive hardships on poor rural communities.

In the model presented above, a higher discount rate is associated with a lower steady state level of forest stock and greater levels of illegal logging[4]. Therefore, another option available to a government in trying to maintain a target level of forest stock would be to change the contractor's discount rate. In practice this would mean extending the contract periods awarded to commercial contractors. Contractors with either a short or uncertain contract will make decisions using a higher discount rate as they would be less likely to benefit from future state quotas or forest regrowth. As with policy implications for fine levels, the prevalence of corruption complicates any discount rate related policy implications. Contracts

[4]The discount rate's impact on the steady-state solution is deduced from equation (7). Assuming $(p^h - c) < \Psi(G(h) + hG_h)$, increasing δ will decrease equation (7)'s numerator and therefore increase $\dot{h}$. This in turn implies $\dot{x}$ will decrease via equation (2).

may be awarded to friends and relatives or in exchange for bribes, rather then to a competitive tender.

5 Conclusions and Suggestions for Further Work

The model presented above uses optimal control theory to analyse a sub-problem associated with the timber industry in Laos - illegal logging by commercial contractors. For a government wishing to maintain a target level of native forest, some straight-forward policies are suggested - increase fines, contract payments and the duration of contracts. However, the policy options for the Lao government are complicated by corruption and financial constraints. Further work may be considered to incorporate these issues into the modelling framework.

Corruption could be analysed by endogenising fines and contract rates. Lao enforcement policy is set by the DOF. If, however, as suggested above, penalties take the form of bribes, then it will be the RMC's that negotiate the "fine" levels. Contracts are controlled by DOF. Therefore, corruption may be analysed by modelling the dynamics of contract and fine negations between the DOF, RMCs and illegal loggers.

The model presented above assumes exogenous enforcement and rigid quota setting policy. Enforcement expenditure may usefully be endogenised to add to the analysis. With regards to the rigid quota policy, an implied assumption is that the government acts with little knowledge of illegal activities, and therefore cannot logically be expected to react quickly to illegal logging. The rigid quota policy may be applicable to the problem, however, a rigid policy may still be employed although with an endogenously determined target level of forest stock.

Another potential area for further work could be to develop an endogenous representation of illegal timber prices. Legal log prices are fixed by the DOF (MAF 1992) and in the model presented in this paper, it has been assumed that illegal logs attract the same fixed prices. Hassan and Hertzler (1988), however, show that lack of property rights result in undervaluation and overuse of forest resources in Sudan. This scenario may also relevant to Laos (MAF 1992).

Common to all these suggestions for further research, is that they all involve differential games played over time, with various agents seeking to maximise different and conflicting payoff functions. Analysing such problems can be handled using the maximum principle in the form of the Isaacs equation as an extension to the work completed above. Unfortunately, such work is extremely difficult to perform and is therefore left as an area of future research.

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