Systemic Corruption, Scale Effects and Forest Harvesting

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Abstract

This paper explores the influence of scale effects and corruption on forest harvesting. Policy-maker and bureaucratic corruption are considered sequentially. Overall, the corrupt policy maker chooses a less stringent forest policy. Moreover, this permissive forest policy partly enhances bureaucratic corruption. This paper therefore partially supports the idea of systemic corruption. Finally, it appears that a larger number of lobbying firms tends to increase this effect.

Keywords: corruption, scale effects, concentration, forest harvesting.

JEL classification: D73, Q23.

1 Introduction

Corruption, i.e. *"the unlawful use of public office for private gain"* (Transparency International, 2003), is one of the main features behind deforestation and over-harvesting of natural resources, especially in developing countries. Illegal logging represents more than 90 per cent of logging in Indonesia (Dudley et al., 1995), 80 per cent in Brazil and 90 per cent in Cambodia (Winbourne, 2002). In Indonesia, logging concessions covering more than half the country's total forest area were awarded by former President Suharto, many of them to his relatives and political allies (Global Forest Watch, World Resource Institute). In 1995, in Cambodia, the two prime ministers in power at that time gave concessions, contrary to the law, for the remaining parts of tropical forest (Harris White, 1996)[1].

Addressing rigorously this issue of corruption and forest harvesting requires to precise which type of corruption is considered. An important distinction is between policy-maker and bureaucratic corruption (Rose-Ackerman, 1978, 1999; World Bank, 2000; Wilson and Damania, 2005). First, policy-maker or "grand" corruption consists of offering bribes to the policy maker in order to influence his policy choices. Second, bureaucratic or "petty" corruption consists of paying bribes to civil agents to avoid the consequences of a particular rule. Of course, the two types of corruption are rarely observed separately. Corruption is generally a systemic phenomenon. A corrupted policy maker often coexists with a corrupted bureaucracy, and *vice versa*. Moreover, both kinds of corruption may interact. A key objective of this paper is thus to analyze how bureaucratic corruption may be linked to policy-maker corruption in the context of forest harvesting.

An important pattern of forest management is the allocation of forest concessions to logging firms. The policy maker is supposed to decide both the size of the forest to exploit, the number of loggers harvesting it (or number of concessions) and thus the concessions size. Case studies usually notice the large variety of forest policies (see Karsenty, 2007 for Central and West Africa). A increased knowledge of the links between systemic corruption, over-harvesting of forest resources and forest policies is thus a crucial issue. In this context, it appears that scale effects play a key role in determining those relationships.

[1]For an overview of corruption and illegal activities in the forestry sector, see Contreras-Hermosilla (2001) and Callister (1999)

The first part of the paper investigates the impact of scale effects and bureaucratic corruption on forest over-harvesting, taking the forest policy as given. The logging firms may be inspected by a bureaucrat they might be willing to bribe. Moreover, an uncorrupt authority may audit both the firm and the bureaucrat to verify the enforcement of the forest policy. Two factors influence the impact of bureaucratic corruption. First, a large number of loggers reduces the probability for the firm to be inspected by the bureaucrat and audited by the authority. Therefore, a large number of loggers on the market decreases the expected penalty and is an incentive not to respect the logging rules and to over-harvest the forest resources. Second, scale effects are important. Considering previous studies, it is difficult to have a clear idea of the impact of the concessions size on the productivity of effort. Thus both cases of increasing and decreasing return to scale need to be considered. If the marginal productivity of effort decreases with the size of concessions, small concessions represent an incentive to over-harvest the forest. In this case, a larger number of concessions tends to increase forest over-harvesting. Moreover, a larger harvested forest area and more stringent harvest quota tend to decrease logging intensity and over-harvesting.

The second part presents a model of policy-maker corruption, following Grossman and Helpman (1994). The policy maker designs the forest policy, which consists of the number of concessions, the size of the forest to be harvested and the maximum harvest intensity. It maximizes a weighted sum of social welfare and received bribes. An exogenous number of firms act as one lobby, bribing the policy maker to set a more permissive forest policy, i.e to increase the size of the exploited forest, the number of concessions and the harvest quota. In this context, the policy maker tends to set a sub-optimal and too permissive forest policy, when more corrupted.

Considering the links between policy-maker and bureaucratic corruption, this paper supports partially the idea of systemic corruption. Indeed, policy-maker corruption tends to enhance the impact of bureaucratic corruption through two key policy instruments, and to decrease it through the third one. The net impact remains to be determined, but depends crucially on the specification of the loggers net harvest function, of the welfare function and of the bribe schedule.

Section 2 presents a short literature review on the links between corruption and forest harvesting. Bureaucratic corruption is analyzed in section 3, while section 4 presents a model of policy-maker corruption. Finally, section 5 discusses the systemic patterns of the models presented and section 6 concludes and discusses the policy implications.

2 Corruption and the environment

Some papers consider the impact of corruption (or lobbying) on forest exploitation. Using a political economy model, Eerola (2004) considers two lobbies, the wood industry and an environmental organization, competing to influence a government choice. The timber industry is a monopoly and the policy instrument is the level of conservation of the country's forests. One of the main results of the paper is that an exporting monopoly tends to face stricter conservation policies than a monopoly producing for the domestic market, because the costs of conservation are partly borne by foreign consumers when the timber is exported.

The context described by Eerola may not fit with the context of many developing countries. First, the political influence of environmental organizations in developing countries is often weak compared to the one of the logging industry. Considering competition between both types of actors is likely not to be relevant in the case we analyze here. Second, even if forestry sectors are usually quite concentrated, assuming a monopoly restricts the analysis too much, avoiding potential interactions between logging firms. Third, Eerola assumes that forest exploitation provides constant return to scale. In contrast, this paper states that scale effects may be of importance in determining returns to effort and thus incentive to over-harvest. Finally, it is assumed in the paper that two uses of timber may be considered: roundwood and the production of a wood product. However, most developing countries have weak opportunities to transform the timber locally, and have the only opportunity to sale non-transformed timber. Overall, it seems that the context described by Eerola fits better to industrialized countries situation than to developing countries contexts.

Barbier et al. (2005) consider and test the influence of terms of trade, resource dependency, and corruption on resource conversion. Mainly, they find that increased corruption and resource dependency and decreasing terms of trade increase land conversion.

These two papers consider land conversion (or forest conservation) as the unique instrument of the forest policy. In contrast, we consider a policy mix, including an indicator of land conversion (size of the harvested forest), a quota on forest exploitation (maximum harvest effort), and an indicator of forestry sector concentration (number of concessions). This extension thus gives an overview of the complexity of the forest policy, by considering both the extensive and the intensive side of forest degradation.

Amacher et al. (2008) also consider the design of the forest policy as a mix between several instruments. They analyze how bureaucratic corruption may influence the policy design by an uncorrupt government. In their paper, the authors consider that the policy maker may anticipate corruption, and take its occurrence into consideration when choosing the forest policy. In contrast, we consider that both bureaucrats and the policy maker may be corrupted, and that both types of corruption may be interrelated.

Indeed, the three papers mentioned above only analyze one type of corruption: government corruption for Eerola and Barbier et al., and bureaucratic corruption for Amacher et al. However, as mentioned before, corruption is often systemic and distinguishing policy-maker and bureaucratic corruption is important and relevant when analyzing contexts of the developing world. To our knowledge, Wilson and Damania (2005) is the first paper that considers this two-scales corruption. The authors show that political competition increases the stringency of the environmental policy, but that its impact is limited. Indeed, if judicial institutions are weak, an increase in political competition may increase bureaucratic corruption, which limits the enforcement of the environmental policy. Moreover, political competition does not necessarily deter bureaucratic corruption.

Although Wilson and Damania (2005) consider pollution in an industrialized country, their two-step analysis is relevant to analyze the systemic patterns of corruption in developing countries. Thus we consider it in the context of developing countries to study the occurrence of corruption at different levels of governments and its effects on forest harvesting. The object of this study is however quite different. Wilson and Damania focus their analysis on the links between corruption and political competition, and their impact on environmental policies. In contrast, we study an incumbent government and focus our analysis on the importance of scale effects on systemic corruption and the forest policy design.

Proceeding backward, we will analyze in the next section bureaucratic corruption, considering the forest policy as given. Then, we will consider the choice process of the forest policy.

3 Scale effects and bureaucratic corruption

The forest policy is supposed to have been designed by the policy maker. It consists of the size of the forest to be harvested $\overline{F}$, the number of concessions, $\overline{N}$, and the maximum harvest effort, $\overline{e}$. This last policy instrument can be considered as a harvest quota [2]. For example, it can be the minimum rotation age, or a maximum amount of timber to log per hectare. We proceed backward. $\overline{F}$, $\overline{N}$ and $\overline{e}$ are considered as given by the firm. In the next section, the choice process of the forest policy is described.

We assume that the logging firms have an interest not to respect the quota and to set $e > \overline{e}$, i.e a positive level of non-compliance $v = (e - \overline{e}) > 0$. To verify that the quota is respected, bureaucrats may inspect the logging firm. However, the means being limited, only a fixed number of loggers N^c can be inspected. Moreover, if the inspected firm does not respect the effort limit, it may offer a bribe B to the bureaucrat, in order for him to declare that the quota has been respected.

Finally, an independent uncorrupt authority is in charge of auditing both the bureaucrat and the firm, to verify the enforcement of the forest policy. If both parties are convicted of over-harvesting and corruption, the authority imposes some penalties per hectare (proportional to the level of non-compliance) $h^f(v)$ and $h^b(v)$ to the firm and the bureaucrat, respectively. The authority audits a share σ of the inspected loggers[3]. Assuming such a kind of authority allows to consider different cases of anti-corruption policies. As an extreme case, the authority has no mean to audit loggers: $\sigma = 0$. As another extreme, the authority has full means to fight against corruption, and audit every inspected firm: $\sigma = 1$. The control potential of such an authority depends on the countries institutions. Moreover, the existence of an independent authority may come from international organizations. Anti-corruption policies are one of the main objective behind World Bank interventions.

[2]The case of an environmental tax is addressed in Damania and Wilson (2005). The level of non-compliance would then reduce the tax basis.

[3]Equivalently, we can assume that every firm is audited, and that σ represents the probability of detection by the authority.

3.1 The logger-bureaucrat interaction

3.1.1 The logger

The concessions size is the result of the forest policy chosen by the government: $\overline{N}$ concessions of size $s = \frac{\overline{F}}{\overline{N}}$.

Harvest and land-holding costs and timber prices are integrated in the net harvest function. Loggers are price takers, which makes sense if we consider a small open economy: harvesting firms trade at the international market price and do not influence this price. In this sense, concentration is addressed trough the impact of the number of logging firms and the concessions size on corruption.

The net harvest function depends on the concessions size (exogenous to the logger) and the logging effort (the logger's choice variable), and takes the form $H(s;e)$, with standard properties[4]: $H_e > 0, H_{ee} < 0, H_s > 0, H_{ss} < 0$. The number of loggers and the size of the exploited forest determine the concessions size, which implies: $H(s;e) = H(\frac{\overline{F}}{\overline{N}}, e)$, $H_F = \frac{H_s}{N} > 0, H_N = \frac{-FH_s}{N^2} < 0, H_{FF} = \frac{H_{ss}}{N^2} < 0, H_{NN} = \frac{F}{N^4}(H_{ss} - 2NH^s) < 0$.

Economies of scale or cost sharing? The type of return to scale is yet to be defined. In our specification, it is represented by the effect of the concessions size on the net marginal productivity of effort (H_{se}).

Forest harvesting involves potentially important costs of implementation. It seems plausible that transport costs and the costs of opening access (mainly the creation of roads) to the forest are positively correlated with the concessions size, which tend to decrease the net marginal productivity of effort. Moreover, loggers may cooperate and share a part of opening access costs, which suggests that the size of concessions decreases the net marginal productivity of effort. On the other hand, there might be some economies of scale, with a reverse relationship. Indeed, small concessions may generate congestion and thus decrease the marginal productivity of effort.

Intuitively, countries with a relatively long history in forest harvesting are likely to experience smaller implementation costs, due to existing infrastructures and learning by doing. Conversely, countries with less accessible forests (e.g. in mountain region) probably have

[4] The subscripts refer to first and second derivatives.

larger transport and road creation costs. Therefore, this relationship is potentially highly dependent of the considered country.

Only few studies treat this issue. Ruiz Perez et al. (2005) find a negative relationship between the size of concessions and logging ratio (i.e. the concessions surface logged) in the Congo Basin. This suggests a higher pressure on small concessions (and thus $H_{se} < 0$). Gray (2002) also describes small concessions as an incentive for unsustainable logging. Finally, Gray (2000) argues that *"large concessions (...) have little incentive (...) to practice more intensive forest management"*, which also suggests that marginal productivity of logging effort decreases with the concessions size.

Although those case studies tend to validate the hypothesis of decreasing returns with the concessions size, empirical evidence is rather meagre. It is therefore difficult to conclude the links between the effort net marginal productivity and the size of concessions. We will thus consider all cases in this paper, keeping in mind that this relationship may go both ways.

The loggers may have an interest to exceed the harvest quota imposed by the policy maker: $H(\frac{\overline{F}}{\overline{N}};\overline{e}) < H(\frac{\overline{F}}{\overline{N}};e^*)$, with $\overline{e} < e^*$. As an extreme case, both players have the same optimum, $e^* = \overline{e}$, and the problem is trivial. Indeed, an inter-temporal profit maximization would suggest that a logger would not over-exploit the resource because of expected future lost. Unsustainable forest exploitation is nevertheless frequently observed. First, short-term concessions and/or political instability may be a source of incentive to exceed the logging limits. If the logger anticipates that he may lose his concession in the next period, he is likely not to respect sustainability. Second, non-internalization of externalities could represent an incentive not to respect the logging limits: if environmental damages of over-harvesting are borne by other agents than loggers (local communities, biodiversity losses...), it may be profitable for them to exceed the logging quotas. In this paper, we take these incentives as given and focus the analysis on their consequences.

The logger may be inspected with probability $(\frac{N^c}{\overline{N}})$. Thus a larger number of loggers decreases the individual probability of being inspected. One could argue that the number of inspected loggers should depend on the concessions size. Indeed, a logger with a large concession could take longer to inspect that a logger with a smaller concession. Thus N^c would be positively related to $\overline{N}$, which decreases the concessions size: $\frac{\partial N^c}{\partial s} < 0$; $\frac{\partial N^c}{\partial \overline{N}} > 0$.

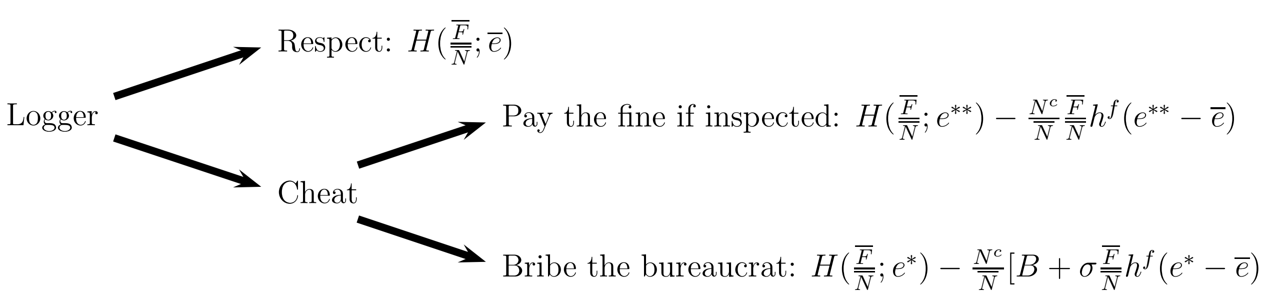
Such an assumption would reduce this dilution effect, and mitigate the following results. Nevertheless, those results would still hold if: $\frac{\partial N^c}{\partial \overline{N}} < \frac{N^c}{\overline{N}}$. We keep thus a fixed N^c, not depending on $\overline{N}$.

The logger possibly pays the bureaucrat a bribe B. In this case, with probability $\sigma\frac{N^c}{\overline{N}}$, the authority audits and the logger has to pay a penalty $\frac{\overline{F}}{\overline{N}}h^f(v)$. Note that the penalty is increasing and convex in the level of non-compliance v: : $\partial h^i/\partial v > 0$ and $\partial^2 h^i/\partial v^2 > 0$, for i = f, b. It is also proportional to the concessions size $\frac{\overline{F}}{\overline{N}}$.

Overall, the logger has to make two choices. First, it chooses whether to respect the quota (set $e = \overline{e}$) or not. Second, if the choice of cheating has been made and if the logger is inspected, it has to choose whether to bribe the bureaucrat (and set $e^* > \overline{e}$) or to accept to pay the fine (and set $e^{**} > \overline{e}$). If choosing to pay a bribe, the logger still risks to be audited by the independent authority (with probability σ) and pay the fine anyway. The following table summarizes the different strategies and payoffs.

	Not inspected	Inspected Not audited	Inspected by the bureaucrat Audited by the authority
Probability	$(1-\frac{N^c}{\overline{N}})$	$(1-\sigma)\frac{N^c}{\overline{N}}$	$\sigma\frac{N^c}{\overline{N}}$
Respect	$H(\frac{\overline{F}}{\overline{N}};\overline{e})$	$H(\frac{\overline{F}}{\overline{N}};\overline{e})$	$H(\frac{\overline{F}}{\overline{N}};\overline{e})$
Cheat/Pay the fine	$H(\frac{\overline{F}}{\overline{N}};e^{**})$	$H(\frac{\overline{F}}{\overline{N}};e^{**}) - \frac{\overline{F}}{\overline{N}}h^f(e^{**}-\overline{e})$	$H(\frac{\overline{F}}{\overline{N}};e^{**}) - \frac{\overline{F}}{\overline{N}}h^f(e^{**}-\overline{e})$
Cheat/ Bribe	$H(\frac{\overline{F}}{\overline{N}};e^{*})$	$H(\frac{\overline{F}}{\overline{N}};e^{*}) - B$	$H(\frac{\overline{F}}{\overline{N}};e^{*}) - [B + \frac{\overline{F}}{\overline{N}}h^f(e^{*}-\overline{e})]$

Consequently the strategies and their related expected payoffs are presented in the following figure.



The objective of the fine is to enforce the harvest quota and therefore deter incentives to cheat. Thus, it seems reasonable to assume that the fine is set such that the *cheat/pay-*

the-fine strategy is dominated by the *respect* strategy, which implies that the expected fine should exceed the harvest gains from cheating:

$$\frac{N^c}{\overline{N}}\frac{\overline{F}}{\overline{N}}h^f(e^{**}-\overline{e}) > H(\frac{\overline{F}}{\overline{N}};\overline{e}) - H(\frac{\overline{F}}{\overline{N}};e^{**}) \tag{1}$$

Moreover, the *cheat/bribe* strategy is strictly dominant, if:

$$B \quad < \quad \frac{\overline{N}}{N^c}(H(\frac{\overline{F}}{\overline{N}};e^*) - H(\frac{\overline{F}}{\overline{N}};\overline{e})) - \sigma\frac{\overline{F}}{\overline{N}}h^f(e^*-\overline{e}) \equiv \overline{B} \tag{2}$$

The *cheat/bribe* strategy is chosen if the expected bribe is cheap enough to compensate for the potential fine involved by the audit. $\overline{B}$ therefore represents the reservation value of the bribe for the logger.

The logger's expected net benefit from the bribe is the expected payoff from the *cheat/bribe* strategy, minus the payoff of the *respect* strategy, i.e. the safe strategy:

$$\Psi^f = H(\frac{\overline{F}}{\overline{N}};e) - \frac{N^c}{\overline{N}}[B + \sigma\frac{\overline{F}}{\overline{N}}h^f(v)] - H(\frac{\overline{F}}{\overline{N}};\overline{e}) \tag{3}$$

When choosing the *cheat/bribe* strategy, the logger gets a larger net output $H(\frac{\overline{F}}{\overline{N}};e)$. Its is inspected by the bureaucrat with probability $\frac{N^c}{\overline{N}}$ and pay a bribe B. Moreover, it may be convicted by the audit authority with probability $\frac{N^c}{\overline{N}}\sigma$ and pay a fine $\frac{\overline{F}}{\overline{N}}h^f(v)$. Finally, the *respect* strategy provides a safe payoff $H(\frac{\overline{F}}{\overline{N}};\overline{e})$.

3.1.2 The bureaucrat

The bureaucrat is risk-neutral and gets a wage w for each inspected logger. Assuming the inspected logger did not respect the harvest quota and offers a bribe, he may accept the offer and be audited with probability σ. If he is convicted, he loses his wage and is imposed a penalty $\frac{\overline{F}}{\overline{N}}h^b(v)$. The bureaucrat has therefore to make a choice between two behaviors: to refuse the bribe and to make the logger pay the fine, or to accept it and to take the risk of being punished. The payoffs related to each strategy in each case are given in the following table.

	Not audited	Audited
Probability	$(1-\sigma)$	σ
Refuse the bribe	w	w
Accept the bribe	$w+B$	$B-\frac{\overline{F}}{\overline{N}}h^b(v)$

The following figure shows the expected payoffs related to both strategies.

Bureaucrat → Refuse the bribe: w

Bureaucrat → Accept the bribe: $(1-\sigma)w + B - \sigma\frac{\overline{F}}{\overline{N}}h^b(e^* - \overline{e})$

We consider the situation in which accepting the bribe is the dominant strategy, implying:

$$B > \sigma(w + \frac{\overline{F}}{\overline{N}}h^b(e^* - \overline{e})) \equiv \underline{B} \tag{4}$$

Indeed, the bureaucrat accepts the bribe if it is larger than the expected loss of being audited. $\underline{B}$ is therefore the reservation value of the bribe for the bureaucrat. The bureaucrat's net expected payoff is therefore his expected payoff of accepting the bribe, minus the payoff of refusing it:

$$\Psi^b = (1-\sigma)w + B - \sigma\frac{\overline{F}}{\overline{N}}h^b(v) - w \tag{5}$$

If he accepts the bribe B, the bureaucrat is audited with probability σ and pays a fine $\frac{\overline{F}}{\overline{N}}h^b(v)$. Moreover, he only keeps his wage w with probability $(1-\sigma)$ (i.e. if he is not audited). Finally, the *refuse* strategy generates a safe payoff of w.

3.2 Equilibrium harvest effort and bribe

The process to the equilibrium could be described as a *maximize-then-share-the-pie* process. First, the effort intensity of the logger is set in order to maximize the joint payoffs of both parties, taking $\overline{N}$, $\overline{F}$ and $\overline{e}$ as given. Second, the logger and the bureaucrat share the surplus through a Nash bargaining process.

3.2.1 Equilibrium harvest effort

Following Wilson and Damania (2005), the equilibrium harvest effort is set in order to maximize the joint net payoffs of the logger and the bureaucrat.

$$\max_e \ \Omega(e) = \psi^f + \psi^b = H(\frac{\overline{F}}{\overline{N}}; e) - H(\frac{\overline{F}}{\overline{N}}; \overline{e}) - \sigma w + B(1 - \frac{N^c}{\overline{N}}) - \sigma\frac{\overline{F}}{\overline{N}}[\frac{N^c}{\overline{N}}h^f(v) + h^b(v)] \tag{6}$$

The first order condition gives:

$$\Omega_e = H_e - \sigma\frac{\overline{F}}{\overline{N}}[\frac{N^c}{\overline{N}}h_v^f + h_v^b] = 0 \tag{7}$$

The logger's optimal harvest effort $e^*(\overline{N}, \overline{F}, \overline{e}, N^c, \sigma, h_v^f, h_v^b)$ is implicitly given by equation (7). In equilibrium, it is set such that the marginal productivity of effort equals the marginal expected penalty.

Considering the factors influencing the logger's harvest effort, the parameters related to the control of the harvest volumes, σ, N^c, h_v^f and h_v^b, unsurprisingly induce a smaller effort intensity in equilibrium: $e_x^* < 0$, for $x = \sigma, N^c, h_v^f, h_v^b$. Controlling more intensively the logger (and the bureaucrat) thus decreases the equilibrium effort intensity.

Harvest quota: the harvest quota $\overline{e}$ has a positive impact on the effective harvest effort. Indeed, a less stringent harvest quota reduces the extent of the potential fine:

$$e_{\overline{e}}^* = \frac{-\sigma\frac{\overline{F}}{\overline{N}}(\frac{N^c}{\overline{N}}h_{vv}^f + h_{vv}^b)}{H_{ee} - \sigma(\frac{N^c}{\overline{N}}h_{vv}^f + h_{vv}^b)} > 0 \tag{8}$$

The stringency of the harvest quota is crucial to determine the extend of over-harvesting, and thus of the expected fine. A more stringent harvest quota naturally raises the amount that a logger would have to pay for a given harvest effort, and thus reduces the incentive to over-harvest.

Harvested forest: The impact of the size of the exploited forest $\overline{F}$ on the equilibrium harvest effort is given by:

$$e_{\overline{F}}^* = -\frac{\frac{H_{se}}{\overline{N}} - \frac{\sigma}{\overline{N}}[\frac{N^c}{\overline{N}}h_v^f + h_v^b]}{H_{ee} - \sigma(\frac{N^c}{\overline{N}}h_{vv}^f + h_{vv}^b)} \tag{9}$$

Scale effects are thus a key factor to determine the influence of the forest policy on the actual effort intensity. If forest harvesting is characterized by important economies of scale, an increase in the size of the harvested forest increases the harvest effort of the loggers. In contrast, if effort effectiveness decreases with the concessions size, it seems that there is a trade off between primary forest preservation (through the size of the harvested forest) and over-harvesting (through harvest effort).

Concentration: The impact of $\overline{N}$ on the equilibrium effort level is:

$$e^*_{\overline{N}} = -\frac{\frac{-\overline{F}H_{se}}{\overline{N}^2} + \sigma\frac{\overline{F}}{\overline{N}}[\frac{1+\overline{N}}{\overline{N}^2}N^c h^f_v + h^b_v]}{H_{ee} - \sigma(\frac{N^c}{\overline{N}}h^f_{vv} + h^b_{vv})} \tag{10}$$

First, the fine is proportional to the concession size. Thus smaller concessions (and a larger number of loggers) reduce the expected fine. Second, a large number of loggers reduces the probability of being inspected by the bureaucrat and audited by the authority, and thus reduces the expected marginal fine. This smaller expected fine is an incentive to raise the effort intensity and over-exploitation of the resource. Finally, the impact of $\overline{N}$ on the marginal productivity of effort is important. If an increase in the concessions size tends to decrease the marginal productivity of effort ($H_{se} < 0$), a large number of loggers tends to increase the harvest effort ($H_{Ne} > 0$), and *vice versa*.

Proposition 1 : *A more stringent harvest quota tends to decrease the equilibrium harvest effort. Moreover, if the concession size has a negative impact on the marginal productivity of effort (or a positive but sufficiently small impact), the size of the harvested forest (a larger number of concessions) tends to decrease (increase) the equilibrium harvest effort. Conversely, if the effort marginal productivity reduces rapidly with the size of concessions, the size of the harvested forest (a larger number of concessions) increases (decreases) the equilibrium harvest effort.*
Proof: see appendix A.

3.2.2 Equilibrium bribe

The equilibrium bribe is set through a Nash bargaining process. Both parties are assumed to have the same bargaining power, so that they share equally the benefit of not respecting the harvest quota. We consider here that the bargaining is successful. It implies that the equilibrium bribe must respect the reservation values described in equations (2) and (4).

The equilibrium bribe is set maximizing the Nash bargain:

$$\max_B \ \Psi^f\Psi^b = [H(\frac{\overline{F}}{\overline{N}}; e^*) - \frac{N^c}{\overline{N}}(B + \sigma\frac{\overline{F}}{\overline{N}}h^f(v)) - H(\frac{\overline{F}}{\overline{N}}; \overline{e})][-\sigma w + B - \sigma\frac{\overline{F}}{\overline{N}}h^b(v)] \tag{11}$$

The first order condition gives:

$$B = \frac{1}{2}[\frac{\overline{N}}{N^c}(H(\frac{\overline{F}}{\overline{\overline{N}}}; e^*) - H(\frac{\overline{F}}{\overline{\overline{N}}}; \overline{e})) + \sigma w - \sigma\frac{\overline{F}}{\overline{\overline{N}}}(h^f(v) - h^b(v))] \quad (12)$$

This equilibrium bribe must lie in between the reservation values of both parties $[\underline{B}, \overline{B}]$, which implies that the benefit of not respecting the quota must exceed the global expected loss of being convicted:

$$H(\frac{\overline{F}}{\overline{\overline{N}}}; e^*) - H(\frac{\overline{F}}{\overline{\overline{N}}}; \overline{e}) \quad > \quad \frac{N^c}{\overline{\overline{N}}}\sigma(w + \frac{\overline{F}}{\overline{\overline{N}}}(h^f(v) - h^b(v))) \quad (13)$$

First, in order to insure that higher fines induce a decrease in the equilibrium bribe, we need to assume: $h^f > h^b$. Indeed, the punishment has to be more severe on the bribe giver. For otherwise, a higher fine on the recipient would incite the giver to raise the bribe to compensate for the recipient's expected fine. This assumption is consistent with the conclusions emerging from the literature (Mookherjee and Png, 1995; Basu et al., 1992).

Second, the equilibrium bribe increases with the gain in revenue from not respecting the quota, $(H(\frac{\overline{F}}{\overline{\overline{N}}}; e^*) - H(\frac{\overline{F}}{\overline{\overline{N}}}; \overline{e}))$. Indeed, if the quota is stringent with respect to the net harvest function, the incentive to cheat is high, but corrupting is expensive, because of the extend of potential fines. Finally, the impact of the probability of being audited σ depends on what both agents have to lose: if the bureaucrat has more to lose than the logger $(w + \frac{\overline{F}}{\overline{\overline{N}}}h^b(v) > \frac{\overline{F}}{\overline{\overline{N}}}h^f(v))$, the bribe is increasing in σ and *vice versa*.

Third, the equilibrium bribe is positively correlated with the agent's wage. Indeed, it seems reasonable to assume that the bureaucrat is deprived from his wage if he is convicted of not enforcing the quota and being corrupt. Moreover, this assumption provides the insight that a well-paid bureaucrat is more expensive to corrupt, simply because he has more to lose.

Finally, the bribe reduces with the number of loggers inspected by the bureaucrat N^c. Indeed, N^c raises the probability of being inspected, and thus reduces the expected share of extra-effort got by the logger, which naturally reduces its incentive to cheat.

Finally, the impact of the number of concessions is not clear:

$$B_{\overline{\overline{N}}} = \frac{1}{2}[\frac{1}{N^c}(H(\frac{\overline{F}}{\overline{\overline{N}}}; e^*) - H(\frac{\overline{F}}{\overline{\overline{N}}}; \overline{e})) + \frac{\overline{F}}{\overline{\overline{N^c}}}(H_s(\frac{\overline{F}}{\overline{\overline{N}}}, \overline{e}) - H_s(\frac{\overline{F}}{\overline{\overline{N}}}, e^*)) + \sigma\frac{\overline{F}}{\overline{\overline{N^2}}}(h^f(v) - h^b(v))] \quad (14)$$

The first part of the equation, $(H(\frac{\overline{F}}{\overline{\overline{N}}}; e^*) - H(\frac{\overline{F}}{\overline{\overline{N}}}; \overline{e}))$, which corresponds to the productive incentive to cheat, is positive. The second part, $(H_s(\frac{\overline{F}}{\overline{\overline{N}}}, \overline{e}) - H_s(\frac{\overline{F}}{\overline{\overline{N}}}, e^*))$, depends on the cross derivative of the net harvest function H_{se}. As $\overline{e} < e^*$, this second part of the equation is also positive, if $H_{se} < 0$. Finally, the third part of the equation expresses the impact of the concession size on the fine, which is positive. Overall, a larger number of concessions increases the equilibrium bribe if the impact of concessions size on the net marginal productivity of effort is negative (or positive but sufficiently small).

4 Lobbying and the forest policy design

Proceeding backward, we analyze now the choice process of the forest policy ($\overline{N}$, $\overline{F}$ and $\overline{e}$) (the socially optimal policy is given in appendix B).

An exogenous number of loggers N_l acts as one lobby, the aim of which is to get a less stringent forest policy. The lobby's objective thus consists of increasing the size of the forest to exploit $\overline{F}$ and the harvest quota $\overline{e}$, and setting a number of concessions $\overline{N}$ close to the number of loggers in the lobby. N_l may represent the number of political allies that the policy maker may reward.

Neither the policy maker nor the lobby consider the impact of the forest policy instruments on bureaucratic corruption. In that sense, they have a naive point of view concerning the forest policy and implicitly assume that the policy is enforced. This assumption makes sense if we consider the fact that public policies are usually chosen considering implicitly that they will be enforced. The fact that bureaucratic corruption may influence the policy choice of the government is treated in Amacher et al. (2008).

The total forest area is set to 1. Thus $\overline{F}$ is the share of the forest to be exploited, while the share $(1 - \overline{F})$ represents protected primary forest.

4.1 The logger-policy maker interaction

To address this issue, we build on Grossman and Helpman (1994). The policy maker's objective function is a weighted sum of social welfare and bribes.

$$G(F, N, e) = \alpha W(NH(\frac{F}{N}; e); (1 - F); e) + (1 - \alpha)C(F, N, e) \tag{15}$$

W is the social welfare function. It is increasing in the total harvested volumes. Moreover, the social welfare function is increasing in the size of primary protected forests $(1 - F)$

(and thus decreasing in the size of harvested forest), because of the environmental services provided, such as biodiversity conservation or hydrological benefits. Finally the social welfare function is decreasing in the harvest effort, assimilated to environmental degradation (biodiversity loss, erosion, wildlife habitat degradation): $W_H > 0$, $W_{(1-F)} > 0$ $W_e < 0$, $W_{HH} < 0$, $W_{(1-F)(1-F)} < 0$ and $W_{ee} < 0$.

$(1-\alpha)$ is the degree of corruptibility of the policy maker and $C(F, N, e)$ is the bribe schedule offered by the lobby to the policy maker. The bribe is increasing in the size of the exploited forest and the harvest quota: $C_F > 0$, $C_e > 0$.

Moreover, the bribe is increasing in the number of concessions, as long as it is smaller than the number of lobbying loggers: $C_N > 0$, for $N < N_l$; $C_N = 0$, for $N \geq N_l$. The shape and sign of the bribe schedule $C(N)$ depends on the relationship between the policy maker and the lobbying loggers. As an extreme case, if the political allies of the policy maker are very powerful and can put enough pressure on the policy maker, the choice of the number of concessions is not a choice anymore, but becomes a constraint for the policy maker. In this case: $C(N) < 0$, for $\overline{N} < N_l$ and $C(N) = 0$ for $\overline{N} \geq N_l$.

The forestry sector acts as a lobby. We define the lobby's degree of satisfaction as the share of lobbying loggers receiving a concession: $\frac{N}{N_l}$. The lobby's payoff increases with its degree of satisfaction and the total net harvest volumes, and decreases with the bribe paid to the policy maker. The lobby's payoff therefore captures a dilution affect: it is more difficult to satisfy the whole lobby if it is composed of a large number of loggers.

$$\Pi(F, N, e) = \frac{N^2}{N_l} H(\frac{F}{N}; e) - (1 + \lambda(N_l))C(F, N, e) \tag{16}$$

The effect of the number of loggers N_l on the lobby coordination is captured by $\lambda(N_l)$, which corresponds to the coordination costs of the lobby and the costs due to free rider behaviors by the lobby members. This set up follows Laffont and Tirole (1991) and Fredriksson et al. (2004). It is assumed that: $\lambda_{N_l} > 0$.

4.2 Equilibrium forest policy

The equilibrium consists of the size of the exploited forest $\overline{F}$, the harvest quota $\overline{e}$ and the number of concessions $\overline{N}$.

Overall, it is easy to see that a more corrupt policy maker (with low α) puts more weight on the lobby's objective and thus designs less stringent forest policy. The conditions for equilibrium are consistent with the political economy literature.

4.2.1 Equilibrium harvest quota

First, the equilibrium harvest quota $\overline{e}$ maximizes both (i) $G(e)$ and (ii) $(G(e) + \Pi(e))$ and the first order conditions satisfy:

$$(i) \quad \alpha W_H H_e + \alpha W_e + (1-\alpha)C_e = 0$$
$$(ii) \quad \alpha W_H H_e + \alpha W_e + (1-\alpha)C_e + \frac{\overline{N}^2}{N_l} H_e - (1+\lambda(N_l))C_e = 0$$

$\overline{e}$ is implicitly given by:

$$((1-\alpha)\frac{\overline{N}^2}{N_l} + \alpha(1+\lambda(N_l))W_H)H_e = -\alpha(1+\lambda(N_l))W_e \tag{17}$$

Impact of the number of lobbying loggers N_l on the equilibrium harvest quota $\overline{e}$: The impact of the number of lobbying loggers is given by:

$$\overline{e}_{N_l} = \frac{-((1-\alpha)\frac{\overline{N}^2}{N_l})^2 H_e + \lambda_{N_l}\alpha(W_H H_e + W_e)}{(1-\alpha)\frac{\overline{N}^2}{N_l} H_{ee} + \alpha(1+\lambda(N_l))(W_H H_{ee} + W_{ee})} > 0 \tag{18}$$

4.2.2 Equilibrium size of exploited forest

$\overline{F}$ maximizes both (i) G(F) and (ii) $(G(F) + \Pi(F))$. The first order conditions are:

$$(i) \quad \alpha W_H H_s - \alpha W_{(1-F)} + (1-\alpha)C_F = 0 \tag{19}$$
$$(ii) \quad \alpha W_H H_s - \alpha W_{(1-F)} + (1-\alpha)C_F + \frac{N H_s}{N_l} - (1+\lambda(N_l))C_F = 0 \tag{20}$$

Which imply:

$$((1-\alpha)\frac{\overline{N}}{N_l(1+\lambda(N_l))} + \alpha W_H)H_s = \alpha W_{(1-F)} \tag{21}$$

Which gives implicitly the equilibrium size of the exploited forest $\overline{F}$. A more corrupt policy maker therefore tends unsurprisingly to put less weight on social welfare and more weight on the lobby's harvest. Thus, the equilibrium size of the exploited forest is greater than the social optimum.

Impact of the number of lobbying loggers N_l on the equilibrium size of exploited forest: The impact of N_l on $\overline{F}$ is given by:

$$\overline{F}_{N_l} = \frac{-\frac{(1+\lambda(N_l))+N_l\lambda_{N_l}}{(N_l(1+\lambda(N_l)))^2}\overline{N}H_s}{(1-\alpha)\frac{H_{ss}}{N_l(1+\lambda(N_l))}+\alpha(\frac{W_H H_{ss}}{N}+W_{(1-F)(1-F)})} > O \tag{22}$$

4.2.3 Equilibrium number of concessions

The choice of the number of concessions allocated $\overline{N}$ follows the same analysis. $\overline{N}$ maximizes both (i) $G(N)$ and (ii) $(G(N)+\Pi(N))$ and the first order conditions satisfy:

$$(i) \quad \alpha W_H(H(\frac{F}{N};e)-\frac{F}{N^2}H_s)+(1-\alpha)C_N = 0$$

$$(ii) \quad \alpha W_H(H(\frac{F}{N};e)-\frac{F}{N^2}H_s)+(1-\alpha)C_N+\frac{1}{N_l}(2NH(\frac{F}{N};e)-FH_s)-(1+\lambda(N_l))C_N = 0$$

The equilibrium number of concessions $\overline{N}$ is implicitly given by:

$$((1-\alpha)\frac{2\overline{N}}{N_l(1+\lambda(N_l))}+\alpha W_H)H(\frac{\overline{F}}{\overline{N}};e) = ((1-\alpha)\frac{1}{N_l(1+\lambda(N_l))}+\alpha W_H)\overline{F}H_s \tag{23}$$

Impact of the number of lobbying loggers N_l on the equilibrium number of concessions $\overline{N}$: The impact of the number of lobbying loggers is given by:

$$\overline{N}_{N_l} = \frac{\frac{(1+\lambda(N_l))+N_l\lambda_{N_l}}{(N_l(1+\lambda(N_l)))^2}2\overline{N}(H(\frac{\overline{F}}{\overline{N}};e)-\overline{F}H_s)}{\frac{2(1-\alpha)}{N_l(1+\lambda(N_l))}H(\frac{\overline{F}}{\overline{N}};e)-(\frac{2(1-\alpha)\overline{N}}{N_l(1+\lambda(N_l))}+\alpha W_H)\frac{\overline{F}}{\overline{N}^2}H_s+(\frac{(1-\alpha)}{N_l(1+\lambda(N_l))}+\alpha W_H)(\frac{\overline{F}}{\overline{N}})^2H_{ss}} > 0 \tag{24}$$

Proposition 2 : *A more corrupt policy maker sets a more permissive forest policy. Moreover, a larger number of lobbying loggers tends to increase the equilibrium harvest quota, the size of the exploited forest, the equilibrium number of concessions.*

Proof: see appendix C.

Therefore, we can consider in this context that a larger number of political allies to reward tends to increase policy-maker corruption for the whole forest policy.

5 Corruption as a systemic concern

The literature on corruption often considers that corruption is a systemic concern: a corrupt policy maker often coexists with a corrupt bureaucracy. The model presented here allows to consider the relationship between both types of corruption in the context of forest harvesting.

Scale effects play a key role to determine if corruption tends to present systemic patterns. A crucial element is how marginal productivity of effort evolves with the concessions size.

Cost sharing: considering decreasing returns to scale, i.e a negative impact of the concessions size on the effort marginal productivity. This case is potentially consistent for countries with less accessible forest resources and small infrastructure implementation (e.g: Chile, Congo Basin).

Policy-maker corruption tends to increase the size of the exploited forest, the number of concessions and the harvest quota. Considering proposition 1, a larger harvested forest tends to decrease the equilibrium harvest intensity, and that less stringent harvest quota and a larger number of concessions increases harvest intensity. Therefore, policy-maker corruption tends to enhance the impact of bureaucratic corruption for two key forest policy instruments and to decrease it for the other one.

The net effect depends on two types of elasticities: the elasticity of equilibrium harvest (e^*) to the policy instruments ($\overline{e}$, $\overline{N}$, $\overline{F}$), and the elasticity of the policy instruments to corruption (α). It is not possible to determine the net impact under the model described here, because deriving elasticities requires a less general specification of the harvesting and social welfare functions.

In the case of cost sharing, policy-maker corruption (PMC) enhances bureaucratic corruption (BC) through harvest intensity and the number of concessions, while it decreases it through the size of the harvested forest. Overall, policy-maker corruption thus increases the impact of bureaucratic corruption if:

$$\underbrace{\overbrace{[\frac{\partial \overline{e}}{\partial \alpha}\frac{\alpha}{\overline{e}}]}^{-}\overbrace{[\frac{\partial e^*}{\partial \overline{e}}\frac{\overline{e}}{e^*}]}^{+}+\overbrace{[\frac{\partial \overline{N}}{\partial \alpha}\frac{\alpha}{\overline{\overline{N}}}]}^{-}\overbrace{[\frac{\partial e^*}{\partial \overline{\overline{N}}}\frac{\overline{N}}{e^*}]}^{+}}_{PMC\nearrow BC}+\underbrace{\overbrace{[\frac{\partial \overline{F}}{\partial \alpha}\frac{\alpha}{\overline{\overline{F}}}]}^{-}\overbrace{[\frac{\partial e^*}{\partial \overline{\overline{F}}}\frac{\overline{F}}{e^*}]}^{-}}_{PMC\searrow BC}<0 \tag{25}$$

Economies of scale: increasing return to scale, if marginal effort productivity increases with the concessions size. This case corresponds to countries with more accessible forest resources and well-implemented infrastructure (e.g: Brazil, Indonesia).

In this case, from proposition 2, a larger exploited forest and less stringent harvest quota tend to increase the equilibrium harvest intensity and a larger number of concessions tends to decrease harvest intensity. Therefore, government corruption also enhances the impact of bureaucratic corruption for two key forest policy instruments and to decrease it for the other one. Overall, policy-maker corruption thus increases the impact of bureaucratic if:

$$\underbrace{\overbrace{[\frac{\partial \overline{e}}{\partial \alpha}\frac{\alpha}{\overline{e}}]}^{-}\overbrace{[\frac{\partial e^*}{\partial \overline{e}}\frac{\overline{e}}{e^*}]}^{+}+\overbrace{[\frac{\partial \overline{F}}{\partial \alpha}\frac{\alpha}{\overline{F}}]}^{-}\overbrace{[\frac{\partial e^*}{\partial \overline{F}}\frac{\overline{F}}{e^*}]}^{+}}_{PMC\nearrow BC}+\underbrace{\overbrace{[\frac{\partial \overline{N}}{\partial \alpha}\frac{\alpha}{\overline{N}}]}^{-}\overbrace{[\frac{\partial e^*}{\partial \overline{N}}\frac{\overline{N}}{e^*}]}^{-}}_{PMC\searrow BC}<0 \quad (26)$$

6 Conclusion

This paper explores the links between scale effects, systemic corruption and forest harvesting.

Corruption may occur at different scales of governments. First, logging firms may bribe the bureaucrat in charge of the inspection, so that he underreports the harvest volume. Second, a lobby composed of several loggers may bribe the policy maker to set a more permissive forest policy.

In the first case of bureaucratic corruption, scale effects constitute a key variable. If the harvest marginal productivity decreases with the concessions size (or increases slightly), a forestry sector composed of a large number of small concessions tends to increase the impact of corruption on forest over-exploitation. Indeed, a large number of logging firms reduces the control capacity of the civil agency. Moreover, in this case, small concessions (i.e a large number of loggers) appear to be an incentive for harvest intensification. On the other hand, more stringent harvest quota decrease the incentive to over-harvest. Finally, a larger exploited forest tends to decrease the harvest intensity, which support the idea of a trade off between primary forest conservation and over-harvesting: a larger exploited forest is related to a smaller protected area, but tends to decrease over-exploitation. In contrast, if important economies of scale characterize forest harvesting, then small concessions and a larger exploited forest tend to decrease over-harvesting and the impact of bureaucratic corruption.

In the second case of policy maker corruption, a corrupt policy maker tends to set a larger exploited forest, less stringent harvest quota and a larger number of concessions. Moreover, a larger number of lobbying loggers (or political allies) is related to less stringent forest policies.

Those two set of results allows to consider corruption as a systemic problem. Indeed, a corrupt policy maker tends to set a less stringent forest policy. Less stringent harvest quotas are always related to more intensive equilibrium harvest effort. In the case of decreasing return to scale, a larger number of concessions is also positively related to over-harvesting. In the case of increasing return to scale, policy-maker corruption enhances the impact of bureaucratic corruption through the size of the harvested forest. Overall, this paper partly supports the idea of systemic corruption, through two key forest policy instruments. The net impact of policy-maker corruption on bureaucratic corruption depends on the specification of net harvest function.

Two main policy implications are underlined in this paper. First, scale effects need to be taken into account when considering bureaucratic corruption. If important economies of scale characterize forest harvesting, then a larger number of small concessions may help to restrain the impact of ”petty” corruption. Second, policy-maker and bureaucratic corruption need to be considered as a whole. More precisely, the design of the forest policy may have an impact on the extent of bureaucratic corruption.

This model presents some limitations, which gives scale for further research. A crucial limitation is that loggers and concessions are assumed to be homogeneous in size. However, in real life, small and large concessions often coexist. Thus it could be interesting to consider the difference in corruption patterns between heterogeneous loggers. For example, small loggers might choose to bribe bureaucrats, while large loggers find more profitable to bribe directly policy makers.

Moreover, the process of concessions allocation is not modeled explicitly in this paper. Nevertheless, concessions allocation is an important pattern of corruption and forest exploitation in developing countries. Indeed corrupt regimes often use these allocation process to reward their political allies or to increase the wealth of their friends or family. In this context, concessions would be given according to the number of these allies and their ”worthiness", which would determine the concessions size. Moreover, logging firms may compete for concessions allocations.

Appendix A: proof of proposition 1

Harvest quota: in equation (8), both the nominator and the denominator are unambiguously negative. Thus a more stringent harvest quota reduces the equilibrium harvest effort: $e^*_{\overline{e}} > 0$.

Harvested forest: in equation (9), the denominator is unambiguously negative. Thus, the sign of the equation is of the sign of the nominator. The equilibrium harvest effort is therefore decreasing with the size of the exploited forest, $e^*_{\overline{F}} > 0$, if

$$H_{se} < \sigma[\frac{N^c}{\overline{N}} h^f_v + h^b_v] \tag{27}$$

Number of concessions: in equation (10), the sign of the denominator being unambiguously negative, equation (10) has the sign of $\frac{-\overline{F} H_{se}}{\overline{N}^2} + \sigma\frac{\overline{F}}{\overline{N}}[\frac{1+\overline{N}}{\overline{N}^2} N^c h^f_v + h^b_v]$. Thus, the condition for the equilibrium harvest effort to increase with the number of harvesting firms, $e^*_{\overline{N}} > 0$, is

$$H_{se} < \sigma\overline{N}[\frac{1+\overline{N}}{\overline{N}^2} N^c h^f_v + h^b_v] \tag{28}$$

Appendix B: socially optimal policy

The socially optimal forest policy is given for a non-corrupt policy maker: $\alpha = 1$.

The socially optimal size of the exploited forest is implicitly given by:

$$W_H H_s = W_{(1-F)} \tag{29}$$

The socially optimal number of concessions is implicitly given by:

$$H(\frac{\overline{F}}{\overline{N}}; e) = \overline{F} H_s \tag{30}$$

The socially optimal harvest quota is implicitly given by:

$$W_H H_e + W_e = 0 \tag{31}$$

Appendix C: proof of proposition 2

$\overline{e}_{N_l} > 0$**.** Note from equation (23) that $(1-\alpha)\frac{\overline{N}^2}{N_l} + \alpha(1+\lambda(N_l)) > \alpha(1+\lambda(N_l))$, which implies that: $W_H H_e < -We$. Thus the nominator is negative.

Moreover, by assumption, $H_{ee} < 0$, $W_H > 0$ and $W_{ee} < 0$. Thus the denominator is also negative.

Overall, a larger number of lobbying loggers thus increases the equilibrium harvest quota.

$\overline{F}_{N_l} > 0$**.** We know that, by assumption, $\lambda(N_l) > 0$, $\lambda_{N_l} > 0$, and $H_s > 0$. Thus the nominator of equation (20) is negative.

Moreover, by assumption, $H_{ss} < 0$, $W_H > 0$, and $W_{(1-F)(1-F)}$. Therefore, the denominator is also negative. Thus $\overline{F}_{N_l} > 0$.

$\overline{N}_{N_l} > 0$**.** Note from equation (21), that: $(\frac{2(1-\alpha)\overline{N}}{N_l(1+\lambda(N_l))} + \alpha W_H) > (\frac{(1-\alpha)}{N_l(1+\lambda(N_l))} + \alpha W_H)$. Which implies necessarily that, in equilibrium: $H(\frac{F}{\overline{N}}; e) < \overline{F} H_s$.

This result implies that both the nominator and denominator of equation (22) are negative, which proves that $\overline{N}_{N_l} > 0$.

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