Deforestation and Illegal Logging in Developing South-East Asian Countries

R. McAllister[a], R. Beard[b] and J. Asafu-Adjaye[c]

[a] *School of Economics, University of Queensland, Brisbane QLD 4072, Australia (r.mcallister@mailbox.uq.edu.au)*

[b] *School of Economics, University of Queensland, Brisbane QLD 4072, Australia*

[c] *School of Economics, University of Queensland, Brisbane QLD 4072, Australia*

Abstract This paper uses an optimal control model to analyse how illegal logging can impact on a government trying to retain some minimum target level of forest stock. The results show that a government may optimally tolerate some illegal logging.

Keywords: Deforestation; Optimal control; Illegal logging.

1. INTRODUCTION

While unsustainable agricultural practices, such as slash and burn, contribute to deforestation in developing South-East Asian countries, it appears that market driven logging is the primary agent [Dudley et al., 1995; Miller and Tangley, 1991]. Much of this activity is legal. However, in many developing South-East Asian countries, illegal logging is believed to be equally if not more prevalent than legal logging [Dudley et al., 1995]. This illegal logging means that even if a government is committed to maintaining a minimum level of forest stock, its efforts are likely to be undermined. This paper analyses the relationship between forest stock and illegal logging in a stylised industry structure whereby a government owns forest property rights but contracts commercial loggers to extract logs from defined regions (Vietnam and Lao PDR provide examples of South-East Asian countries where such contracting occurs). In the model there are incentives for the commercial loggers to log illegally above their contractual arrangements.

2. ANALYTICAL FRAMEWORK

This paper adopts a market based explanation of deforestation in that loggers are modeled as profit maximisers. Profits are generated by commercial contracts to log for the government, as well as illegal logging. The contractors face a chance of getting caught and fined for illegal logging $G(h)$, where h refers to the level of illegal log harvesting. However, given the prevalence of corruption and a poorly developed institutional structure, bribe payments are more likely than any monetary penalties enforced through a legal system. In the model, bribe payments are determined by $\Psi G(h)$, where Ψ represents some exogenous factor determind by a corrupt bureaucrat. For the contractor, the term $\Psi G(h)$ can be viewed as an expected cost associated with illegal harvesting. As illegal harvests increase, there is an increasingly large expected cost - that being the payment of Ψ. The term $\Psi G(h)$ may therefore be viewed as similar to a cost function. The function $G(h)$ is assumed to be logistic and to lie between 0 and 1, with G_h lying between 0 and some positive finite number.

Government expenditure on policing commercial contractors also affects the chance of being caught and fined. Clarke et al. [1993] explicitly model this enforcement expenditure in a game-theoretic setting. We, however, assume that a developing country's enforcement expenditure is not market driven and therefore make such issues exogenous. 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.

Forest regrowth is determined endogenously by some 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. The government is assumed to have a target level of forest stock (Υ). If 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.

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

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

subject to,

$$\dot{x} = f(x) - h - q(x) \quad (2)$$
$$x(0) = x_0$$
$$x, h \geq 0.$$

where h refers to the quantity of timber illegally harvested in hectares, p^h the average per hectare price received for illegally harvested timber, c the average per hectare cost associated with harvesting timber, p^c the average per hectare contract value associated with logging government quotas, $G(h)$ the chance of being caught and fined for illegal logging, x the remaining stock of natural forest in hectares, Ψ a payment determined by corrupt bureaucrats, $(p^c - c)$ the average per hectare gross margin received for legally harvested timber, $(p^h - c)$ the average per hectare gross margin received for illegally harvested timber, $f(x)$ the function determining forest regrowth, $q(x)$ the function determining government quota levels (this may be interpreted as a rule rather than a discretionary policy, and therefore we do not model the government quota setting decision), ϕ the exogenous tenure risk faced by the contractors [as used by Clark, 1990; and Angelsen, 1999], and δ the discount rate used by contractors in their decision process. All variables have an implicit time subscript (t), which has been ignored for ease of notation.

3. 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,

$$H = h((p^h - c) - \Psi G(h)) + (p^c - c)q(x) + \lambda(f(x) - h - q(x)). \quad (3)$$

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

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

$$\lambda(\delta + \phi - f_x + q_x) - (p^c - c)q_x = \dot{\lambda}. \quad (5)$$

Solving the first order condition (4) for λ, totally differentiating with respect to time, then equating to (5) yields,

$$\dot{h} = \frac{((p^h - c) - \Psi(G(h) + hG_h))}{-\Psi(2G_h + hG_{hh})} \times \frac{(\delta + \phi - f_x + q_x) - (p^c - c)q_x}{-\Psi(2G_h + hG_{hh})}. \quad (6)$$

The equation of motion of illegal harvests (6) and the equation of motion of forest stock (3) represent the system dynamics. Figure 1 shows this system as a phase diagram with a saddle point equilibrium.

The intersection of demarkation lines $\dot{x}= 0$ and $\dot{h}= 0$ in Figure 1 shows 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.

To analyse the problem more carefully, consider the range of possible steady-state solutions. Any steady-state 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 requires x^* to fall between 0 and Υ.

Now consider 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 (i.e. $f(\Upsilon) = q(\Upsilon)$). 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 assumed to be zero when there are no illegal harvests (i.e. if $h = 0$ then $G(h) = 0$). Therefore, substituting $G(h) = 0$ and $h = 0$ into equation (6) yields an equation of motion of illegal harvest where the forest stock has converged on the government target.

$$\dot{h} = \left[\frac{(p^h - c)(\delta + \phi - f_x + q_x) - (p^c - c)q_x}{1}\right] \left[\frac{1}{-\Psi 2G_h}\right] |h = 0. \quad (7)$$

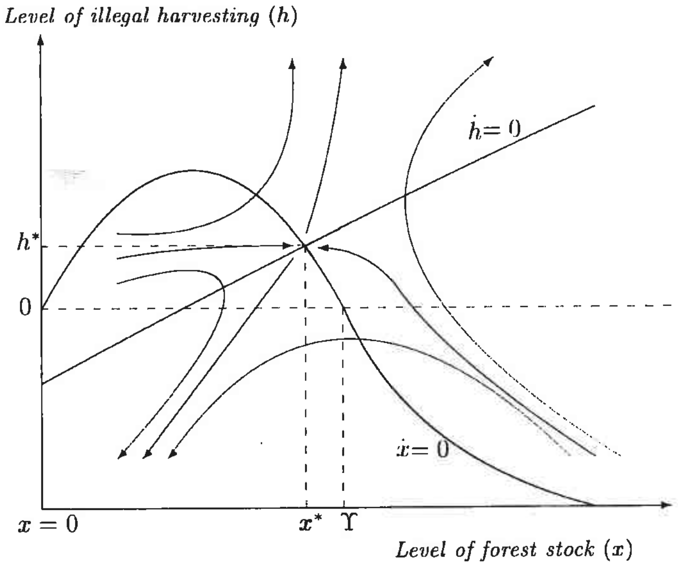

Figure 1: Phase Diagram

Given $\dot{x}=0$, then if $\dot{h}$ from (7) equals zero the system will represent a steady state. This is significant because if (2) and (7) do represent a steady state then the solution is one that sees the government's target Υ being realised. For $\dot{h}$ from (7) to equal zero, either $\{-1/(\Psi 2G_h)\}$ or $\{(p^h - c)(\delta + \phi - f_x + q_x) - (p^c - c)q_x\}$ must equal zero. The first term will approach zero if G_h equals infinity, which we assumed above is not possible. The second term is set to zero and re-arranged to give condition (8) below. Condition (8) shows that the system will represent a steady state only when the ratio of the gross margin for contracts to the gross margin for illegally logged timber equals $(\delta + \phi - f_x + q_x)/q_x$,

$$\frac{\delta + \phi - f_x + q_x}{q_x} = \frac{(p^c - c)}{(p^h - c)}. \qquad (8)$$

If condition (8) does not hold, $\dot{h}=0$ will either intersect $\dot{x}=0$ to the left or right of Υ. If condition (8) 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 condition (8) 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 $(x^* < \Upsilon, h^* > 0)$.

Assuming the developing country's prices p^h and costs c are given, the government's policy tool is limited to that of contract values p^c. Condition (8) can be re-expressed in terms of p^c as,

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

Equation (9) represents the contract value that must be paid in order to remove the contract loggers motivation to illegally harvest timber.

4. CONCLUSION

The problem of logging contractors exceeding their contractual arrangements is just one of many complex issues concerning deforestation in developing South-East Asian countries. However, given that commercial timber exploitation is a leading contributor to deforestation in the region, understanding this issue adds significantly to the overall analysis. The model presented above indicates that paying contractors above some threshold will totally remove any motivation to log illegally. However, the existence of illegal logging in both developing and developed countries suggests that it may not be optimal for a government to pay at such a level. The reality of the situation, it seems, is that a government will tolerate some illegal logging and accept a level of forest stock lower than its target level.

5. FUTURE RESEARCH

This paper has used an optimal control model to analyse deforestation and illegal logging. McAllister and Bulmer [2001] develop such analysis further by extending the framework to that of a dynamic game. Analytical conclusions become increasingly hard to derive. McAllister and Bulmer therefore explore the use of a genetic algorithm approach to approximate numerical results. Future research may involve developing this dynamic game framework further.

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