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A theoretical analysis of illegal wood harvesting as predation – with two Ugandan illustrations

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Abstract

By assuming a forest growing logistically and a local population that harvests wood illegally in a manner similar to predation, a bio-economic model gives the following results: 1) when local population is very low, optimal deterring effort is zero; 2) as long as the population is sufficiently low, no deterring effort is required to avoid complete deforestation; 3) when population is above minimum threshold, optimal deterring effort is determined by the cost of deterrence relative to the value of wood; 4) when human population grows above a higher threshold, deterring effort must be greater than zero to avoid complete deforestation; 5) the larger the population grows, minimum deterring effort to avoid exhaustion approaches maximum effort; 6) when human population is very large, the relative cost of deterrence must be low, or the price of wood very high, to make deterrence worth wile.

Keywords: bio-economics, deterrence, forest management, ownership.

Introduction

Forests in many parts of the world, particularly those in the developing countries, are exploited with little control by the owner, which may be the state, a co-operative, a private enterprise, or an individual person. In some instances wood is harvested in spite of serious attempts by the owner to deter illegal activities. Authorities like the public forest service or police may be involved in harvest control. Just as often, however, the formal owner does not take measures to reduce illegal harvesting in spite of knowing well what goes on. This is often the case in large parts of Sub-Saharan Africa. To some observers the little effort in deterrence on part of the owner seems incomprehensive, or at least less than optimal (Poore 1989).

In cases of illegal harvesting of valuable timber with a well defined owner who tries to deter illegal operations, one may analyse the behaviour of illegal operators as well as owners or authorities in terms of avoidance costs, probability of detection, level of fines, and the cost of patrolling (Milliman 1986, Clarke et al. 1993, Amacher et al. 2004). This type of activity is quite similar to theft. Normative economics may then be used to study optimal behaviour of both the thief and the police.

In the following a slightly different situation is analysed. Consider a fairly large tract of forest or woodland which is state owned and under public management. A local population lives in or near the forest, and they use wood both for own consumption and sale. The public manager of the forest imposes some regulations requiring wood harvesting to be licensed. Licenses are only sold for a limited volume of wood in each time period. These measures are taken to achieve sustainable harvest rates, and are imposed in accordance with democratically determined rules and procedures. Many people harvest wood in this forest without a licence in spite of the regulation, and this is well known to the manager. This illegal harvest leads to degradation of forest vegetation. The manager, however, does not spend much effort in deterring people from illegal exploitation. The objective here is to analyse the behaviour of the manager of such a forest, and to make some general recommendations on the optimal level of deterring effort.

Model

Optimal management of illegal harvest is analysed by use of a bio-economic model (Beltrami 1993). Assume for simplicity that volume of wood in the forest grows logistically:

$$F(x) = rx\,(1 - x/K), \tag{1}$$

where x is the stock of wood, $F(x)$ is increment, r is the intrinsic growth rate, and K is the forest carrying capacity of land. Depensation may occur, but this complication is not considered here. However, there is no reason to believe that we have a growth function with critical depensation (Stigter & van Langevelde 2004) as long as we deal with common woodland trees.

In the absence of regulation, the local population harvests wood like predators:

$$h = \alpha x n, \tag{2}$$

where h is volume of harvested wood, α is the predation coefficient, and n is the number of local people using the forest. It is reasonable to assume increasing harvest with both availability – stock – of wood, and number of people in or around the forest. The latter is particularly realistic as long as wood harvesting is for subsistence or for additional income generation among peasants. If wood exploitation becomes the main economic undertaking of a few entrepreneurs, the relationship between harvest level and population is better modelled as an ordinary commodity market. One may, even in our case, assume a saturation level of wood consumption among local people. If so, a multiplicative equation with a constant predation coefficient, as in (2), overestimates harvest at large stocks.

Size of local population does not depend on wood harvest, but is an exogenous variable related to profitability of agriculture and alternate employment opportunities in other (urban) sectors.

The authorities prohibit wood harvesting[40], and undertake patrolling activities to deter people from (illegal) harvesting. The volume of deterred wood harvest is a function of the authorities' effort and the total volume of illegal harvest:

$$a = \beta E h, \tag{3}$$

where a is the volume of deterred wood harvest, β is the "catchability" of illegal wood harvesting, and E is the deterring effort. Catchability depends on the structure of the forest (closed, open) as well as the type of produce extracted, e.g. logs, firewood, charcoal. Catchability may be affected by the behaviour of loggers, but this feed-back is not considered further here.

If deterrence is undertaken by the authorities, the extracted quantity, h_d, is given by:

$$h_d = h - a = \alpha x n\,(1 - \beta E). \tag{4}$$

The intuitive understanding of (4) is that the predation coefficient is reduced from α to $\alpha\,(1 - \beta E)$ as a result of deterring effort on part of the authorities[41].

[40] This may also include harvest regulation by licenses or quota, but the discussion is simplified without much loss of understanding by concentrating on full prohibition.

[41] If deterring effort has a diminishing marginal effect on the predation coefficient, h_d could be expressed as $\alpha xn(1-\beta E^{\gamma})$, $0 < \gamma < 1$. This would imply that higher efforts are optimal than in the above case, but the fundamental behaviour of the model would not change.

The rate of change in resource stock can then be expressed as:

$$\mathrm{d}x/\mathrm{d}t = F(x) - h_d = rx\,(1 - x/K) - \alpha xn\,(1 - \beta E), \tag{5}$$

where h_d is extracted quantity when the authorities act to deter illegal harvest.

For a given effort, $\overline{E}$, steady state is characterised by increment being equal to harvest:

$$F(x) = h_d \Rightarrow 1 - \frac{x}{K} = \frac{\alpha}{r} n(1 - \beta\overline{E}),$$

which means that the equilibrium stock of wood is given as:

$$x^* = K\left(1 - \frac{\alpha \cdot n}{r}(1 - \beta\overline{E})\right).$$

Harvested volume of wood in equilibrium, $h_d^*(E)$, is then given as:

$$h_d^*(E) = \alpha\, nK(1 - \beta E)\left(1 - \frac{\alpha\, n}{r}(1 - \beta E)\right).$$

(6)

The authorities' objective is to maximize social welfare in the long-run. For situations of equilibrium this implies the maximisation of the surplus, S:

$$S = p_x\, h_d^*(E) - cE\,,$$

(7)

where, p_x is the net price of standing wood, and c is the unit cost of controlling effort. If h_d is not large enough to affect price, p_x is constant[42], and the necessary condition for maximisation is

$\mathrm{d}h_d/\mathrm{d}E = c/p_x$.

Results

[42] Some price-demand relationships are explored in the Appendix.

In line with general resource economics (Clark 1990), one may notice that if effort costs something, maximum social surplus is always achieved at less than maximum sustainable yield, and less than maximum effort.

The derivative of $h_d{}^*(E)$ is

$$\frac{dh_d{}^*}{dE} = \alpha nK\left[\frac{2\alpha n\beta}{r} - \frac{2\alpha n\beta^2}{r}E - \beta\right],$$

which is zero for

$$E = \frac{1}{\beta} - \frac{r}{2\alpha n\beta}.$$

This means that both $\mathrm{d}h_d/\mathrm{d}E = 0$ and $E = 0$ when $n = r/2\alpha$. When $n < r/2\alpha$, $\mathrm{d}h_d/\mathrm{d}E = 0$ for $E < 0$, which is impossible in practice. What this implies is that maximum social surplus is achieved at zero deterring effort whenever $n < r/2\alpha$ because the $h_d{}^*(E)$ curve is strictly falling for positive and increasing E. This seems reasonable since small populations will harvest little wood, higher increment rates require lesser deterring effort, and a high predation coefficient requires more effort.

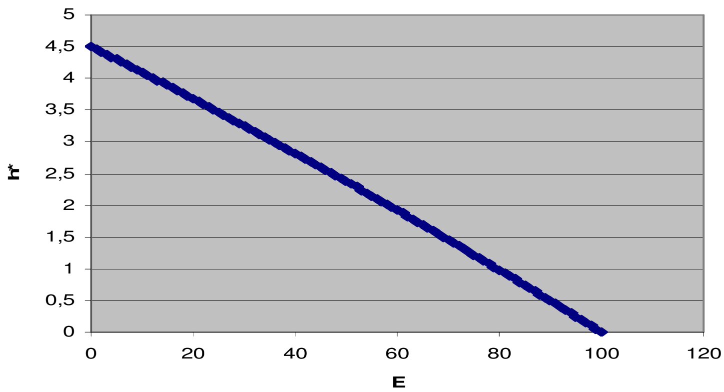

Figure 1. The relationship between deterring effort and equilibrium harvest when human population is very small. (Parameters used: r = 0.5, K = 100, $\alpha = \beta = 0.01$, n = 5, and E = 75).

It is also interesting to note that $h_d{}^*(E) = 0$ at the following points: $E_{max} = 1/\beta$ and $E_{min} = \frac{1}{\beta}\left(1 - \frac{r}{\alpha n}\right)$. E_{max} is maximum effort which stops harvesting completely and keeps forest density at carrying capacity. On the other hand, E_{min} is the minimum deterring effort that results in open access and complete deforestation. When $n < r/\alpha$, E_{min} is less than zero, complete deforestation is impossible even at no deterring effort. When n > r/α, $E_{min} > 0$, deterring effort must be greater than zero to avoid complete exhaustion of wood resources in the forest. As human population grows, the deterring effort necessary to avoid complete deforestation approaches maximum effort at $E_{max} = 1/\beta$.

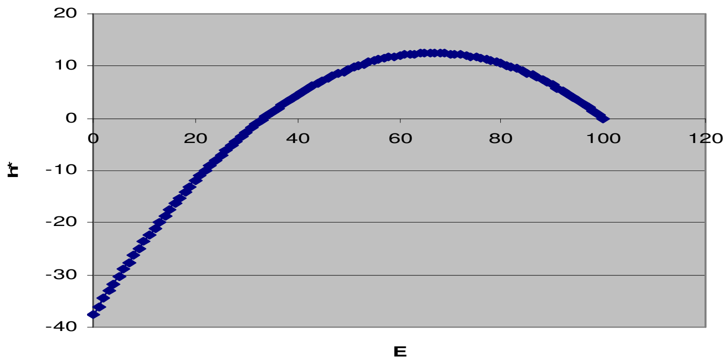

Figure 2. The relationship between deterring effort and equilibrium harvest when human population is large.
(All parameters as in Fig.1, except $n = 75$).

Conclusions:

1. When local population is very low, $n < r/2\alpha$, in relation to forest increment and the predation coefficient, optimal deterring effort is zero (Fig.1).
2. As long as the population is sufficiently low, $n < r/\alpha$, no deterring effort is required to avoid complete deforestation.
3. When population is above minimum threshold, $n = r/2\alpha$, optimal deterring effort is determined by the cost of deterrence relative to the value of wood, $\mathrm{d}h_d/\mathrm{d}E = c/p_x$. The more expensive deterrence is, less effort is optimal. The more valuable the wood is, more effort is optimal.
4. When human population grows above a higher threshold, $n < r/\alpha$, deterring effort must be greater than zero in order to avoid complete deforestation (Fig.2).
5. The larger the population grows, minimum deterring effort to avoid exhaustion approaches maximum effort determined by "catchability", $E_{max} = 1/\beta$.

6. When human population is very large, the relative cost of deterrence must be low, or the price of wood very high, in order to make deterrence worth wile, thereby avoiding complete deforestation.

Two numerical examples from Uganda

To illustrate how this analysis may explain the different levels of effort in harvest control, or even advice owners and authorities on the optimal level of such effort, two examples are constructed based on parameter values that are broadly consistent with empirical evidence from Uganda.

Open woodland

Consider 1500 ha of woodland (Namaalwa et al. 2007) now stocked with an average of 40 tons ha^{-1}, which means that growing stock, x, is 60,000 tons. We assume the parameters of the logistic growth function to be; r = 0.04 and K = 150 [tons ha^{-1}] ·1500 [ha] = 225,000 [tons]. 2,000 people live in the villages using this woodland. If these people harvest approximately 1 ton per capita per year now, we may estimate the predation coefficient, α, from (2) as follows: $h = 2\ 10^3$ [tons $year^{-1}$] $= \alpha \cdot 60\ 10^3$ [tons] $\cdot\ 2\ 10^3$ [people] $\Rightarrow \alpha = 1.67 \cdot 10^{-5}$ [tons cap^{-1} $year^{-1}$].

If we measure deterring effort in manyears, and apply a cost of \$ 1 per day, we have an estimate of c = 250 \$ $manyear^{-1}$. Assuming that one manyear is spent on deterring illegal harvesting from this woodland area, and that this reduces actual harvest by 10 %, catchability, β, is 0.1. We estimate a value of 2 \$ ton^{-1} of woody biomass, based on a roadside price of \$ 1 per bag (50 kg) of charcoal, a burning efficiency of 15 %, and an insignificant cost of labour.

Because there are many people using the resource, and the predation coefficient is relatively high compared to the biological yield of this woodland, equilibrium stock for zero deterring effort will be quite low (37,000 tons). Although there is no danger of complete exhaustion of the resource, a few guards patrolling the woodland would reduce the predation coefficient and thereby increase biomass density so that the total quantity harvested could be maintained at a higher level. Four guards would result in an equilibrium stock of 112,000 tons, and an annual harvest of 2,250 tons. Since there is a cost of deterring effort, however, the optimal effort is slightly lower, i.e. three guards as shown in Fig.3.

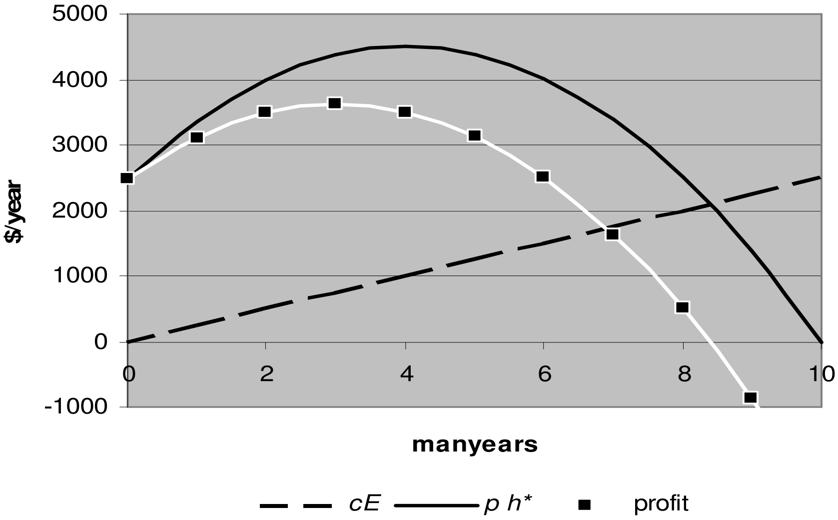

Figure 3. Income, expenses and profits in equilibrium determined by varying deterring effort. In this woodland example 3 man-years is optimal effort.

Charcoal

Consider a woodland area (Namaalwa et al. 2008) of 1.2 10^6 ha in central Uganda supplying the 2 10^6 inhabitants of Kampala with charcoal. The urban population consumes 0.18 tons cap^{-1} of charcoal annually, i.e. a total of 360 10^3 tons year^{-1}. Charcoal is produced from woody biomass at an efficiency of 17 percent. The annual consumption of charcoal, therefore, corresponds to an annual harvest of 2.1 10^6 tons of woody biomass. Average biomass density in the woodland is 30 tons ha^{-1}. This means that growing stock, x, is 36 10^6 tons. We assume the parameters of the logistic growth function to be; r = 0.04 and K = 150 [tons ha^{-1}] ·1.2 10^6 [ha] = 180 10^6 [tons].

We may estimate the predation coefficient, α, from (2) as follows: h = 2.1 10^6 [tons year^{-1}] = $\alpha \cdot 36\ 10^6$ [tons] $\cdot$ 2 10^6 [people] $\Rightarrow \alpha = 2.9 \cdot 10^{-8}$ [tons cap^{-1} year^{-1}].

Deterring effort is measured in man-years as before, and we assume a cost of \$ 2 per day, which means that c = 500 \$ manyear^{-1}. Assuming that 200 man-years are spent on deterring illegal harvesting from this woodland area, and that this reduces actual harvest by 1 %, from (3) we find that catchability, β, is 0.5 10^{-3}.

We estimate a value of 2 \$ ton^{-1} of woody biomass at present demand, based on a roadside price of \$ 1 per bag (50 kg) of charcoal. In this example, however, where we examine the whole supply of charcoal for Kampala it is reasonable to assume there is a functional relationship between harvested quantity and price. The elasticity, η, has been set at 1.5, while the parameter D = 5 10^9. This results in a demand curve as shown in Fig.4.

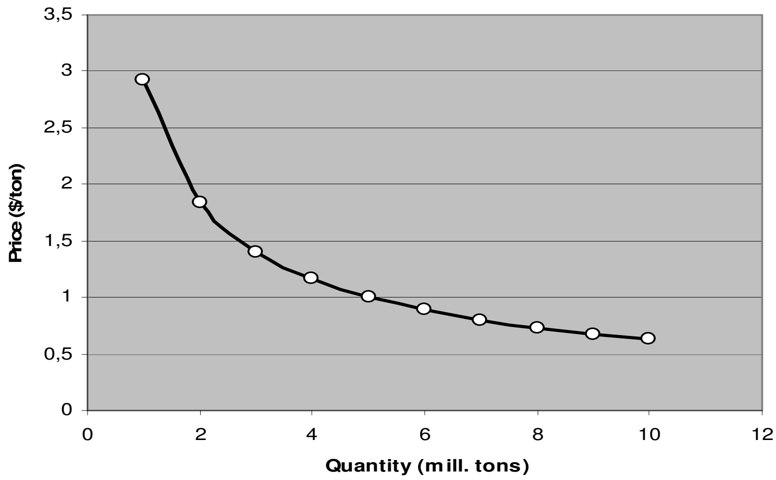

Figure 4. Demand curve for biomass in charcoal production for Kampala

Fig.5 shows the equilibrium harvest as a function of deterring effort. If the annual effort is below 621 manyears, the forest will be depleted.

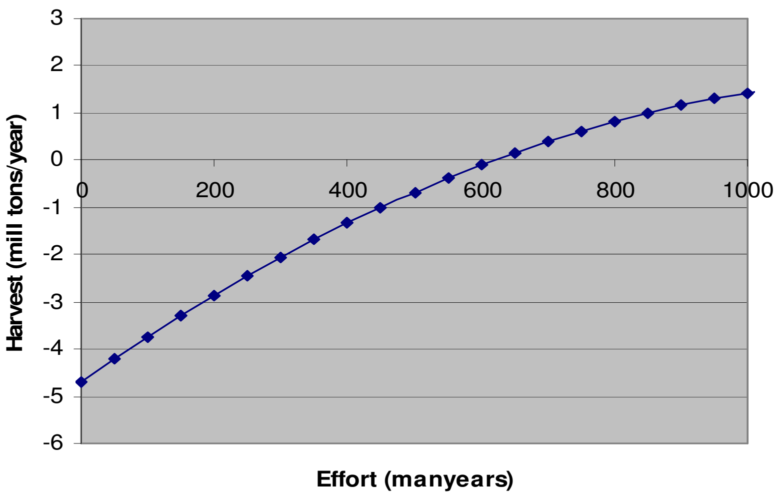

Figure 5. Equilibrium harvest as a function of deterring effort

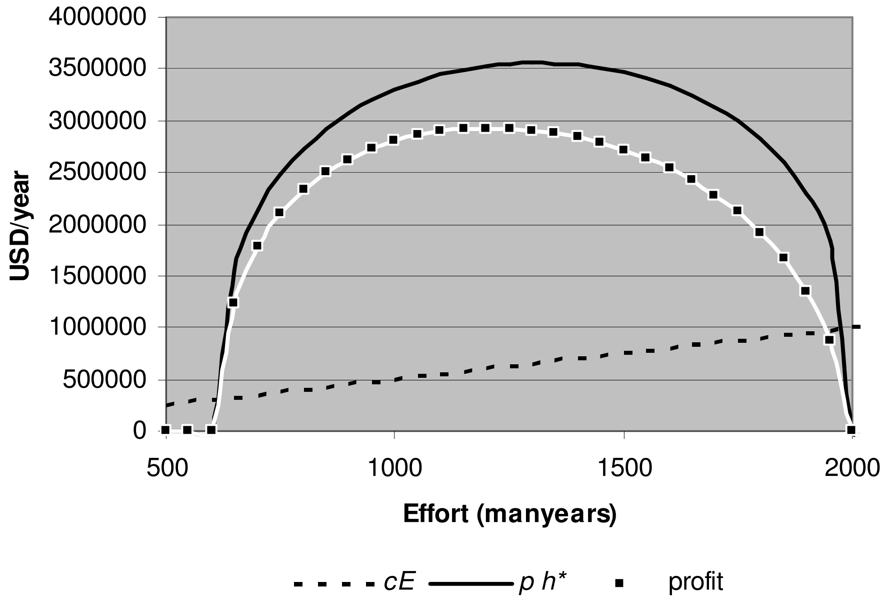

Figure 6. Economics of deterrence. *cE* is cost of deterrence, *ph** is net price times harvested quantity, and profit is the difference between the two.

Fig.6 illustrates the economics of deterrence. It shows that optimal effort is approximately 1200 manyears year^{-1}.

The population of Kampala grows by more than 3 % p.a. In spite of many initiatives to introduce more efficient charcoal stoves, most people continue using traditional stoves for cooking. Electricity, gas and kerosene are substitutes for charcoal, but under present conditions there is little reduction in per capita charcoal consumption. The price of charcoal has not increased substantially (in real terms, i.e. corrected for inflation) during the last 10 years (Hofstad and Sankhayan 1999), however. On this background one may expect harvested biomass to increase for quite some years to come. Even though the above mentioned factors may reduce the predation coefficient over time, population growth will probably outpace substitution effects. Therefore, it is likely that the optimal deterring effort will increase over time also.

Limitations

The analysis has not considered the case where standing forest has a value (Hartman 1976). It is obvious that many tropical forests and woodlands have a value while standing, and not only after felling for firewood, charcoal or timber. The value of standing forests in the tropics may be related to erosion control, stability of water flows, or maintenance of bio-diversity and carbon stocks. The value of standing forests varies considerably depending on the specific ecological characteristics of the site and vegetation in question. As an example; open woodland in Sub-Saharan Africa on land that is not prone to soil erosion may not be very valuable in environmental terms, while the main value of such vegetation lies in its potential to produce wood. Therefore, the above analysis may capture the main concerns of forest managers and policy makers in some cases, but it is not difficult imagining situations where a broader analysis is warranted.

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Appendix

In many cases h_d is large enough to affect price, i.e. $p_x = p(h_d)$. Elasticity of demand, η, is defined as:

$$\eta = -\frac{dh_d}{dp_x}\frac{p_x}{h_d}.$$

A suitable demand function would be: $h_d = D\, p_x^{-\eta}$, where D is a constant. In case of unit elasticity $h_d = D/p_x$, or $p_x = D/h_d$. The social objective is the same as before, and equation (7) is still valid:

$$S = p_x\, h_d{*}(E) - cE\ ,$$

where, p_x is the net price of standing wood, and c is the unit cost of controlling effort. In the case of unit elasticity, equation (7) can be written as

$$S = D - cE.$$

Then the optimal policy is not to engage in deterring activities at all. If c is positive, S is maximised when $E = 0$.

If $\eta \neq 1$, equation (7) becomes

$$S = h_d^{\,*}(E)\ \sqrt[\eta]{\frac{D}{h_d^{\,*}(E)}} - cE\ .$$

In this case the magnitude of D is important for deciding whether deterrence makes economic sense. Except for that, the conclusions are quite similar to those found in the case of constant price.