State - Local Community Games of Forest Land Appropriation

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Summary:
This paper explores possible strategic interactions between the state and local community in games of tropical forest land appropriation. Two key questions are addressed. First, how does the structure of the game influence the extent of deforestation? Second, under which circumstances does higher forest appropriation by the state promote local deforestation? Three different cases are discussed, corresponding to a development over time towards increased forest land competition and integration of the local community into the national economy. Particular attention is given to the assumptions made about the local economy and the local costs of state deforestation. The local response to more state appropriation depends critically on these assumptions, and less on the structure of the game (Cournot or Stackelberg). The state will fuel local deforestation if state deforestation is associated with provision of infrastructure (roads) which reduces the local costs of agricultural expansion, or if the local economy is isolated (autarky) and local behaviour is determined by survival needs rather than income maximization.

Indexing terms:
Deforestation
Game theory
Economic models

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Contents

1 Introduction[1]

Several studies of deforestation within the political economy tradition focus on the conflict between the state or state sponsored users and local, traditional users in the utilization of tropical forest resources (e.g., Colchester, 1994; Colchester and Lohmann, 1993; Bromley and Chapagain, 1984). There have, however, been few (none?) attempts on formal modelling of such conflicts and the strategic behaviour they may give rise to.[2] This paper attempts to formalize the interaction between the state and a local community in forest land appropriation by applying relatively simple game theoretic models.

A central issue to be addressed is the effect on local forest clearing of higher forest appropriation by the state. Does state deforestation stimulate or replace local deforestation? Under which circumstances does the state fuel local "land grabbing"? Further we want to explore the impact on the overall level of deforestation (state and local) of different kinds of strategic interaction between the state and the local community (structure of the game).

The models of this paper are complementary to Angelsen (1996b), which studies the effects of external land appropriation on farmers' choices related to tenure security, and Angelsen (1994; 1996a), which study the effects on agricultural land expansion. These models assume parametric interaction. The present paper focuses on *strategic* behaviour and interactions, that is, where the players take into account the effect of their choice on the other player's choice of forest appropriation.

There is a substantial literature which uses game theory to study resource problems. A large share of this literature analyzes resource management issues by using binary choice models, for example, prisoner's dilemma (PD) or assurance games. Baland and Platteau (1996) and Ostrom *et al.* (1994) are among the best examples of the usefulness of such an approach, which -- due to its simplicity and flexibility -- can be used to study a variety of resource games. The Cournot game presented in this paper can be considered a continuous choice version of the conventional (binary choice) PD game. The continuous choice model offers, however, a richer approach as one can study the local response to exogenous changes in situations where one, both before and after the change, has non-cooperation in a PD game.

Another large sub-category of the literature deals with dynamic games, which in addition to the multi-period strategic interaction between economic agents, also incorporates the resource dynamics (differential games). The latter is particularly important in games involving renewable resources with high growth rates, for example, fish (e.g., Levari and Mirman, 1980). In our model, which is a game of land appropriation, this aspect is of much less relevance. Compared to the static games studied in this paper, dynamic games could offer additional insights by studying the

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[1] Thanks to Rögnvaldur Hannesson, Karl O. Moene, Ottar Mæstad, Karl R. Pedersen, Ussif Rashid Sumaila, and Arne Wiig and other colleagues at CMI for comments to a draft version of the paper.

[2] A comprehensive review by Kaimowitz and Angelsen (1997) on economic models of deforestation does not find any such models.

interaction over time. The approach of this paper is, however, to explore the implications of the underlying assumptions in relatively simple games rather than to use simplistic assumptions in more complex, dynamic games. Hopefully, static (Cournot) or simple sequential (Stackelberg) games reveal important structures and incentives of real-life games which, obviously, are dynamic.

A critical assumption for applying game theoretic models of only two players is that the local community and the state can be viewed as single actors. Are there mechanisms, for example, in terms of local resource management institutions, uniform ways of thinking and responding, etc. within the local community which make it appropriate to study the local community as one agent? If not, the situation is better studied as one of open access, that is, games with a very large number of players. As is well known from the literature, the Nash-Cournot equilibrium converges to the competitive market equilibrium when the number of players increases. The latter situation has already been discussed in Angelsen (1994; 1996a). The game models of this paper explore another extreme with only two players. Thus the models of the present and the complementary papers analyze two extreme situations, while we keep in mind that actual behaviour shows great variation between these.

The outline of the paper is as follows. Section two presents the basic elements of the models. Three different cases or games are discussed in the following sections. In section three we focus on a poor, isolated local community. The interaction with the state is studied as a static game with simultaneous moves (Cournot). Section four discusses a situation with higher forest land scarcity and a local-led land race, that is, the local community is the leader in a Stackelberg game. Section five analyzes a case with intense resource scarcity and competition, and a local community integrated into the regional/national economy. The state is assumed to be the Stackelberg leader in this case. Section six compares the different cases, discusses possible developments over time in the local response, and the possibilities for cooperation in forest management. The final section concludes.

2 Preliminaries

We consider a given forest area (H^T) which has three uses: it can be converted to agricultural land by the local community (H^L), to plantations, logging or other large scale projects by the state (H^S), or it can remain virgin/natural/primary/pristine/ old-growth forest (H^F).

(1) $\quad H^T = H^L + H^S + H^F$

We assume that the state and local community each choose the level of H^S and H^L, respectively. New forest land is allocated on a first-come-first-served-basis.[3]

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[3] Forest clearing may give more permanent land rights, as assumed in model IV in Angelsen (1996a). In this case the income and cost variables should be interpreted as discounted values. Tenure insecurity could then be included by reducing the discounted values, a practice known as risk discounting. If local tenure security is inversely related to the level of state appropriation (as in the model of endogenous tenure security in Angelsen, 1996b), this could also be included in the model in a relatively straightforward manner. To keep the

Local income

The income to the local community and the state are functions of land area converted for their own use, as well as the remaining natural forest. The local forest benefits of primary forest would be in the form of non-timber forest products and various protective functions, whereas the state would benefit from it in the form of, for example, eco-tourism and protective functions, as well as more intangible benefits such as existence values and a green image.[4] The net income to the local community is given by;

$$(2) \qquad L = l(H^L, H^S) = r(H^L) + t(H^F) - \int_0^{H^L} c(H^T - H^S - x, H^S)dx$$

$r(H^L)$ is the gross revenue of forest clearing for agricultural production, for simplicity assumed to be a function of land area only (decisions about, for example, labour input are not included). $t(H^F)$ gives the income from primary forest as a function of total forest area. We do not distinguish between gross and net benefits of virgin forest. We assume decreasing returns, for example, because land is of heterogeneous quality (t_1, $r_1 > 0$, t_{11}, $r_{11} < 0$).

The last element in (2) gives the aggregate cost of agricultural production. The properties of the local cost function are critical for some of the later results. $c(H^F,H^S)$ is the marginal costs of land expansion. First, a larger primary forest area will reduce the costs as new land is more easily available ($c_1 < 0$), but this effect is diminishing ($c_{11} > 0$). Second, state forest clearing has a cost reducing effect on the marginal costs of expansion, as it provides infrastructure, particularly roads ($c_2 < 0$), also at a decreasing rate ($c_{22} > 0$). The net effect of increased state appropriation on the costs is therefore ambiguous: $\frac{\partial c}{\partial H^S} = c_2 - c_1 \gtreqless 0$. A land scarcity effect increases the marginal costs, whereas an infrastructure effect reduces the cost of agricultural land expansion. From the assumptions made, the first effect will increase relative to the second as H^S increases: $\frac{\partial c^2}{\partial^2 H^S} = c_{11} + c_{22} > 0$.[5] We then have three possibilities: (1) the expression (c_2 - c_1) is negative for all relevant combinations of H^S and H^L, (2) it is positive for all relevant combinations, and (3) it is negative for low levels of H^S (and H^L) and positive for high levels. Intuitively, the last two possibilities appear to be the most realistic ones.

State income

The state revenue is determined in a similar manner, except that local forest clearing does not have any cost reducing effects through provision of infrastructure. We assume

focus on the main mechanisms of the game we shall, however, abstract from the issue of tenure insecurity, noting that the chosen model formulation can be given alternative interpretations.

[4] Virgin forest is to be considered a public good both in the sense that there is *no rivalry* between local and state uses in consumption of services derived from *a certain virgin forest area,* and *exclusion is impossible.* (The latter requirement is, in fact, redundant as there would be no incentive to exclude others since there is no rivalry and the public good is provided for free.) Note that the non-rivalry assumption relates to the two actors in our model at the aggregate level, and not, for example, between villagers in the utilization of fuelwood from a given forest area. Finally, we note that the *total* forest benefits depend on total virgin forest area; thus there is rivalry in land allocation.

[5] We assume $c_{12} = c_{21} = 0$.

that the state is only concerned with maximizing own income (a predatory state) and not total income (a developmental state). This assumption is discussed further in case 1 and relaxed in Appendix 1.

(3) $S = s(H^S, H^L) = v(H^S) + g(H^F) - \int_0^{H^S} h(H^T - H^L - y)dy$

$v()$ is the gross income from forest appropriation by the state, whereas $g()$ is the state's benefits from primary forest. The benefit functions are strictly concave (g_1, $v_1 > 0$, g_{11}, $v_{11} < 0$). The marginal cost of forest appropriation, $h(H^F)$, is lower the larger the area of virgin forest, but this effect is diminishing ($h_1 < 0$, $h_{11} > 0$).

The formulation in (1) implicitly assumes that state and local land uses are mutually exclusive. This may be a fair assumption for land uses which involves forest clearing and permanent use of the land, for example, permanent agriculture, plantations, hydropower and infrastructure developments. For other uses, particularly logging, this may not be the case. Logging companies are basically interested in the big trees, not the land. Farmers' main interest is in the land (soil) for cultivation. Thus, as observed throughout Asia, shifting cultivators may follow in the wheel tracks and clear logged forest. Related to our model, this could be interpreted as each hectare of state deforestation having a strong infrastructure component; the infrastructure effect will be strong relative to the land scarcity effect ($c_2 - c_1 < 0$).

Three key assumptions

We identify three critical assumptions in the modelling of state local interactions, cf. also Appendix 2: (i) the effect of state deforestation on local expansion cost, (ii) the degree of openness of the local economy, and (iii) the structure of the game. Each of these reflects the empirical variation found in developing countries, and they are briefly examined below.

First, *the effect of state forest appropriation on the marginal costs of local forest clearing*, as discussed above. The strength of the land scarcity effect *v.* the infrastructure effect of higher state forest clearing depends on particularly two factors. In a forest abundant situation the infrastructure effect will be relatively stronger, as included in the assumptions about the cost function. It also depends on the type of forest conversion by the state: logging has a stronger infrastructure component relative to area directly cleared compared to, for example, plantations or commercial agriculture.

Second, *the openness of the local economy.* As shown elsewhere (Angelsen, 1996a), the response of farm households depends critically on the market assumptions. In particular, it is crucial whether an off-farm labour market exists or not, for example, through migration, such that the opportunity costs of labour can be taken as exogenous in the model. In that case the model becomes recursive: the production decisions can be separated from the consumption decisions and studied as a profit maximizing problem. If some prices are *not* market-determined, the production and consumption decisions must be solved simultaneously and the behaviour of the local community is studied as a utility maximizing problem; see Angelsen (1996a) for a further discussion.

The distinction between profit and utility maximizing local behaviour relates particularly to the labour market assumption. This depends, *inter alia,* on the openness of the local economy and the existence of an off-farm sector and its size relative to the agriculture/forestry sector. It also relates to the time horizon for the analysis; the small, open economy assumption is relatively more relevant for long term analysis when migration is an option. In the first two cases we assume a local autarky, i.e., the local community's deforestation decisions are studied as a utility maximizing problem. In the third we use the conventional profit-maximizing approach, which corresponds to the small, open economy assumption.

Third, *the structure of game.* We analyze three types of games. In the first case we assume a static game with simultaneous moves (Cournot). Then we look at sequential, two period games (Stackelberg). In the second case the local community moves first (leader) and the state second (follower). In the third case, we reverse the sequence, and let the state be the leader.

In each game we study the Nash equilibrium, being defined as "a set of strategies, one for each player, such that given the strategies being played by others, no player can improve her pay-off by adopting an alternative strategy" (Heap *et al.,* 1992: 101). The equilibrium in the Cournot game is often referred to as the Nash, Nash-Cournot or Cournot equilibrium; we use the term Cournot equilibrium as all equilibria studied in this paper (including Stackelberg) are Nash equilibria.

The Cournot equilibrium is at times referred to as a zero conjecture or independent adjustment equilibrium; the players do not expect any change in the opponent's decision variable when they change their own decision variable, and the equilibrium is reached after an adjustment process. An alternative, more appropriate and "modern" interpretation of how the equilibrium is reached is the following: when the players move simultaneously, both assume the other to make a rational choice, they have rational expectations about the opponent's choice, and then both select simultaneously the best strategy given that the opponent does the same.

The structure of the game is similar to a standard Cournot game of duopoly (e.g., Shapiro, 1989; Friedman, 1983), and have also similarities to games of public goods provision (e.g., Cornes and Sandler, 1986).[6] A special feature of this paper is a careful specification of the local objective function (preferences and market assumption) and the cost structure, and the analysis shows that conventional conclusions from this literature cannot readily be replicated in state-local resource games.

In a leader-follower or Stackelberg game, the follower observes the leader's choice and chooses the optimal strategy based on that in a similar manner as in the Cournot game.

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[6] Whereas there are some similarities with the standard duopoly games, one should also note some important differences. First, there is no competition in an output market in our model, only in forest appropriation. Second, and related to the first, there is no price as such in the model; thus we only have games of quantity competition. Third (and more relevant to dynamic models), there are no separation between investment and production decisions, as the income is a function of only land investments (forest clearing). Fourth, as will be seen below, the local response curve may be forward bending.

The leader, choosing first, anticipates the response of the follower, and includes the follower's response in his optimization problem.

Three cases

As already indicated, formal modelling of state-local interactions in forest resource use represents a new research area. It is therefore hard to find factual evidence for which games that will apply in different empirical contexts. Even in empirical research it may be difficult to reveal the exact structure of the game and the sequence of the moves. Indeed, this is a general problem in applying game theory: the theory provides few empirically verifiable criteria for which structure of the game that should be assumed in the model. The discussion of the empirical relevance of the different structures of the game therefore becomes somewhat tentative, and clearly calls for further investigations. One argument could be that the Stackelberg games represent situations where one of the players is more aggressive than the other.

By varying the three key assumptions discussed above we get 12 different games, cf. Appendix 2. We have chosen to focus on three cases. The case studies have been selected partly based on their perceived empirical relevance, and partly to review the implications of different assumptions: how robust are the conclusions to variations in the assumptions?

Case 1 deals with a poor, isolated local community, where the interaction with the state is studied as a Cournot game. Case 2 discusses a situation with higher forest land scarcity and a local-led land race, that is, the local community is the leader in a Stackelberg game. Case 3 analyzes a situation with intense resource scarcity and competition, and a local community integrated into the regional/national economy. The state is assumed to be the Stackelberg leader in this case. In some respects, the three cases correspond to a possible development over time in terms of (i) increased resource scarcity, (ii) increased integration of the local community in the regional/national economy, and (iii) more aggressive behaviour by one of the players.

3 Case 1: Poor, isolated local community

In the first case we consider the interaction between state and local deforestation in the context of a poor, isolated local community. This case could describe the situation for many tribal communities. Their livelihood, based on forest income from hunting, gathering and extensive forms of agriculture such as long-fallow shifting cultivation, is being undermined as the area of natural forest declines through state appropriation. Examples of this situation are found in the Amazon and Southeast Asia, e.g., Colchester and Lohmann (1994).

We have identified three key assumptions in state - local games: the type of game, the local economy, and the local cost effects of state deforestation. In the poor, isolated local community case we assume the following for each of these.

Type of game: The most difficult assumption relates to the type of game that should be modelled; it is hard *a priori* to determine the game formulation that most realistically describe the situation. We shall analyze a Cournot game in this case, that is, a static game with complete information, and both players choose their strategy simultaneously.

Local economy: In our case when the local community is isolated, the utility maximizing approach is the relevant one. We make the assumption that all income is derived from agriculture and direct forest uses (no off-farm income).

Local cost structure: Poor, isolated forest communities are normally associated with forest abundance, which suggest that the infrastructure effect will dominate. The technological level among such communities -- most transport is done by foot -- implies, however, that they may not make much use of state provided infrastructure. We shall therefore not make any *a priori* assumptions about which effect dominates.

The state's response curve

The objective of the state is to maximize income as given in (3). The state will then choose the amount of land for plantations, logging, etc. such that the following first order condition is satisfied;[7]

(4) $s_1 = v_1 - g_1 - h(H^F) = 0$

The first element gives the marginal gross income from forest conversion, whereas the last two are the costs in terms of reduced forest benefits (opportunity costs) and the direct costs related to forest clearing.

The optimal amount of land clearing by one agent is a function of the amount appropriated by the other. We define the optimal levels of H^S as a function of the local community's choice, i.e., the *response or reaction function* for the state;

(5) $H^{S*} = H^S(H^L)$

To explore the characteristics of the response function, we differentiate (4) to obtain;

(6) $\frac{dH^{S*}}{dH^L} = -\frac{s_{12}}{s_{11}} = -\frac{g_{11}+h_1}{v_{11}+g_{11}+h_1} < 0$

The response curve of the state of backward sloping in an H^L- H^S diagramme for two reasons. More local forest clearing implies that the remaining forest becomes more valuable, i.e., the net marginal benefits of virgin forest (g_{11}) and the opportunity costs of conversion increase. Further, the marginal costs of forest conversion will be higher as the remaining forest is less suitable or accessible (h_1).

The iso-profit curves for the state are defined by setting $S = \bar{S}$. The shape of the curves is found by total differentiation of (3);

(7) $\frac{dH^L}{dH^S} = -\frac{s_1}{s_2} = -\frac{v_1-g_1-h(.)}{-g_1+\int_0^{H^S} h_1 dy}$

Whereas the response curve shows the *optimal* response to changes in the other player's choice, the iso-profit curves simply show the change necessary to maintain the same

[7] It follows from the assumptions made that $s_{11} < 0$.

income. s_2 is always negative, whereas s_1 is positive for small values of H^S, zero in optimum (cf. (4)), and negative for larger values. Thus the state's iso-profit curves will therefore be inverted C-shaped in an H^L-H^S diagramme.

We have assumed a rather narrow objective function for the state, in the way that only own income is maximized. The implications of including local income in the state's objective function (a developmental state) are examined in Appendix 1. Under realistic assumptions the response curve will still be downward sloping, but the location and slope will change. If the land scarcity effect dominates, for example, the curve will move downwards. Nevertheless, since the qualitative results only depend on the slope of the response curve we do not pursue the case with a more developmental state.

The local response curve

Local behaviour is studied as a problem of balancing the utility of consumption and the disutility of labour. This is known as the Chayanovian model in agricultural economics. The cost related to agricultural expansion and cultivation is expressed in terms of labour; $c(H^F,H^S)$ therefore represents the labour input required for a marginal expansion of agricultural land. Formally, the problem is one of maximizing;

(8) $$U = U\left(r(H^L) + t(H^F), \int_0^{H^L} c(H^T - H^S - x, H^S)dx\right) = u(H^L, H^S)$$

We assume the utility function to be well-behaved, cf. Angelsen (1996a). The optimality condition is given by;

(9) $$u_1 = 0 \Leftrightarrow r_1 - t_1 - zc(H^T - H^S - H^{L*}) = 0;\ z \equiv -\frac{U_2}{U_1}$$

Net marginal income from forest conversion (r_1 - t_1) should in optimum equal the marginal labour requirement for land expansion multiplied by the shadow wage rate (z). z can also be given the interpretation as the virtual price of labour. As discussed in Angelsen (1996a: appendix 1), the use of virtual prices facilitates the comparative statics. The substitution effect is given by keeping z constant, whereas the income effect is determined by the change in z.

(9) implicitly defines the optimal local deforestation (H^{L*}) as a function of H^S, or the response function.

(10) $$H^{L*} = H^L(H^S)$$

The inverse of the slope of the response curve H^L-H^S diagramme is;

(11) $$\frac{dH^{L*}}{dH^S} = -\frac{u_{12}}{u_{11}} = -\frac{t_{11} - z(c_2 - c_1) - c(.)z_{H^S}}{r_{11} + t_{11} + zc_1 - c(.)z_{H^L}} \gtrless 0;\ z_{H^S} \equiv \frac{\partial z}{dH^S}, z_{H^L} \equiv \frac{\partial z}{dH^L}$$

The denominator in (11) is negative, corresponding to the second order conditions for maximum ($u_{11} < 0$). The response of the local community to higher H^S, i.e., the sign of u_{12}, is ambiguous. The analysis of the sign of the numerator in (11) is done in two steps. In the first step, we assume that z is fixed, corresponding to a small open economy approach (only substitution effects apply). There are three effects to consider. *First*, more land appropriated by the state means that the net marginal benefits of virgin forest increases (t_{11}), i.e., the opportunity costs of agricultural conversion increases. *Second,* the marginal costs of land expansion will be higher as the remaining forest is less suitable for agricultural production or is less accessible (c_1). *Third,* state clearing provides infrastructure which has the opposite effect on land expansion (c_2). If the latter effect is sufficiently large, the response may be positive. As shown above, the third (infrastructure) effect will be relatively larger to the second (land scarcity) effect the lower the level of H^S, whereas the impact on the first effect cannot be determined from the assumptions made. However, we can conclude that if the infrastructure effect is sufficiently strong the expression ($t_{11} - z(c_2 - c_1)$) in (10) will be positive.

In the second step, we must also consider the effect of changes in the shadow wage rate (z), which reflects the income effects. We always have $z_{H^L} > 0$ as higher H^L increases income and labour input, both of which augment the shadow wage rate. The effect of higher H^S is more complicated. Assuming additive utility ($U_{12} = U_{21} = 0$), we get;

$$(12) \qquad z_{H^S} = -\frac{U_{22}U_1\int_0^{H^L}(c_2-c_1)dx + U_{11}U_2t_1}{U_1^2} \gtrless 0$$

There are two different effects on z. First, higher H^S affects the total costs as shown by the first element in the numerator. If the land scarcity effect is strong ($c_2 - c_1 > 0$), more state deforestation implies higher labour input and therefore higher z. If the infrastructure effect is strong, however, more state deforestation will reduce z. Second, higher H^S will reduce the income by lowering the primary forest area, which reduces z. In the case where the infrastructure effect is strong, (12) is therefore unambiguously negative.

In the case of small infrastructure effects, (12) may be positive or negative. I have in Angelsen (1996a; 1996c) used and discussed an additive utility function with a subsistence consumption level. This formulation gives, in accord with economic intuition, that the income effect dominates the substitution effect when consumption is close to the subsistence level, or when the preferences are such that marginal utility of consumption above the subsistence level is rapidly declining. This implies that the absolute value of U_{11} will be large and the second element in the numerator dominates. Hence in poor local communities we could expect $z_{H^S} < 0$.

Returning to the numerator of (11), there is now a fourth effect to consider related to the change in z (income effect). A lower z will pull in the direction of more local forest conversion as the (subjective) costs are lowered; a higher z will reduce local deforestation.

In summary, if the infrastructure *or* the income effects (or both) are strong, we get a forward bending local response curve ($u_{12} > 0$). In our case we have assumed the local community to be poor, which implies strong income effects. The qualitative response will in this case be as in a "full belly" model, that is, when the local preferences are such that they minimize labour efforts given a subsistence target.[8]

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[8] An extreme version of the utility maximizing approach is to assume that the local community has lexicographic preferences: the households shall reach a subsistence level of

The local indifference curves are defined by setting $U = \overline{U}$, and the curvature is found by differentiation of (8);

$$(13) \quad \frac{dH^S}{dH^L} = -\frac{u_1}{u_2} = -\frac{r_1 - t_1 - zc(.)}{-t_1 - z\int_0^{H^L} (c_2 - c_1)dx}$$

u_1 goes from being positive to negative as H^L increases, and is zero in optimum. The shape of the indifference curves depends on the sign of u_2, which may be either positive or negative. When the infrastructure effect is small, $u_2 < 0$. The local iso-profit curves are then inverted U-shaped.

Note that the conditions for inverted U-shaped indifference curves are not the same as the condition for a backward bending response curve, although they are related. The latter condition ($u_{12} < 0$) concerns the effect of higher state clearing on the *marginal* utility of local agricultural expansion, whereas the first ($u_2 < 0$) reflects the effect on *total* utility. Moreover, the sign of u_{12} is influenced by the relative strength of the income effect, whereas u_2 is not.

Given our assumptions about the cost function, it is possible for a certain range of values of H^S that $u_{12} < 0$ and $u_2 > 0$. In addition, it may well be that the infrastructure effects are small ($u_2 < 0$) but that the response curve is forward bending due to strong income effects ($u_{12} > 0$). To simplify the presentation, we shall in the following assume a forward bending response curve due to strong income effects and that the indifference curves are inverted U-shaped, i.e., there are small infrastructure effects of state deforestation.

Cournot equilibrium

The Cournot equilibrium is given where the two response curves intersect (A) in Figure 1. This is the only point where the level of forest clearing, for both players, is the best reply to the level chosen by the other. In other words, there is consistency for both players between their own optimal level of forest clearing and the level chosen by the other.

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consumption or income (Q) at minimum labour costs ("full belly" preferences). The optimization problem is very simple in this case: the local community gets a basic income from natural forest, $t(H^F)$, and then clears as much forest as required to reach the subsistence target, given by $r(H^L) + t(H^F) = Q$. This also defines the response curve of the local community. Differentiation yields the inverse of the slope of the response curve; $dH^{L*}/dH^S = t_1 / (r_1 - t_1) > 0$, i.e., the response curve is forward sloping. More state deforestation reduces the local forest income, and this has to be compensated for by expanding agricultural land area. The slope depends on the marginal income from the two types of land use. If the marginal benefits from non-timber forest products are small relative to the benefits from agricultural land, state forest clearing only has modest effect on local agricultural expansion.

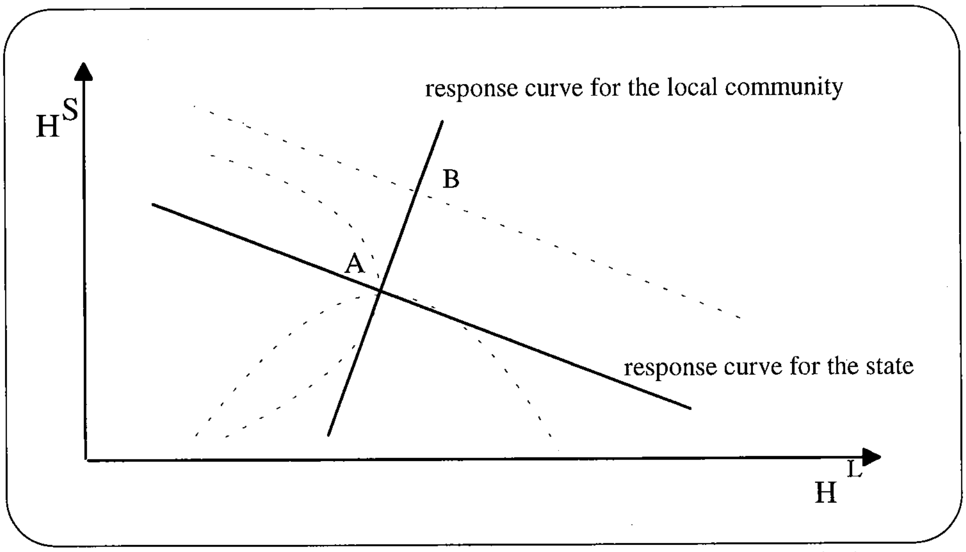

Figure 1: The response curves for the local community and the state in the poor, isolated community case.

The condition for stability of the system is;[9]

(14) $\quad u_{11}s_{11} - u_{12}s_{12} > 0$

As seen from (11) and (6), we have u_{11}, s_{11}, $s_{12} < 0$; $u_{11} < u_{12}$; $s_{11} < s_{12}$. It then follows that the necessary condition for a stable equilibrium is met. Graphically, this implies that the local response curve, when moving south, must intersect with the state's response curve from above.

Consider an exogenous shift in the state's response curve, represented by the dotted line in the figure. For any given value of H^L the state wants to appropriate more land than before. This could be due to, for example, higher prices of plantation products, technological progress, or less value attached to virgin forest. The local response will be more forest clearing, and the new equilibrium is in point *B*.

State deforestation fuels local deforestation in this case. The main mechanism is that state appropriation of forest reduces local forest income, which must be compensated for by expanding the local agricultural area. If state deforestation in addition provides infrastructure such that the cost of agricultural expansion is reduced, this gives an additional argument for local land expansion.

An illustration of the empirical relevance of this case is given in a review of local studies on poverty and tropical forest degradation by Kates and Haarmann (1992). They identify two major sources of displacement of indigenous hunter-gatherers or poor farmers; one is by (state-sponsored) commercial activities, the other by spontaneous immigrants or government planned resettlement programmes. This leads to degradation of forest resources on which the traditional users depend, and forces them to expand their activities into new forest areas.

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[9] See, for example, Shapiro (1989: 386)

4 Case 2: Increased forest land competition; local-led land race

When forest land scarcity and competition increases, one possibility is that we move from a Cournot game to a Stackelberg game with the local community as the leader and the state as the follower. This game would then describe a race for primary forest where the local community is the "aggressive" player, and clear forest in order to squeeze the state. As discussed towards the end of this section, this game could describe an important aspect of the process of deforestation in many locations in Indonesia and Latin America.

Why is it fair to assume the local community to be a Stackelberg leader? Besides the need to test the implications of different game assumptions, there are some reasons that make the case with the local community as the leader a relevant one to study. One could argue that the local community has greater flexibility than the state in adjusting its forest clearing, for example, because the state's decisions must move through a bureaucracy, and often require heavy capital investments. Further, the local community may know the decision procedures of the state, and therefore be able to predict the state's actions.

We make no *a priori* assumptions about the local economy, and discuss the autarky (utility maximizing) case which could be considered the most general one as both income and substitution effects are present. We further assume in this game that the land scarcity effect of state deforestation is large compared to the infrastructure effects. This is related to the type of game studied; the Stackelberg game with a local leader appears to be most reasonable in a situation where state deforestation is costly to the local community (cf. Appendix 2).

Local behaviour and the Stackelberg equilibrium

The problem for the local community as a leader is to maximize utility as given in (8), subject to the response function for the state as given in (5). The state will as a follower be on its response curve. The optimal level of forest clearing by the local community is such that the following condition is met;

$$(15) \qquad u_1 + u_2 \frac{dH^{S*}}{dH^L} = r_1 - t_1 - zc(.) + \frac{dH^{S*}}{dH^L}\left[-t_1 - z\int_0^{H^L}(c_2 - c_1)dx\right] = 0$$

The first part of the expression (u_1) is similar to the Cournot case, cf. (9). In addition, the local community takes into account the state's response on local forest clearing, $\frac{dH^{S*}}{dH^L} < 0$. In the case where state deforestation is costly to the local community (the land scarcity effect dominates), $u_2 < 0$ and the indifference curves are inverted U-shaped in the H^L-H^S diagramme, cf. (13). Compared to a Cournot game we have added a negative element in the optimality condition. Local forest clearing has become *less costly* on the margin because local deforestation reduces state deforestation, which both increase the forest income (t_1) and reduces the costs of agricultural expansion.

The Stackelberg equilibrium is presented in Figure 2. The local community's preference direction is south, and the equilibrium is given in point *B* where the local indifference curve tangents the state's response curve.

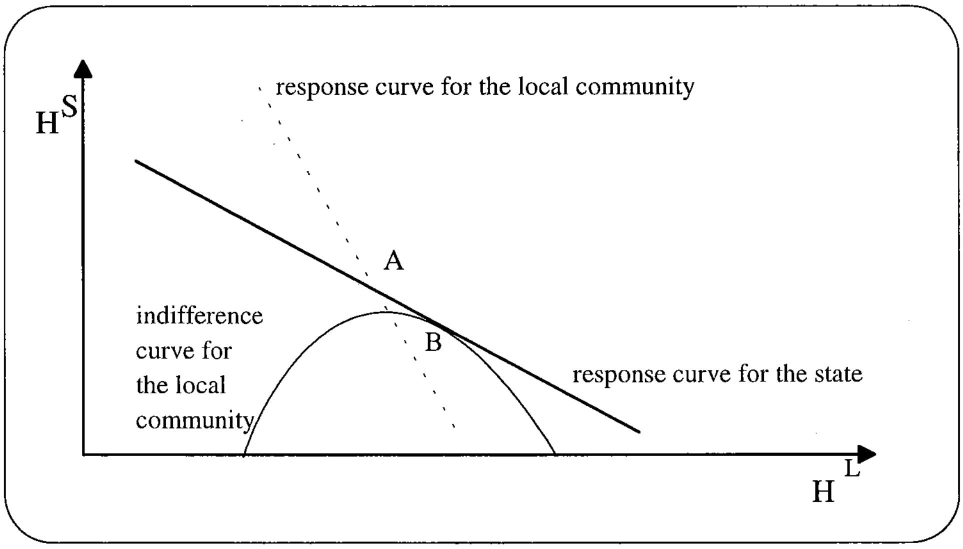

Figure 2: Local community as the leader in a Stackelberg game.

Compared to a Cournot equilibrium (A), the local community will clear more and the state less forest. The local community is aware of its strategic position as the leader, and uses it to "squeeze the state" from converting as much forest as the state would have done in a Cournot game.

A Stackelberg game with the local community as the leader gives more overall deforestation compared to a Cournot game as the absolute value of the slope of the state's response curve is less than one. The local community will receive a higher utility, whereas the state's profit will be lower in *B* compared to *A*. Note that the above results do not depend on the slope of the local response curve; hence the conclusions so far are valid both in situations where either income or substitution effects dominate.

Local response to higher state deforestation

The effect of an exogenous upward shift in the state's response function is found by differentiation of (15);

$$(16)\qquad \frac{dH^{L*}}{dH^S} = -\frac{u_{12}+\frac{dH^{S*}}{dH^L}u_{22}+\frac{\partial(dH^{S*}/dH^L)}{\partial H^S}u_2}{u_{11}+\frac{dH^{S*}}{dH^L}u_{21}+\frac{\partial(dH^{S*}/dH^L)}{\partial H^L}u_2}$$

$$= -\frac{t_{11}-z(c_2-c_1)-c(.)z_{H^S}+\frac{dH^{S*}}{dH^L}\left(t_{11}-z\int_0^{H^L}(c_{22}+c_{11})dx-z_{H^S}\int_0^{H^L}(c_2-c_1)dx\right)+\frac{\partial(dH^{S*}/dH^L)}{\partial H^S}\left(-t_1-z\int_0^{H^L}(c_2-c_1)dx\right)}{r_{11}+t_{11}+zc_1-c(.)x_{H^L}+\frac{dH^{S*}}{dH^L}\left(t_{11}-z(c_2-c_1)-z_{H^L}\int_0^{H^L}(c_2-c_1)dx\right)+\frac{\partial(dH^{S*}/dH^L)}{\partial H^L}\left(-t_1-z\int_0^{H^L}(c_2-c_1)dx\right)}$$

We assume the denominator to be negative (second order conditions for maximum). The numerator consists of three terms. The first term, which gives the Cournot response (u_{12}) can be either negative or positive. We showed in the analysis of case 1 that if both the infrastructure and the income effects are small, this effect is negative. We are now considering the case when the infrastructure effect is small, hence the sign depends on the strength of the income effect relative to the substitution effect.

The second term relates to the change in the local costs (benefits) of higher (lower) state clearing. Consider first the case when z is determined exogenously (small, open economy). For a given slope of the state's response curve, more state clearing implies that on the margin, state clearing is more costly to the local community. However, as higher local forest clearing reduces state clearing, this effect will push in the direction of higher local deforestation. The gain from squeezing the state is higher.

Then we must take into account that z will change in an autarky. As argued earlier, if the income effect is weak, then $z_{H^S} > 0$, and the second effect in (16) is unambiguously positive ($u_{22} < 0$). If, on the other hand, the income effect is sufficiently strong, the sign will change.

The third term relates to the changes in the slope of the state's response curve. From the assumptions made$\partial(dH^{S*}/dH^{L})/\partial H^{S}$: determine the sign of this effect.
denotes the change in the slope of the response curve as one moves north. If this is negative, i.e., the response curve becomes steeper, the "state squeeze per hectare local forest clearing" is higher, hence the third effect is positive and this contributes to higher H^L following an increase in H^S.

Thus, we cannot in general determine the sign of (16). Intuitively, one could expect the first and most direct effect to dominate over the second and third. This will be the case if the slope of the state's response curve is close to zero (second effect small), and the slope of the state's response curves in the relevant region is relatively constant (third effect small).

In the case with *small income effects* the first effect is negative, the second positive, whereas the third is ambiguous. If we maintain that the first effect dominates the second and third, we conclude that higher state deforestation gives *less* local deforestation.

In the case when the *income effects are dominating*, e.g., the consumption is close to the subsistence level, the picture is reversed. In this case the first effect is positive and the second is negative. Now we could expect that higher state forest clearing also gives *more* local deforestation, as in case 1.

Empirical relevance

Two major conclusions emerge from the analysis of this case. First, compared to a Cournot game there will be more local and less state deforestation, and more overall deforestation. The local community gains and the state loses compared to a Cournot game. These results do not depend on the relative strength of the income and substitution effects.

Second, the local response to an exogenous increase in state deforestation is similar to case 1. If there are strong income effects, the result is more deforestation. More state deforestation reduces forest income, and the need to meet a subsistence target dominates in local decisions, thus agricultural land expansion will increase. If the income effects are small, or we are in the open economy case where only substitution effects apply, then more state deforestation implies less local deforestation, as local land expansion has become more costly.

The local community uses its position as the leader to squeeze the state, as expressed by the difference between point B and A in Figure 2. Such a local-led land race that results from a change in the local strategy (from Cournot to Stackelberg leader) has been observed empirically. The development since the mid-1980s in the Seberida district in Sumatra could be interpreted as such a shift (Angelsen, 1995). The local community is not just passively adopting to forest appropriation by the state, but they play strategically in the way that they clear forest that otherwise could have been appropriated by the state. Similar land races have frequently been observed at the forest frontier in Latin America (see Kaimowitz (1995) for a review of Central America).

Note that there are several different "strategic" effects involved in land races. First, there may be speculative motives in the way that forest is cleared for later sale to get capital gains ("rational bubbles"). Second, when forest clearing gives farmers land rights, there are incentives to clear forest beyond the point where the current land rent is zero, cf. model IV in Angelsen (1996a). Third, and the effect studied in this paper, local deforestation might be expanded to squeeze other actors.

It may be difficult in empirical research to isolate the different effects. The present paper should therefore be seen as complementary to other explanations of how a race for forest land can be initiated and maintained.

5 Case 3: Fierce land competition; the state as the leader

As a third case we discuss a situation where the competition for forest land is strong, and the local economy is well integrated into the regional/national strong economy. Compared to the two previous cases, one could think of this case to describe the situation at a later stage in the economic development of a region or a country. This game could therefore be used to illustrate the interaction between the state and local communities in central parts of, for example, Indonesia, the Philippines and Thailand, where there is relatively little forest left and farmers are well integrated into markets.

Related to our main assumptions, this situation implies that the land scarcity effect dominates the infrastructure effect in the local costs function, and that we can assume a perfect labour market and study the local adaptation as a profit maximizing problem.

We assume that the game played is a Stackelberg game with the state as the leader. The following story could provide an argument for this to be a reasonable assumption. The three cases presented may represent a historical development. Assume that the state as a response to the game in case 2 wants to be the leader, which means we enter a period of Stackelberg warfare, as discussed in more details in Appendix 3. There will be excessive forest clearing when the warfare is going on.[10] Both actors would gain by moving back to their response curves, but it would be even better if the other player gives in. The Stackelberg warfare could therefore be studied as a chicken game. The state may have higher credibility in claiming to be the leader, for example, in the form of irreversible commitments to a certain level of forest clearing. Hence we may eventually end up in a Stackelberg game with the state as the leader.

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[10] As will be seen, the conclusion that the state will clear more as a leader compared to the Cournot equilibrium assumes that the local response curve is backward bending.

Local behaviour

The behaviour of the local community is under the open economy assumption studied as an income maximization problem, with the local income given in (2). This gives the following optimality condition;

(17) $l_1 = r_1 - t_1 - c(H^F, H^S) = 0$

The inverse of the slope of the response curve is given by;

(18) $\frac{dH^{L*}}{dH^S} = -\frac{l_{12}}{l_{11}} = -\frac{t_{11}+c_1-c_2}{r_{11}+t_{11}+c_1} < 0$

The local response curve is backward bending as we have assumed that land scarcity effect dominates infrastructure effect ($l_{12} < 0$).

State behaviour and the Stackelberg equilibrium

The objective of the state is to choose its level of H^S such that the revenue given in (3) is maximized, taking into account the response of the local community as given in (18);

(19) $Max\ S = s(H^S, H^L(H^S))$

The revenue is maximized when;

(20) $s_1 + s_2 \frac{dH^{L*}}{dH^S} = v_1 - g_1 - h(H^F) + \frac{dH^{L*}}{dH^S}\left[-g_1 + \int_0^{H^S} h_1 dy\right] = 0$

This is a modified version of the optimality condition in the Cournot game, cf. (4). The state now takes into account the effect on local clearance when deciding its own level of deforestation, given by $\frac{dH^{L*}}{dH^S} < 0$. One hectare reduced local deforestation always increase the net benefits to the state ($s_2 < 0$).

Figure 3 illustrates this case. The Stackelberg equilibrium will be where the (highest possible) iso-profit curve is tangent to the response curve of the local community, that is, in point *B*. Compared to the Cournot solution (A), the present game gives *more* forest clearing by the state and *less* by the local community. The intuition behind these results is straightforward, and parallel to case 2. Forest conversion by the state is less costly to the state because it knows that local deforestation is reduced when its own increases. The state uses its strategic position to squeeze the local community. The distance between *A* and *B* (measured on the x-axis) gives the optimal "squeeze" of local forest appropriation. As the absolute value of the slope of the local response curve is greater than one, the Stackelberg solution also implies higher *total* forest clearing and reduced H^F.

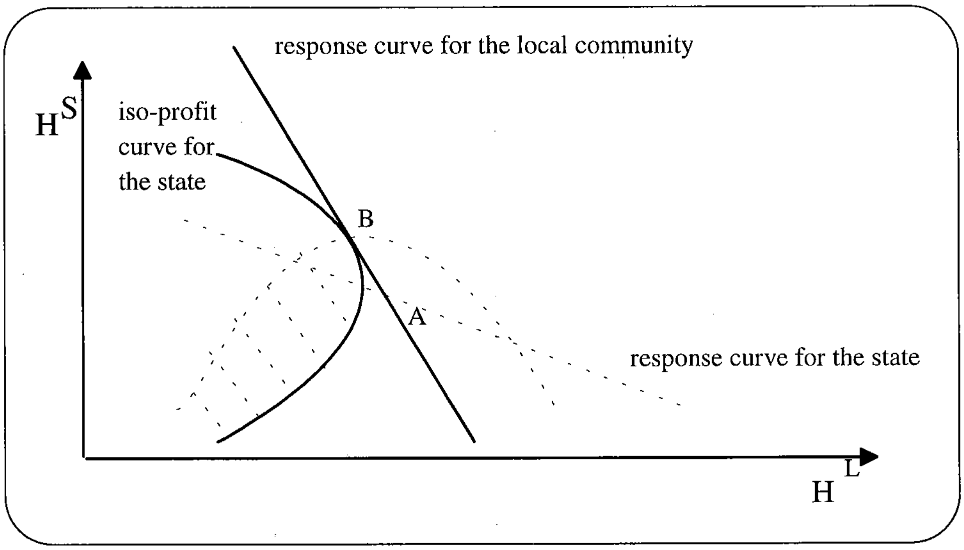

Figure 3. State as the leader in a Stackelberg game: backward bending local response curve.

We also note that the income to the state is higher compared to a Cournot equilibrium, whereas it is lower for the local community. As is generally known from the oligopoly and game theoretic literature, there is a first-mover advantage in games where quantities are the decision variables: the leader could have chosen the Cournot quantity if it were to yield higher income. The last-mover disadvantage is seen both by studying the iso-profit curves, and from the fact that both H^L and H^F are smaller in the Stackelberg model.

A positive exogenous shift in the revenue function of the state (iso-profit curves shift upwards) will obviously make the local community reduce its forest clearing. Total deforestation will, however, increase as the slope of the local response curve is greater than minus one, i.e., the reduction in local deforestation is less than the increase in state deforestation.

It is common that national governments view forest clearing by local farmers as the real problem of deforestation, sometimes referred to as "unplanned" deforestation, whereas "planned" deforestation by the state is desirable. This view is reflected in the assumptions underlying the state's objective function. Given this view, the model provides an explanation of the commonly observed "aggressive" behaviour of the state in forest conversion. By being the leader the state not only increases its own forest clearing and income, but it will also reduce what is considered the real environmental problem -- local deforestation.

6 Discussion

We have studies three different empirically relevant cases of state-local games, corresponding to different assumptions about the local economy, the local cost effects of state deforestation, and the structure of the game. The number of *possible* games by combining these assumptions is much larger, and Appendix 2 gives an overview of 12 possible games.

In the first case of a poor, isolated local community, the response of the local community was determined by the survival needs. Higher state deforestation entails a loss in forest derived income, which must be compensated for by converting more forest into agricultural land; hence local deforestation will increase.

The second case was used to illustrate a local-led land race. The local community uses its position as the leader in a Stackelberg game to squeeze the state. State deforestation is costly to the local community, and the community knows that by increasing own deforestation, state deforestation will be reduced. This provides an incentive for higher local deforestation compared with a Cournot equilibrium, and overall deforestation will also be higher. The response to an exogenous increase in state deforestation is ambiguous in this case. If the income effect is strong relative to the substitution effect, local deforestation will also increase. On the other hand, if the substitution effect dominates in an autarky, or the households are unconstrained in the labour market (small, open economy), then local deforestation will be reduced.

In the third case, the state is the leader in a Stackelberg game, there is strong competition for land (land scarcity effect dominates), and the local community is well integrated into the regional/national economy (small, open economy). In this situation the *state* will use its leader-position to squeeze the local community. The local level of deforestation is determined by the relative profitability of forest conversion and agriculture compared to off-farm employment opportunities, and not by survival needs. The local response to more state deforestation is then reduced deforestation.

Combining the analysis of the three cases with the overview of Appendix 2, we are now able to make some general conclusions regarding the two main questions raised in this paper: which game structures promote deforestation, and what is the local response to higher deforestation by the state.

Which games promote deforestation?

In the small, open economy situation with small infrastructure effects (backward bending local response curve), a Stackelberg game with either the state or the local community as leader gives more overall deforestation than a Cournot game. The leader will use its position to squeeze the follower. Since the "squeezing effort" by the leader is larger than the "squeeze" of the follower, the result is more deforestation than in a Cournot equilibrium. This was the situation both in case 3 where the state was the leader, and in case 2 where the local community was the leader.

One might think that a leader would take some responsibility for environmental conservation and the provision of the public good, and that the Stackelberg games therefore reduce overall deforestation, cf. the discussion in Baland and Platteau (1996, chap. 5). This is not the case here. Each player knows that increased own forest clearing will reduce the clearing by the other player, thus forest clearing is less costly for the leader.

How robust is this result, or, in other words, will Stackelberg games always lead to more deforestation? Consider first games where the state is the leader. When the local response curve is backward bending, either due to strong infrastructure effect or strong income effects, more state deforestation will *increase* local deforestation. Forest appropriation has become *more* costly to the state when they take into account the local response. This provides an incentive for the state to reduce own deforestation, and the result is less overall deforestation. The critical factor in determining whether a Stackelberg game with the state as the leader will lead to more or less deforestation is therefore the slope of the local response curve.

In situations where the local community is the leader, we found in case 2 that irrespective of whether income or substitution effects dominate, the Stackelberg equilibrium yields more deforestation than the Cournot equilibrium. This assumes that the land scarcity effect dominates the infrastructure effect in the local cost function. If the infrastructure effect dominates, however, the conclusion is reversed. This situation yields an intuitively rather strange (though logically correct) result: the local community will reduce its own clearing to promote state clearing, which is beneficial to them, cf. Appendix 2. The empirical relevance of this result is unclear.

In conclusion, even though we found in cases 2 and 3 that the Stackelberg equilibria give more deforestation than the Cournot equilibrium, this conclusion in sensitive to the other assumptions. In particular, in situations when the local response curve is forward bending, a income maximizing and rational state should as a leader reduce its level of forest clearing (compared to the Cournot equilibrium) as state deforestation stimulates local deforestation with a loss of forest derived benefits to the state.

When does state deforestation fuel local deforestation?

The second main question is in which situations increased forest appropriation by the state will stimulate local forest clearing. The answer is quite simple: if the local response curve is backward bending, more state deforestation reduces local deforestation. In other words, when (i) the infrastructure effect is small, and (ii) the income effect is small in an autarky, or in small open economy, higher state deforestation will to some extent replace local deforestation. The result holds in all three game structures.

If either the infrastructure effect or the income effect in an autarky (or both) are strong, the result is reversed. State deforestation fuels local deforestation in any of the three games. The case with strong infrastructure effect has received some attention in the literature on tropical deforestation. It is generally argued that plantations, logging and other large-scale projects provide infrastructure, particularly roads, which gives farmers easier access to primary forest. In this way state appropriation may *increase* the net marginal benefits of agricultural expansion and thereby deforestation by the local community. This phenomenon is sometimes referred to as the "logging-shifting cultivation tandem", common in many Asian countries (Grainger, 1993).

The other possibility for a state stimulated local deforestation is when the need to survival determined the local response (strong income effects), which was discussed in relation to case 1.

The local level of deforestation is also affected by the game played, as discussed above. Moving from Cournot to a game with the local community as the Stackelberg leader will increase local deforestation if the infrastructure effect is weak. Local deforestation will decrease if the infrastructure effect is strong, although this is considered an odd case. Moving from a Cournot game to a Stackelberg game with the state as the leader will always imply less local deforestation, irrespective of the slope of the local response curve. Thus by playing the role as a leader the state will always induce less local forest appropriation. Note, however, that the state's strategy for achieving this will vary with the slope of the local response curve.

If both players want to be a leader, we get a situation with Stackelberg warfare which might, for some period of time, lead to excessive forest clearing, even though this is not a stable (Nash) equilibrium. This situation is discussed further in Appendix 3.

From the table in Appendix 2 and the above discussion we can conclude that the qualitative answer to the question about the local response to higher state deforestation is robust with respect to the type of game played, whereas it is sensitive to the local cost structure and market assumptions. The other question raised relates to whether a Stackelberg game will result in more deforestation than a Cournot game. In addition to the assumptions about local expansion costs and markets, the structure of the game also matter. Moreover, in the very relevant case when land scarcity and income effects dominate (as in case 2), the answer not only depends on whether we have a Cournot or Stackelberg game, but also who is the leader in the game.

A forward-then-backward bending local response curve

One could argue that a forward bending local response curve can describe a forest abundant situation: there is plenty of forest land for expansion, hence there is no strong spatial competition (land scarcity effects small). The main constraint on agricultural expansion is accessibility, and state conversion is commonly linked with the provision of infrastructure which reduces access costs. Furthermore, a large area of virgin forest means that the reduction in benefits from that forest is relatively small (the absolute value of t_{11} is small, cf. (11)).

A plausible hypothesis is therefore that for *large* values of H^F (low values of H^L and H^S) the slope of the response curve of the local community will be positive. For *small* values of H^F, on the other hand, the competition for remaining land is more intense and a further reduction in virgin forest has strong negative impacts, thus the slope will be negative. Such a possible path is reflected in the assumptions made about $c(H^F,H^S)$, cf. the discussion in relation to (2).

This hypothesis of a forward-then-backward bending response curve of the local community is illustrated in Figure 4. Consider a Cournot game. The response of the local community of a shift in the state's response curve now depends on the initial situation. In case *A*, where state appropriation is small, the local community will respond by increasing its appropriation of virgin forest. In case *B*, the response will be the opposite.

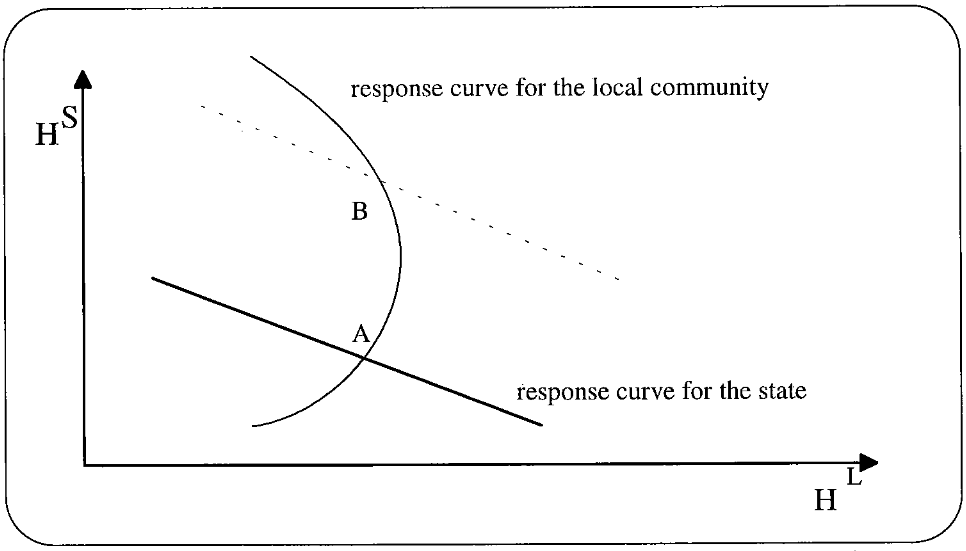

Figure 4: The case with a forward-then-backward bending response curve for the local community.

The hypothesis of a forward-then-backward bending response curve suggests that in forest abundant situations increased state appropriation will stimulate forest clearance by the local community, whereas it will discourage it in a setting with little forest left to expand on. Historically, most countries show a downward trend in the forest cover (the forest transformation hypothesis). Related to the hypothesis of Figure 4, one could argue that at the early stages of this transition, state clearing works in tandem with local clearing, whereas they compete at later stages.

A backward-then-forward bending local response curve

If we instead of looking at the infrastructure effect focus on how the strength of the income effect affects the shape of the local response curve, we may get the opposite story to the one just told. Consider a situation when the infrastructure effect is small (and not dominating at any level of H^S), with little forest appropriation by the state initially and a relatively high local income level. The response of the local community of increased state forest appropriation will be to reduce its own deforestation, cf. the discussion of case 2 and Angelsen (1996a: Model II). As the forest appropriation by the state increases, local income is squeezed, and approaches the subsistence level. Beyond a certain point it is possible that the response to a further increase in state forest appropriation will be dominated by the need to meet the subsistence requirement, thus the response curve becomes forward bending. In this way we could argue for a backward-then-forward sloping response curve, or the mirror image of the one presented in Figure 4.

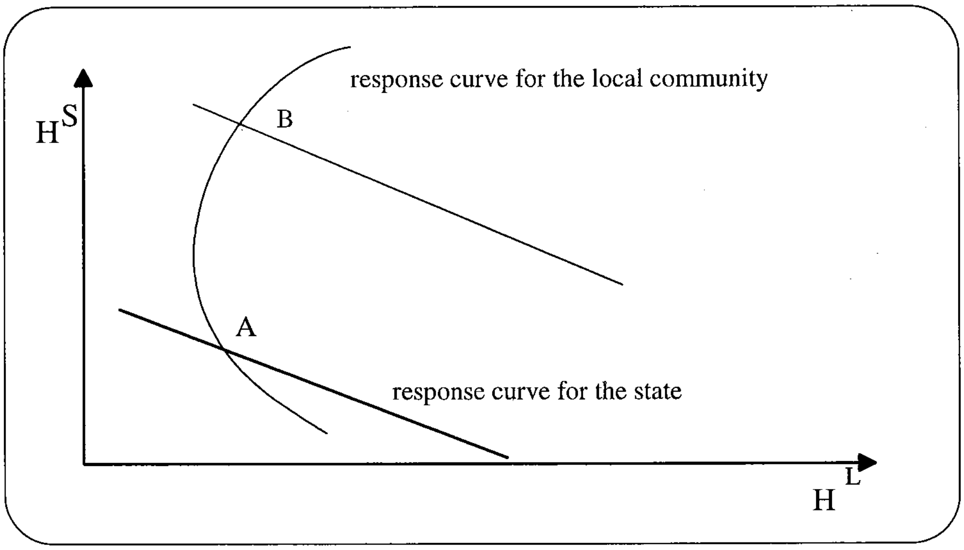

Figure 5. A backward-then-forward bending local response curve.

The C-shaped local response curve suggests the opposite development compared with the one discussed in relation to Figure 4. When state appropriation is relatively low, state deforestation to some extent replaces local deforestation (A). As the state increases its forest appropriation, it will promote local deforestation (B). Combining the arguments underlying the forward-then-backward and the backward-then-forward bending hypotheses could yield that either of the hypothesis will dominate, or an S-shaped or an inverted S-shaped local response curve. The exact shape is, of course, an empirical question. One lesson is that there are several different effects of higher state appropriation to consider, and therefore a number of possible shapes of the response curve.

Cooperation on forest management

The models of this paper can be utilized to illustrate the potential and problems of cooperation in forest management and conservation. Consider case 3. The shaded eye-shaped area in Figure 3 gives the set of combinations of H^L and H^S where both actors have at least as high income as in point *B*, i.e., the area for Pareto improvements. The well-known problem is that even if both parties would gain from being inside the shaded area compared to *B*, both would also have an incentive to defect an agreement. Related to the binary choice game literature, the choice between *B* and any point within the shaded area could be considered a prisoner's dilemma game.[11]

The issues of community participation, co-management or state-local partnership in forest conservation can be viewed as attempts to establish a cooperative solution within the shaded area. Both agents reduce their conversion of forest to contribute to the preservation of the collective good -- primary forest. We shall not pursue the discussion about the design of such contracts, just note that the contract curve will be the line where the iso-profit curves of the two agents tangent each other. Chopra *et al.* (1990,

[11] This binary choice game literature normally considers games with simultaneous moves (Cournot), and not sequential moves (Stackelberg) as here. The problem of making self-enforceable agreement is, however, similar in both the Cournot and Stackelberg games of this paper.

chap. 6) provide a discussion of state-local contracts in forest management through the application of a bargaining model.

The games can also be used to explain why there are limited incentives for each party in unilateral actions for forest conservation. Reduced state appropriation will result in more local conversion in case 3, or more generally in games with small infrastructure and income effects. Particularly, if the slope of the response curve for the local community is close to minus one, a reduction in forest conversion of one hectare by the state will be offset by an almost equal increase in local deforestation. From (11) we see that this will be the case if c_2 and r_{11} are close to zero. The first implies that the cost reducing effect of infrastructure provision is small; the second that the gross marginal benefits of forest conversion are relatively constant, which will be the case when the products are sold in a large market, and there are few constraints on the labour input, for example, through migration. In this situation, the conservation effect of unilateral actions by the state will be negligible.

As a corollary to the above result, we also get that unilateral conservation efforts by the state will be particularly effective in the cases where state appropriation fuels local deforestation, as the local forest conversion will be reduced if the state decides to reduce its own. Unilateral conservation efforts by the local community will always be met by increased deforestation by the state.

Case 2 is similar to case 3 with respect to the possibilities for co-management of forests, with the role of the state and the local community reversed, whereas case 1 yields some new and interesting results. With a forward bending local response curve, it may well be that the local community would prefer the Stackelberg equilibrium with the state as the leader to the Cournot equilibrium, cf. Appendix 3. In fact, if we limit the discussion to the case when the land scarcity effect dominates the infrastructure effect, we always get that the local community would prefer to be the follower in a Stackelberg game compared to a Cournot game. Whereas this is a rather unusual result in a Stackelberg game with quantities as the decision variable, the logic is straightforward. With a forward bending local response curve, the state will as a Stackelberg leader reduce its deforestation compared to the Cournot equilibrium. This will benefit the local community. Furthermore, as shown in Appendix 3, the local community *may* even prefer the state to be the leader to being a leader itself in a Stackelberg game.

Whereas our modelling framework does not provide any theory for which game that will be played, one could intuitively expect a Cournot game with small infrastructure and strong income effects to be an unstable one; both the local community and the state would prefer a Stackelberg game with the state as the leader. This is, however, a premature conclusion. As further discussed in Appendix 3, there is no strictly dominant strategy for the state nor the local community in a game of leader selection.

7 Summary and concluding remarks

This paper has explored some possible strategic interactions between the state and a local community in games of appropriation of forest land. Particular attention has been given to the assumptions made about the local costs of land expansion and the degree of market integration. We found that Stackelberg games with either the local community or the state as the leader give more deforestation than Cournot games. The leader uses its position to squeeze the other actor, and the net result is more deforestation. In this way the kind of strategic behaviour that arise in Stackelberg games is bad from a forest conservation viewpoint. This is a robust result irrespective of the assumptions made about the strength of land scarcity *v.* the infrastructure effects, and the income *v.* substitution effects.

The second main question raised in this paper was under which circumstances higher forest appropriation by the state also will promote local deforestation. Contrary to the conclusions on the first question, the answer is now highly sensitive to the assumptions about the costs of local expansion and the local economy. If the infrastructure and/or the income effects are strong, i.e., the local response curve is forward bending, the state will stimulate local deforestation. If none of these effects dominate, we get conclusions similar to a more conventional duopoly game: higher state appropriation will squeeze the local community. These results are robust with respect to the assumptions made about the structure of the game (Cournot or either of the Stackelberg games). In some respects, this should be viewed as good news since the assumptions about the structure of the game may be the most difficult to test empirically.

Appendix 1: The developmental state

We have assumed throughout the paper that the state maximizes own income, thus disregarding the effect of state deforestation on local income or welfare. A more general formulation of the state's objective function is that the state gives a certain weight (γ) to local income relative to state income (we assume the small, open economy situation);

(21) $\quad Max\ W = S + \gamma L; \quad \gamma \geq 0$

The case with $\gamma = 0$ can be defined as the predatory state, as assumed in the models. The developmental state could be defined as $\gamma \geq 1$, cf. the discussion in Angelsen (1996b: chap. 3.3). What are the implications of introducing a more development oriented state in the models? The first order condition of the state's optimization problem is now;

(22) $\quad s_1 + \gamma l_2 = 0$

Assuming $\gamma > 0$ and $l_2 < 0$ (land scarcity effect dominates infrastructure effect) and given that $s_{11} < 0$, it follows that the "new" response curve for the state lies below the "old" one in the H^L-H^S diagramme, and the distance between the "old" and "new" one is larger the larger γ is. Thus in the case with small infrastructure effects (backward bending local response curve), introducing a more development oriented state results in less state and more local forest clearing.

In the case where infrastructure effects are strong ($l_2 > 0$), the state's "new" response curve will lie above the "old" one. With a forward bending local response curve, the effect will be both more state and local forest clearing. The slope of the state's response curve is now given by;

(23) $\quad \frac{dH^{S*}}{dH^L} = -\frac{s_{12}+\gamma l_{21}}{s_{11}+\gamma l_{22}}$

$l_{22} < 0$, whereas $l_{21} = l_{12}$ can be either positive or negative as discussed above. However, it can be shown that $l_{21} > l_{22}$. We cannot *a priori* exclude the possibility that the state's response curve is forward sloping, when $l_{21} > 0$ and γ is large, although this intuitively appears to be an odd case.

Note that since the state cannot control local deforestation, the welfare optimum cannot be reached even if we set $\gamma = 1$. Thus even with a developmental state we are dealing with second best solutions.

The introduction of a broader state objective does not fundamentally change the game, although it will affect the location and slope of the state's response curve. The introduction of a more developmental state could be discussed as a downward shift in the state's response curve in the case where the infrastructure effect is small, and an upward shift when this effect dominates the land scarcity effect.

Appendix 2: Summary of possible games

By varying the three key assumptions focused on in section 2, we may distinguish between 12 different games. The conclusions in the games on the two main issues raised are summarized in the table below.

Cost structure and market assumptions for the local community		**Type of game**		
		1. Simultaneous moves (Cournot)	*Sequential moves (Stackelberg)*	
			2. Local community as the leader	*3. State as the leader*
A. Income max. (small, open economy), or utility max. (autarky) when substitution effects dominate income effects	*i. Land scarcity effect dominates*	I: n.a. II: decrease	I: higher II: decrease **(Case 2)**	I: higher II: decrease **(Case 3)**
	ii. Infrastructure effect dominates	I: n.a. II: increase	I: lower II: increase	I: lower II: increase
B. Local utility maximization (autarky) when income effects dominate substitution effects	*i. Land scarcity effect dominates*	I: n.a. II: increase **(Case 1)**	I: higher (same[1]) II: increase **(Case 2)**	I: lower II: increase
	ii. Infrastructure effect dominates	I: n.a. II: increase **(Case 1)**	I: lower (same[1]) II: increase	I: lower II: increase

[1] The level of deforestation will be the same in the full belly case.

Table 1: The main results of different local community-state games.
***I:** Total level of deforestation in the Stackelberg games compared to the Cournot equilibrium.*
***II:** Effect on local deforestation of higher forest clearing by the state.*

Regarding the market assumptions, the crucial difference in the qualitative results is between (i) the small open economy and the autarky when substitution effects dominate, and (ii) the autarky when income effects dominate or the "full belly" case.

Of the 12 possible games, some have been studied in some details as cases 1-3. Two important subsets have not, however, been discussed. One is the conventional Cournot duopoly game, that is, when the infrastructure and income effects are small (game 1.A.i in the table). The local response curve is backward bending. The effect of higher forest appropriation by the state is reduced local forest clearing, as in case 3.

Another important subset of games not dealt with is when the state is the Stackelberg leader, and the local response curve is forward bending. This could be due to either local autarky with full belly preferences or Chayanovian preferences with strong income effects, or because state conversion increases the marginal net benefits of local agricultural expansion. The conclusions are the opposite of the ones in case 3 (backward bending response curve). The local response to higher state deforestation is more local deforestation. Due to this fact, the state will as a leader *reduce* its level of deforestation compared to the Cournot equilibrium: from the state's viewpoint higher own forest conversion has an additional cost in terms of more local agricultural expansion and reduced primary forest area. Contrary to the case with a backward sloping local response curve, the Stackelberg game now helps *preserve* natural forest compared to a Cournot game.

As in case 3, the leader (state) will gain compared to the Cournot equilibrium. The local community may lose or gain. If the forward bending response curve is due to strong infrastructure effects such that also the indifference (iso-profit) curves are U-shaped (the preference direction is north), the local community will loose. If, however, the infrastructure effect is small such that the indifference curves are inverted U-shaped and the forward bending response curve is due to strong income effects in a local autarky, the local community will actually *gain* compared to the Cournot equilibrium.

As seen from the table, in a Cournot game and a Stackelberg game with the state as the leader, the key difference between the different games is related to the slope of the local response curve, i.e., the sign of l_{12} or u_{12}. When the local response curve is forward bending, either due to strong infrastructure effects or strong income effects (under autarky), the local response to more state deforestation is also more local deforestation. Furthermore, the Stackelberg game gives less forest clearing by the state and overall compared to the Cournot game.

In a Stackelberg game with the local community as the leader, the critical factor is the shape of the local iso-profit or indifference curves, i.e., the sign of l_2 or u_2. The condition for "large infrastructure effects" is therefore not the same in the different types of game. In this Stackelberg game the conclusions are more complex. In the cases when the infrastructure effect is small, the Stackelberg game gives more overall deforestation compared to a Cournot game. The local response to higher state deforestation depends, however, as shown in case 2 on the strength of the income effect relative to the substitution effect. If the income effect is weak or we have a small, open economy, then the result is less local deforestation than in the Cournot game.

Another sub-set of games not discussed is when the local community is the Stackelberg leader, and the infrastructure effect dominates. State deforestation is beneficial to the local community (lower expansion costs), thus, compared to the Cournot equilibrium, the local community will reduce its deforestation to push the state upwards along its response curve. This appears to be a rather strange form of strategic behaviour of the local community, and one could question the empirical relevance of this case. It is therefore not dealt with any further.

Appendix 3: Stackelberg warfare and leader selection

We have seen that it is an advantage to be a leader in a sequential (two period) game, thus we should expect that both players will wish to have that position. We may therefore get what is termed *Stackelberg warfare.* In the case with a backward sloping local response curve, this implies that both players choose an amount of forest clearing higher than the Cournot equilibrium, hoping that the other will be a follower. Both players want to squeeze the other to clear less forest than they would have in the Cournot equilibrium.

This situation clearly calls for a truly dynamic game model. Some major points can, however, be illustrated by using simple static binary game models, even though other elements will be missing (e.g., reputation building and credible threats). One possible way of thinking about the game discussed in this section is that it is played prior to one of the games studied.

Backward bending local response curve

A Stackelberg warfare (SW) situation is illustrated in Figure 6. Both the state and the local community choose the amount of forest clearing they would do as Stackelberg leaders (SS and SL respectively). The result is a level of overall deforestation which is higher than both the Nash-Cournot equilibrium (C) and either of the two Stackelberg equilibria.

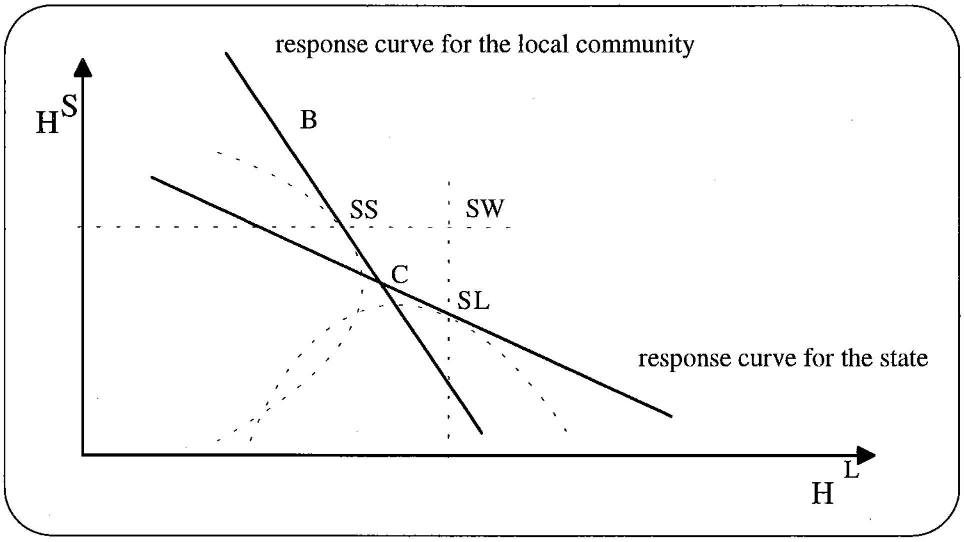

Figure 6. Stackelberg warfare with backward bending local response curve.

The warfare outcome is not stable: both agents will be better off by moving back on their response curve. We may therefore eventually end up in the Cournot equilibrium or that one of the players accept being the follower. As long as the war is ongoing, there will be excessive forest clearing.[12]

[12] In the models of this paper forest is cleared once and for all. To make this rather informal discussion about leader selection more meaningful, one should think within a dynamic perspective where forest clearing over time becomes more beneficial both for the state and the local community, e.g., increasing prices of agricultural and forest products. The warfare

The Stackelberg warfare can be illustrated as a binary choice game between the players about which strategy to pursue. Should one choose a deforestation level as a leader or as a follower? The game is given in Table 2. The ordinal numbering (ranking) of the four different outcomes is uniquely given from Figure 6, with 4 as the most preferred outcome.

		Local community	
		Follower	*Leader*
State	*Follower*	3,3	**2,4**
	Leader	**4,2**	1,1

Table 2. A chicken game on the selection of the leader.

This is a chicken game, which has two possible Nash equilibria (in bold) with either player as the leader and the other as the follower. We cannot within the game determine which of these equilibria will be the final outcome.

One could, nevertheless, provide some economic intuition to the game of leader selection outside the formal model. If one player expects the other to behave as a leader irrespective of what he is doing, then the best strategy would be to choose to be a follower. Thus we have to bring in the issues of expectations and credibility. Are there, for example, certain strategic bindings that make it more credible for one party to claim that he will be the leader? This could be in the form of officially approved plans for forest conversion or capital investments. Such strategic bindings are mainly relevant for the state, thus we could expect the state to be in a better position to make credible commitments.

Forward bending local response curve

A Stackelberg warfare appears to be most likely in a situation when the land scarcity effect dominates the infrastructure effect (inverted U-shaped local indifference curves), but it is still possible that in a local autarky situation the income effect will dominate the substitution effect such that the local response curve is forward bending. This case is illustrated in Figure 7.

is therefore about the clearing of the virgin forest which has become profitable. To incorporate such dynamic aspects in the formal model would complicate it significantly.

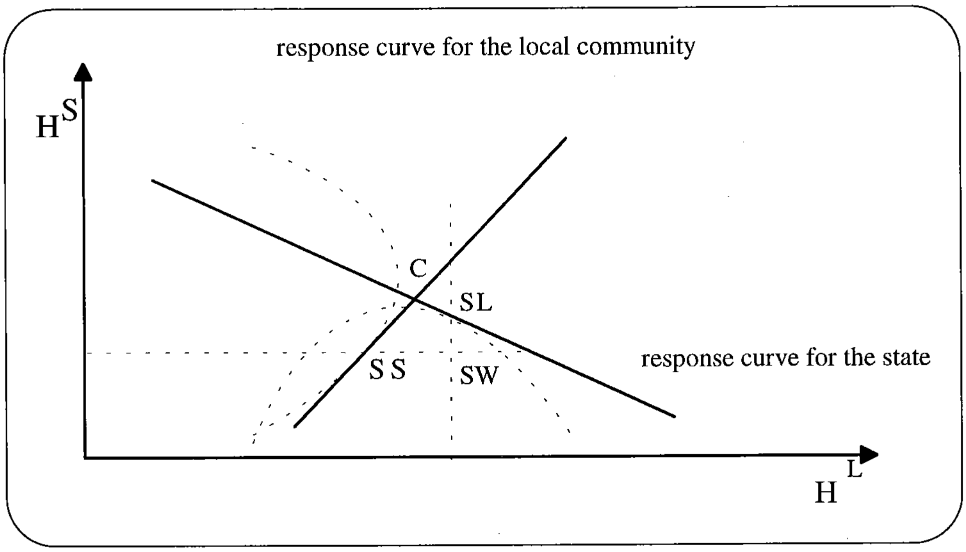

Figure 7. Stackelberg warfare with backward bending local response curve.

The state's ranking of the four different outcomes is the same as in Table 2. The ranking by the local community is more complex. We still have that they prefer, by definition, to be a leader in a Stackelberg game to the Cournot solution (SL $\succ$ C) and a Stackelberg game with the state as the leader is preferred to Stackelberg warfare (SS $\succ$ SW). However, with a forward response curve the local community now prefers the Stackelberg solution with the state as leader to the Cournot solution (SS $\succ$ C). We then have five possible local rankings:

R1: SS $\succ$ SW $\succ$ SL $\succ$ C

R2: SS $\succ$ SL $\succ$ SW $\succ$ C

R3: SS $\succ$ SL $\succ$ C $\succ$ SW

R4: SL $\succ$ SS $\succ$ C $\succ$ SW

R5: SL $\succ$ SS $\succ$ SW $\succ$ C

Figure 7 depicts the first ranking (R1). The game is presented in Table 3. At a first look the obvious solution appears to be a Stackelberg game with the state as the leader (SS), as it has the highest ranking for both the state and local community (Pareto dominating). A Stackelberg game with the local community as the leader is, however, also a Nash equilibrium. If we are in SL, the local community would not like to change strategy to be a follower, and also the state is better off than in SW.

Nevertheless, the state knows that if it starts a warfare the local community would be better off by choosing to be a follower, and in fact also better off than in SL. Similarly, the local community knows that if they choose to be a follower, the state will choose to be a leader. In both cases we end up with the state being the leader. We cannot, however, conclude that this will be the result since there are no single strictly dominant strategy for either of the players.

		Local community	
		Follower	*Leader*
State	*Follower*	3,1	2,2
	Leader	4,4	1,3

Table 3. A game of leader selection with forward bending local response curve, and SS $\succ$ SL for local community.

A possibly more empirically relevant case is when the local ranking is such that SL is preferred to SS as in rankings R4 and R5 above. R4 is presented in Table 4. We see that this game is almost identical to the one given in Table 2, with the exception that in the local ranking, SS is now preferred to C. We still have a chicken game with two Nash equilibria. Unlike the above game, the state have less reason to believe that the local community will choose to be a follower if Stackelberg warfare breaks out. This case is more similar to the one with a backward bending local response curve, and we cannot predict which of the two Nash equilibria that will be the final outcome of the game.

		Local community	
		Follower	*Leader*
State	*Follower*	3,2	2,4
	Leader	4,3	1,1

Table 4. A game of leader selection with forward bending local response curve, and SL $\succ$ SS for local community.

One can, however, conclude that it is less advantageous for the local community to be a leader and disadvantageous to "give" that role to the state in the case of a forward bending local response curve. The state will, as a leader, choose to reduce its forest clearing, which will benefit the local community.

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