Deforestation and Illegal Logging in Developing South-East Asian Countries

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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 Tanglely, 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.

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 \$G(h)\$, where \$\Psi\$ represents some exogenous factor determined 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 \$\Psi\$. 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_1\$ 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 (T). If
forest stock falls below the target level, then the
government will issue quotas totalling less than ex-
pected 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,

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

subject to,

$$\dot{x} = f(x) - h - q(x)$$  \hspace{1cm} (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 ille-
gal logging, $x$ the remaining stock of natural for-
est in hectares, $\Psi$ a payment determined by cor-
rupt bureaucrats, $(p^c - c)$ the average per hectare
gross margin received for legally harvested timber,
$(p^h - c)$ the average per hectare gross margin re-
ceived for illegally harvested timber, $f(x)$ the func-
tion determining forest regrowth, $q(x)$ the func-
tion determining government quota levels (this may be
interpreted as a rule rather than a discretionary
policy, and therefore we do not model the gov-
ernment quota setting decision), $\phi$ the exogenou-
tenure risk faced by the contractors [as used by
Clark, 1990; and Angelsen, 1999], and $\delta$ the dis-
count 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 ana-
lytically as an optimal control model. Given the
equations outlined above, the current value Hamil-
tonian becomes,

$$H = h((p^h - c) - \Psi G(h)) + (p^c - c)q(x) + \lambda(f(x) - h - q(x)).$$  \hspace{1cm} (3)

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

$$((p^h - c) - \Psi (G(h) + hG_h)) - \lambda = 0$$  \hspace{1cm} (4)

$$\lambda(\delta + \phi - f_x + q_x) - (p^c - c)q_x = \lambda.$$  \hspace{1cm} (5)

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

$$\dot{h} = \frac{((p^h - c) - \Psi (G(h) + hG_h))}{\Psi (2G_h + hG_{hh})}$$

$$\times \frac{(\delta + \phi - f_x + q_x) - (p^c - c)q_x}{-\Psi (2G_h + hG_{hh})}.$$  \hspace{1cm} (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 demarcation lines $x= 0$ and
$h = 0$ in Figure 1 shows a steady-state of $(x^*, h^*)$.
Notably, this solution implies a level of forest stock
less than the government target $Y$. 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 $x = 0$. Given $h$ is con-
strained to be positive, then moving to the right of
the government target $Y$ would invoke the con-
straint binding $h$. Therefore any steady-state re-
quires $x^*$ to fall between 0 and $Y$.

Now consider an example where $x^*$ equals the
target rate $Y$. Again the solution must lie on
$x = 0$. Equation (2) reminds us that along $x= 0$, $x$
will equal $Y$ only when government logging quotas
equal forest regrowth (i.e. $f(Y) = q(Y)$). At this
point, not only would $x$ equal $Y$, but $h$ would equal
zero. The chance of getting caught and fined for ille-
gal 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.

$$\dot{h} = \frac{[(p^h - c)(\delta + \phi - f_x + q_x) - (p^c - c)q_x]}{\Psi 2G_h} \Bigg|_{h=0}.$$  \hspace{1cm} (7)
Given \( \bar{x} = 0 \), then if \( h \) 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 \( Y \) being realised. For \( h \) from (7) to equal zero, either \(-1/(\Psi 2 G_h)\) or \((p^h - c)(\delta + \phi - f_x + q_x) - (p^2 - c)q_x\) 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 rearranged 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 \((\delta + \phi - f_x + q_x)/q_x\),

\[
\frac{\delta + \phi - f_x + q_x}{q_x} = \frac{(p^2 - c)}{(p^h - c)}.
\]  

(8)

If condition (8) does not hold, \( h = 0 \) will either intersect \( x = 0 \) to the left or right of \( Y \). If condition (8) fails because the left hand side is too high, \( h = 0 \) will intersect \( x = 0 \) to the right of \( Y \). The constraint holding \( h \) positive will then bind leaving the steady-state at \((x = Y, h^* = 0)\). If condition (8) fails because the left hand side is too small, \( h = 0 \) will intersect \( \bar{x} = 0 \) to the left of \( Y \), and a steady-state will be implied combining a level of forest stock between 0 and \( Y \) and some positive level of illegal harvesting \((x^* < Y, h^* > 0)\).

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,

\[
p^c = c + \frac{\delta + \phi - f_x + q_x}{q_x} (p^h - c).
\]  

(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.

6. REFERENCES


