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Community-based forest management in Côte d'Ivoire: A theoretical investigation

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Abstract

This article investigates the factors that lead to a sustainable management of protected forest by analysing the joint-management policy implemented by forestry authorities through a bio-economic model. A dynamic optimisation technique in continuous time has been used to derive results that explore the policy responses that may stimulate forest conservation. The study shows that joint management improves the level of forest conservation compared to the state management implemented thus far. The results argue that the share of the income from the exploitation of secondary products going to the local community should be at least equal to that resulting from timber exploitation. In particular, forest preservation is better when that share is close to unity, since it constitutes the main incentive of anti-infiltration effort supplied by the local community. However, an absolute increase in the marginal revenue of this secondary activity improves the level of conservation. Finally, the study reveals the need for external funding to account for the public good effect of the forest.

Keywords: anti-infiltration effort, external financial support, joint forest management, local community, protected forest

1 Introduction

The world is confronted today with multiple threats: soil, water and marine resource impoverishment; air pollution; the loss of ozone layer; climate change and, in particular, deforestation. The latter is partly the cause of the first phenomena, since forests play a strategic role in the ecosystem, in particular in terms of their capacity to protect against watershed, the erosion of topsoil cover, the recycling of nutrients at the local economy level and their ability to produce benefits related to biodiversity and carbon sequestration at the international level. Today, environmental and natural resources management problems constitute the major challenges facing decision-makers. Indeed, the tropical forests have decreased strongly under various pressures. According to Lanly (1982), the annual rate of deterioration of the humid tropical forests rose to about 6.113 million hectares for the period 1976–1980. Recent data indicate that the rhythm of the world's yearly deforestation, estimated at about 8.868 million hectares between 1990 and 2000, is argued to reach 7.317 million hectares per year between 2000 and 2005. Thus, the surface of the world's forests decreased from 4.077 billion hectares in 1990, to 3.952 billion in 2005 (FAO, 2007). The forests of Côte d'Ivoire are following the same deforestation trend (Aké, 1984; N'Guessan, 2006). Indeed, shifting agriculture, logging overexploitation and wood-energy-gathering constitute the main activities leading to deforestation in Côte d'Ivoire (FAO, 2003). These actions have led to a deterioration of more than 83 per cent of the forest surfaces. Thus, from 15 million hectares at the beginning of the last century, only 2.5 million hectares of forest remained in 1996 (SODEFOR, 1996) and even less these past years. Today, the forests not yet exploited are estimated to cover only the few thousands of hectares of forest reserves and national parks on which Côte d'Ivoire has based the conservation of its flora and fauna.

Unfortunately, these protected areas are constantly infiltrated for agricultural purposes. Indeed, about 30 per cent of forest surfaces are occupied by agriculture, and more than 72 000 families live inside these forests (AIFORT, 2008).

To overcome this situation, in 1992 the Ivorian government decided to entrust SODEFOR (Society for Forest Development) with the management of all protected Ivorian forests. That public society, established in 1966, which specialises in industrial reforestation, is tasked with finding solutions to the presence of a vast agricultural population now resident in the protected forests. In this regard, SODEFOR implemented a joint management policy (JMP) through a discussion forum called the 'Peasants–Forests Commission'. The ensuing policy aims to involve the local community in the management of protected forests. The expected results are, however, misleading, in the sense that the portion of the forest being cultivated for agricultural purposes, keeps increasing.

Due to the failures of the joint management policy, in March 1997 the government decided to take repressive measures. Its policy of repression allows the forestry authority, SODEFOR, to systematically destroy all perennial crops that are not yet in production, along with all food crops in protected areas. Unfortunately, infiltrations still continue and are threatening the ecological equilibrium of the country despite these promising policies.

The objective of this article is to investigate the factors that could lead to the sustainable management of protected forests in Côte d'Ivoire, in the context of joint management. Questions include: Were JMP instruments set efficiently? Did they take all policy components – especially economic aspects – into account? What are the economic incentives of the JMP? In other words, what economic factors drive optimal levels of forest conservation?

In spite of the widespread implementation of the JMP, it appears that little formal analysis is available on the topic. The few analyses that exist use the game theory approach. This article makes a significant contribution to the literature in the sense that it employs a bio-economic model to analyse the joint forest management approach, taking explicit note of the infiltration phenomenon which was non-existent in previous studies.

A bio-economic model using dynamic optimisation techniques in continuous time has been used to deal with the problem. The main result from this study is that a

JMP, with the support of the international community and with the equitable sharing of forestry income to benefit the local community, will improve the management of protected forest by mitigating peasants’ encroachments.

The article is structured as follows: The following section offers insight into forest management policy in Côte d’Ivoire and presents the Peasants–Forest Commission structure. Section 3 deals with the literature review. Section 4 outlines the methodology, while section 5 presents the results of the study and the final section concludes by formulating a number of recommendations.

2 Forest management policy in Côte d’Ivoire

Côte d’Ivoire has begun its economic development thanks to its forests, which provide favourable conditions for agriculture and timber exploitation. Unfortunately, the country’s forest cover is currently experiencing a very advanced level of degradation, which is threatening the ecological balance and therefore its economy. Indeed, the country’s forest cover, which amounted to almost 16 million hectares in 1900, had decreased to less than three million hectares in 1991 (FAO, 2001) and is estimated to be less than two million today.

Facing the serious ecological, economic and cultural consequences of human development, the government has taken political and institutionally important measures aimed at reversing the trend of forest degradation. Primary amongst these is the design and adoption in 1988 of the forestry management plan (1988–2015), with five major objectives intended to manage the country’s forests in a sustainable way. The Forest Management Plan (FMP) focuses on the effective participation of populations in forest management, in order to achieve the efficient management of this natural resource (MINEFOR, 1988). This arrangement was reinforced by forestry sector reform in July 1994 which aims to manage forests by intensifying controls (the creation of forestry police, litigation, stronger monitoring capabilities) and promoting reforestation activities at village level.

Despite these arrangements, gaps and challenges in promoting the sustainable management of forest remain. These include

- the strong pressure of the population on forest resources for various social needs and agricultural purposes;
- the weak adherence of the population to the principle of sustainable management of forest resources as well as the concept of reforestation;
- a lack of financial resources for the necessary investments.

In that regard, in 1992 the government decided to allocate all protected forests to SODEFOR (established in 1966), a public society whose objective is to efficiently manage 231 protected forests covering a total surface of 4 196 000 hectares. As part of its integrated management policy, SODEFOR has opted for the inclusion of social and agro-economic factors interfering in forest management. The JMP which SODEFOR designed, aims to address the problem of agriculture–forest interface in a consensual manner, through the creation of a discussion forum and decision-making by the PFC. Indeed, this commission is seen as the main tool in the rehabilitation of protected forests, since it links the local population to the forest management, while allowing for a smooth resolution of issues around illegal settlements. The PFC brings together riparian peasant representatives, farmers who have settled in protected forests, local administrators, economic operators and SODEFOR. The committee, which operates according to a charter and internal rules that determine its constitution, has both a local and a national component.

However, many difficulties have affected the implementation of the JMP, in the sense that the message conveyed through the CPF has been misunderstood by stakeholders (Ibo *et al*., 1997). As part of these difficulties, there is the problem of communication amongst field staff, and conflicts between the local population and forest officers which brought about an increase in protected forest clearings. In 1993, for instance, more than 30 per cent of the protected forests were cultivated by more than 500 000 farmers (Leonard, 1997). The average rates of infiltration over the periods 1991–1996 and 1996–1999 were 26 and 27 per cent respectively (FAO, 2001). Between 1960 and 1986, the government had released about 975 000 ha for the benefit of agricultural activities, in order to avoid precisely such a situation (SODEFOR, 1992). The western and the south-western regions presented the highest infiltration rates – 24 and 44 per cent respectively (SODEFOR, 1994). In the same way, various partners in rural areas consider PFCs to be a SODEFOR tool, used by the organisation to oblige them to adopt its decisions.

Overall, the joint management tools designed by SODEFOR have not been used efficiently by SODEFOR agents or by farmers. Indeed, those instruments have mostly been designed without the participation of the local population. In addition, the tools have not been truly tested and sufficiently disseminated. There is also an under-representation of local populations in the commission (1/6) (Ibo *et al*., op.cit.) which constitutes significant evidence of its failure. Finally, there have been financial problems, in the sense that no budget has been drawn up (Lorng, 1999).

Basically, this approach has real advantages aimed at addressing the problem of illegal settlements without leading to open conflict between the planters and the administration. However, its effectiveness and sustainability are related to economic aspects that have not been sufficiently taken into account. In this article, an attempt is made to fill this gap by exploring the economic incentives which local populations are sensitive to (King, 1965).

3 Literature review

In the literature, several approaches have been utilised to attain biodiversity conservation objectives (Oates, 1999; Terborgh, 1999; Schwartzman *et al*., 2000; Wilhussen *et al*., 2002). In this context there are, on one hand, partisans of the full protection of natural forests that are rich in biodiversity, and on the other hand partisans of an approach reconciling forest conservation with the wellbeing of the local population.

The first paradigm envisages the creation of exclusive, protected, natural zones where the local population is considered a threat for biodiversity conservation.

For defenders of this 'forest conservation' approach, some uninhabited natural protected areas would be best suited to sustainably protect natural areas. But, with the sustainable development concept, this paradigm of conservation has been considerably modified. Indeed, in reality, traditional 'top-down' approaches of area protection that aim to exclude all human presence are unsustainable (Brown, 2003), for multiple reasons: it is impossible to enclose the protected areas; staff only have weak means of effecting reserve control; frustrations arises from any exclusion of the local encroaching population, and so on.

Therefore, at the end of the 1980, a new conservation approach was proposed, based on the capacity-building strategy of the local population as a fundamental means to reach conservation objectives. Known as 'new conservation' or 'people-oriented approaches', the rural population's dependence on the forests contributes to the deterioration of natural resources. Indeed, the poorest agriculturists are those whose incomes and agricultural production are low, thus they depend more on the forests (Pascal *et al*., 2002). The poor are growing in number, which exerts increasing pressure on the natural resources and damages them (Malthus, 1980). Therefore, all conservation projects should aim, primarily, to improve the living conditions of the local population. This approach has been accepted and adopted by institutions in charge of conservation, by countries and by non-governmental organization (NGOs).

A first approach of this indirect method of conservation is to develop ecotourism in forest zones, and this has the support of financial institutions such as the World Bank (Nicholls, 2004). However, indirect conservation measures have been severely criticised. On the one hand, criticism was related to the low profits the local populations derive from this method. Most local communities involved in ecotourism projects receive a limited share of the profits earned from that activity, and rather rely on activities that are extremely aggressive (Oates, 1999; Nicholls, 2004). Worse still, indirect conservation approaches failed because of the local population's incorrect perceptions of the desires and the will of forestry conservationists, the ambiguous effects of conservation incentives, the difficulties of implementation, and problems related to the achievement of the spatial and temporal aspects of conservation objectives (Ferraro and Simpson, 2005).

To contribute to the debate, this study not only aims to investigate the incentives for forest conservation, but also to determine their optimal levels through a rigorous modeling of the case of Côte d'Ivoire. In this perspective, Ferraro *et al.* (2002, 2005) propose a new concept of conservation, namely: 'You should pay for what you want to get.' In other words, if financial institutions want to reach conservation objectives they should pay for conservation efforts, not for activities related to conservation (Ferraro & Kiss, 2002). Indeed, the profits deriving from forestry services, and current and future option values, benefit the international community rather than locals (Balmford & Whitten, 2003). Therefore, the recourse to direct mechanisms in the form of aid to the local population for 'conservation performances' would constitute a win-win solution, because it would help attain conservation objectives as well as development goals (Gueneau *et al*., 2004).

Using an econometric model, Ferraro and Simpson (2005) show that in the case of Madagascar, for example, for the same budget allocated to conservation, the direct payments option would have permitted 80 per cent of tropical forests to be protected, against 12 to 22 per cent with indirect measures. Also, the incomes of the local population would have doubled thanks to direct measures. For these authors, biodiversity would be endangered in less developed countries, because the profits the local population derive from its destruction exceeds whatever they derive from its preservation. For them, protected areas represent a loss of income and an opportunity cost that is not efficiently compensated. For example, according to some evaluations, two national parks in Madagascar have reduced the income of neighbouring communities by about ten per cent (Nicholls, 2004).

For some authors, conserving tropical forests is an integral part of economic systems where the supply and demand of biodiversity are privatised (Lescuyer, 2004). Therefore, biodiversity is considered a ‘commodity’ that can be sold or bought (Nicholls, op. cit.). This is known as the trade approach to conservation or ‘market-based conservation’, where contracts between states, private firms, NGOs and local communities are based on market instruments.

However, the JMP as a solution to the sustainable management of protected areas has been imposed in a dogmatic manner, without reference to research works based on the bio-economic model. A number of authors have attempted to deal with joint forest management issues by using the game theory approach (Angelsen, 2001; Caputo & Lueck, 2003; Lise, 2001; Rotillon & Tazdait, 2003; Shahi & Kant, 2007). In addition, improving the indirect approach to conservation through research aimed at understanding the complexity of local communities, highlights efficient conditions for a participatory process, determines which factors affect the responsibility of local populations, and values the impact of sustainable development actions.

Therefore, this study uses the bio-economic model to analyse the JMP, taking into account the infiltration phenomenon. Globally, the author agrees with Nicholls (2004) that the remittance of direct support will be well designed with strategies where indirect instruments (dialogue, education and other factors) are necessary to orient the practices of the local population toward sustainable development. According to this perspective, the study attempts to determine which factors will ensure the efficient and sustainable management of the protected forests of Côte d’Ivoire, based on appropriate modeling.

4 The model

4.1 JMP formalisation

A bio-economic model with two agents (local community and SODEFOR) is proposed, along with two activities (agriculture and forest conservation), to analyse the JMP using dynamic optimisation techniques in continuous time. The model is adapted from Fischer *et al.* (2011) to the context of forest management by considering intraspecific interactions within the dynamic of agricultural land, along with a general form for profit functions.

SODEFOR has a fixed amount of (protected) forest to maintain and reforest. The local community living adjacent to the protected forest and has user rights over the remaining land for agricultural purposes. These two agents act within a defined area, but conflicts arise when farmers go into the protected forest in search of fertile land to cultivate. Indeed, in this article, the only strategic interaction between forest users is assumed to be unidirectional, in the sense that the local community (farmers) infiltrate protected areas as the density of the forest increases. The converse is not meaningful, as SODEFOR (timber harvester) cannot find timber on non-forested land. Thus, the forest vs. agriculture conflict in this particular setting is dependent on the density of the protected forest: As the density of the forest increases, the rate of infiltration increases.

Two cases can be considered in the context of profit sharing:

- - The market solution, where each agent (local community and SODEFOR) maximises its own profit;
- - The social solution, where social planners undertake unified resource management.

From these two solutions, it is possible to derive socially optimal economic measures.

4.1.1 Local community

In a joint management context where the local community is involved in managing the protected forest, it receives a discounted profit π^{cl}. By implication, it receives remuneration (α and β) as part of the different types of revenue generated by SODEFOR. These revenues are considered net of exploitation costs.[1] Indeed, SODEFOR sells logging exploitation permits to forest harvesters and in return receives a net revenue $R(q_{1t})$ where q_{1t} represents the standing volume of wood contained in a given surface and sold in the year t. Suppose that $R^{'}_{q_{1t}}(q_{1t}) > 0$ and $R^{''}_{q_{1t}q_{1t}}(q_{1t}) < 0$. SODEFOR also receives net revenue $R(x_{1t})$ from the exploitation of by-products[2] such as charcoal, rafters, planks and beams, etc. Suppose that this income grows with the stock of the protected forest x_{1t} with a positive first derivative and a negative second derivative, i.e., $R^{'}_{x_{1t}}(x_{1t}) > 0$ and $R^{''}_{x_{1t}x_{1t}}(x_{1t}) < 0$. The local community receives net revenue $R(q_{2t})$ from its agricultural activity on its own lands outside of the protected forest, with x_{2t} the surface in agricultural exploitation at time t. This function is such that $R^{'}_{q_{2t}}(q_{2t}) > 0$ and $R^{''}_{q_{2t}q_{2t}}(q_{2t}) < 0$. In return, the local community must provide a monitoring effort θ of the protected forest at the cost $C(\theta)$ with first and second positive derivatives, i.e., $C^{'}_{\theta}(\theta) > 0$ and $C^{''}_{\theta\theta}(\theta) > 0$.

1 All revenues throughout this article are considered net of exploitation cost. Only the monitoring cost is explicitly considered to emphasise relative importance in this setting, compared to traditional exploitation costs.

2 Wood residues represent 60 per cent of the volume of timber harvested (Aifort, 2008).

The maximisation of this profit takes into account the dynamics of the forest resource. $g_2(x_{2_t})$ is the natural growth of the unprotected forest, with the positive first derivative and negative second derivative, i.e., $g_2^{'}(x_{2_t}) > 0$ and $g_2^{"}(x_{2_t}) < 0$. $g_1(x_{1_t})$ is the natural growth of the protected forest with a positive first derivative and the negative second derivative, i.e., $g_1^{'}(x_{1_t}) > 0$ and $g_1^{"}(x_{1_t}) < 0$. Finally, $I(x_{1_t}, \theta)$ is the function of farmer infiltration that grows with the stock of protected forest and decreases with the level of effort θ. The properties of this infiltration function are as follows:

$I(0,\theta) = 0, I_{x1_t}^{'}(x_{1_t},\theta) > 0, I_{\theta}^{'}(x_{1_t},\theta) < 0, I_{x1_t x1_t}^{"}(x_{1_t},\theta) > 0, I_{x1_t\theta}^{"}(x_{1_t},\theta) < 0, I_{\theta x1_t}^{"}(x_{1_t},\theta) < 0,$ and $I_{\theta\theta}^{"}(x_{1_t},\theta) > 0$

4.1.2 SODEFOR

The discounted profit for SODEFOR π^{SOD} is constituted of the sum of the remaining parts after the extraction of the local community, and is equal to $(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})$ since $0 < \alpha < 1$ and $0 < \beta < 1$. It is possible to solve this problem by considering two cases: The market and the social planner. Indeed, forest resources are a public good which produces external effects that are not always taken into account by market mechanisms. This will help to control different aspects of forest resource management.

4.2 Market- based optimisation problems

According to this approach, it is possible to solve the optimisation programme of each economic agent (the local community and SODEFOR) independently.

4.2.1 Local community's optimisation programme

For the local community, it is a question of maximising over an infinite time horizon, the flux of net revenue from forest preservation and agricultural activities by taking into account the dynamic of the resource. Therefore, the optimisation programme of the local community is:

$$\underset{(q_{2t},\theta)}{Max}\, \pi^{cl} = \int_0^{\infty} [\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) - C(\theta)] e^{-\delta t} dt \quad (1)$$

s/c

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) \quad (2)$$

$$\dot{x}_{2t} = g_2(x_{2t}) - q_{2t} \quad (3)$$

Where $e^{-\delta t}$ is a discount factor and δ a discount rate.

4.2.2 SODEFOR's optimisation programme

For this structure, it is a question of maximising over an infinite time horizon, the incomes from its main and secondary activities, while taking into account the dynamics of the resource – especially the infiltration phenomenon.

$$\underset{(q_{1t})}{Max}\, \pi^{SOD} = \int_0^\infty [(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})]e^{-\delta t}dt \tag{4}$$

s/c

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t}, \theta) \tag{2}$$

Where $e^{-\delta t}$ is a discount factor and δ a discount rate.

4.3 Social planner's optimisation problem

From the optimisation problems above, the public good effect of forests (externality) is not taken into account. To correct this market failure, the social planner maximises the discounted value of forest and agricultural profits, taking into account the nuisance costs and the public good effect of forests, $B(x_{1t})$ by choosing x_{1t}, x_{2t} and θ subject to the dynamics of the stock of forest and agricultural land. $B(x_{1t})$ captures the value of the forest to the general public in the form of its contribution to biodiversity, option value and existence value. We would expect that $B(0) = 0, B'_{x_{1t}}(x_{1t}) > 0$ and $B''_{x_{1t}x_{1t}}(x_{1t}) < 0$ for a stock of forest that is regarded as a public good.

Contrary to the market logic, the social planner takes into account externalities due to the 'public property characteristic' of the forest and the nuisance generated by the presence of the protected forest in terms of limitations on the expansion of agricultural activity on the part of the local community. The question facing the social planner is whether to maximise, over time, the social profit of the different actors (local community and SODEFOR) by taking into account the public good effect (existence and option value) of the forest, i.e., $B(x_{1t})$.

$$\underset{(q_{1t}, q_{2t}, \theta)}{Max}\, \pi^{Social} = \int_0^\infty [\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) + B(x_{1t}) - C(\theta) + (1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})]e^{-\delta t}dt \tag{5}$$

s/c

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t}, \theta) \tag{2}$$

$$\dot{x}_{2t} = g_2(x_{2t}) - q_{2t} \tag{3}$$

Where $e^{-\delta t}$ is a discount factor and δ a discount rate.

5 Results

The different optimisation programmes will be solved using Pontryagin's maximum principles. Here, market-based solutions are differentiated from the social planner's solution.

5.1 Market-based solutions

In this sub-section, the private decision-making process (market-based resource use situation) is outlined in which the agents (SODEFOR and the local community) do not take into account the externalities of forest conservation. Under consideration is a resource use regime where the agents share profits. The problems are solved using Pontryagin's maximum principles.

Solution to SODEFOR's problem

SODEFOR maximises equation (4) subject to equation (2). Thus, the current value Hamiltonian (H^c) is formulated as follows:

$$H^c = [(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})] + \mu_{3t}(g_1(x_{1t}) - q_{1t} - I(x_{1t}, \theta))$$

When we apply Pontryagin's maximum principles, we get the following necessary conditions from equations (6) to (8):

$$\frac{\partial H^c}{\partial q_{1t}} = 0 \Leftrightarrow (1-\alpha)R'_{q_{1t}} - \mu_{3t} = 0 \Rightarrow \mu_{3t} = (1-\alpha)R'_{q_{1t}} \quad (6)$$

$$\frac{\partial H^c}{\partial \mu_{3t}} = \dot{x_{1t}} \Leftrightarrow g_1(x_{1t}) - q_{1t} - I(x_{1t}, \theta) = \dot{x_{1t}} \quad (7)$$

$$\frac{\partial H^c}{\partial x_{1t}} = -\dot{\mu_{3t}} + \delta\mu_{3t} \Leftrightarrow (1-\beta)R'_{x_{1t}} + \mu_{3t}\left(g'_{x_{1t}} - I'_{x_{1t}}(.)\right) = -\dot{\mu_{3t}} + \delta\mu_{3t} \quad (8)$$

Assuming the steady state where , the co-state equation yields

$$(1-\beta)R'_{x_{1t}} + \mu_{3t}\left(g'_{x_{1t}} - I'_{x_{1t}}(.)\right) = \delta\mu_{3t}$$

$$\mu_{3t} = \frac{(1-\beta)R'_{x_{1t}}}{\delta - (g'_{x_{1t}} - I'_{x_{1t}}(.))} \quad (8a)$$

Considering equation (13), we get

$$(1-\alpha)R'_{q_{1t}} = \frac{(1-\beta)R'_{x_{1t}}}{\delta - (g'_{x_{1t}} - I'_{x_{1t}}(.))} \quad (8b)$$

In an equilibrium case with main and secondary activities we have

$$\frac{(1-\beta)R'_{x_{1t}}}{(1-\alpha)R'_{q_{1t}}} = \delta - (g'_{x_{1t}} - I'_{x_{1t}}(.)) \quad (8c)$$

Solution to the local community's problem

The local community maximises equation (1) subject to equations (2) and (3). Thus, the current value Hamiltonian (H^c) is formulated as follows:

$$H^c = [\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) - C(\theta)] + \mu_{1t}(g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta)) + \mu_{2t}(g_2(x_{2t}) - q_{2t})$$

When we apply Pontryagin's maximum principles, we get the following necessary conditions from equations (9) to (14):

$$\frac{\partial H^c}{\partial \theta} = 0 \Leftrightarrow -C'(\theta) - \mu_{1t} I'_\theta = 0 \Rightarrow \mu_{1t} = \frac{C'(\theta)}{-I'_\theta} \quad (9)$$

$$\frac{\partial H^c}{\partial q_{2t}} = 0 \Leftrightarrow R'_{q_{2t}} - \mu_{2t} = 0 \Rightarrow \mu_{2t} = R'_{q_{2t}} \quad (10)$$

$$\frac{\partial H^c}{\partial x_{1t}} = -\dot{\mu_{1t}} + \delta\mu_{1t} \Leftrightarrow \beta R'_{x_{1t}} + \mu_{1t}\left(g'_{1x_{1t}} - I'_{x_{1t}}(.)\right) = -\dot{\mu_{1t}} + \delta\mu_{1t} \quad (11)$$

$$\frac{\partial H^c}{\partial x_{2t}} = -\dot{\mu_{2t}} + \delta\mu_{2t} \Leftrightarrow \mu_{2t} g'_{2x_{2t}} = -\dot{\mu_{2t}} + \delta\mu_{2t} \quad (12)$$

$$\frac{\partial H^c}{\partial \mu_{1t}} = \dot{x_{1t}} \Leftrightarrow g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) = \dot{x_{1t}} \quad (13)$$

$$\frac{\partial H^c}{\partial \mu_{2t}} = \dot{x_{2t}} \Leftrightarrow g_2(x_{2t}) - q_{2t} = \dot{x_{2t}} \quad (14)$$

Rewriting equation (9), we get $C'(\theta) = -\mu_{1t} I'_\theta$ (9a)

Assuming the steady state solution where $\dot{\mu}_{1t} = \dot{\mu}_{2t} = 0$ and an interior solution, the co-state equations yield

$$\mu_{1t} = \frac{\beta R'_{x_{1t}}}{\delta - (g'_{1x_{1t}} - I'_{x_{1t}}(.))} \quad (11a)$$

Considering equation (9), we have

$$\frac{\beta R'_{x_{1t}}}{\delta - (g'_{1x_{1t}} - I'_{x_{1t}}(.))} = \frac{C'(\theta)}{-I'_\theta} \quad (11b)$$

If we also consider equation (8c), we get

$$\mu_{1t} = \frac{\beta(1-\alpha) R'_{q_{1t}}}{(1-\beta)} \quad (11c)$$

From equation (12), when we assume the steady state, we get

$$g'_{2,x_{2t}} = \delta \quad (12a)$$

The results derived from the maximisation problems of these agents are analysed according to the agriculture vs. forest conflict and welfare implications. Two resource use regimes are considered here: The joint management case, where the local community gets fixed shares of the profit from secondary activities and logging (sale of forest concession permits); and a situation where the local community does not reap any benefits from the forest (no joint management case).

5.1.1 Joint management case where $\beta \neq 0, \alpha \neq 0$

Equations (6) to (14) give the necessary conditions[3] for the forest authority (SODEFOR) and local community maximisation problems. From these equations, we note that the local community has its own valuation of the forest, which differs from the valuation of the forest authority.

Condition (9a) shows that the local community will apply anti-infiltration efforts up to a level at which the marginal cost of such efforts is equal to their marginal benefit. The marginal benefit consists of the value of the forest saved from infiltration as a result of anti-infiltration efforts and is evaluated at the current shadow price of the forest resource. The shadow value of the forest, from the point of view of the local community, is strictly positive since $(\delta - (g^{'}_{1,x1t}(x_{1t}) - I^{'}_{x1t}(x_{1t}, \theta)))$ (equation 8c) is positive. From equation (11a) we note that the larger the β, the higher the value attributed to the forest resource by the local community. Likewise, from equation (11c) the local community's shadow value of the forest is positively related to β and negatively related to α. It comes from equations (9 and 11c) or 11b that the level of the anti-infiltration effort and the share of revenue β accruing to the local community are positively related. Thus, β is nothing other than the level of incentive provided to the local community to exert an anti-infiltration effort aimed at forest preservation. β can also be seen as the degree of integration (implication) of the local community in the joint management project.

In addition, the forest authority obviously has a positive existence value as a forest resource, as shown in equation (6). But, this value decreases with α. Thus, the higher the share of revenue from secondary activity, the higher the level of anti-infiltration effort. The optimal (highest) anti-infiltration effort is obtained when β is close to unity while α is close to zero. This will give incentives to both the local community and SODEFOR, to conserve the forest.

In equilibrium with main and secondary activities, equation (8c) states that the sum of relative marginal value of forest exploitation activities and forest capital gain should be equal to the social opportunity cost when taking into account revenue sharing. Otherwise, equation (8c) implies that the marginal natural growth of the forest net of infiltration is slower than the discount rate, as the secondary activity is relatively more valuable than the main one. These two variables are growing almost at the same rate when the converse is applied, that is, when the main activity is more valuable than the second. This shows that the rate of time preference is mitigated and grows at the same rate as the marginal natural growth of forest net of infiltration, to

3 First-order conditions are also sufficient for optimality, since all functions are concaves and the co-state variables are all positives.

the extent that SODEFOR's main activity is relatively more valuable than the second. This is desirable for environmental purposes, especially for forest conservation. The more the main activity is relatively valuable, the more forest conservation will be implemented. At a given value of $R'_{x1t}(x_{1t})$ and $R'_{q1t}(q_{1t})$, the conservation of the forest will be better if β is close to unity, while α is close to 0. Globally, the joint management of forest resources is sustainable if $R'_{q1t}(q_{1t}) \geq R'_{x1t}(x_{1t})$ and $\beta \geq \alpha$. It comes from these considerations that the forest resource exploitation will be sustainable only if the social discount rate does not exceed the marginal natural growth of the forest net of infiltration.

Equation (8) shows that the stock of forest will be expanded by the forest authority up to the point where the marginal cost of that expansion is equal to its marginal benefit. Indeed, an increase in the stock of forest generates the benefits of expansion: additional secondary revenue, increase in the value of the forest resource, and the stock effect. The opportunity cost of forest conservation is the foregone net proceeds from the sale of forest products (timber) if the forest is not conserved, and an additional level of forest that has been saved with forest conservation. This opportunity cost is evaluated at the shadow price of the forest resource.

Equation (11) solves for the optimal stock of forest to be conserved x_{1t}^{*JM} [4] given the value of θ^{*JM} derived from the local community's optimisation programme. Indeed, from equation (11c) we can get μ_{1t} given β and α. Then, from equation (9), we get θ^{*JM}. The optimal stock of non-protected forest land x_{2t}^{*JM} is obtained from equation (12a). Indeed, according to equation (12), the local community will expand its agricultural surface until the marginal cost is equal the marginal benefit. The marginal benefit of non-protected forest land conservation consists of the stock effect that comes with an increase in the stock of agricultural land and the increase in the value of agriculture. The opportunity cost of conservation of non-protected land is the foregone interest receipt on proceeds from the sale of agricultural products that would have been realised if non-protected forest land were converted to agriculture. This opportunity cost is evaluated at the shadow price of non-protected forest land.

The local community has a positive valuation of the non-protected forest land, as shown in equation (10). Equation (12a) shows that the non-protected forest land must grow at the discount rate δ which is the opportunity cost of conservation of non-protected forest land.

From equation (13) and equation (14) we can get q_{1t}^{*JM} and q_{2t}^{*JM} knowing x_{1t}^{*JM}, x_{2t}^{*JM} and θ^{*JM} assuming steady state.

The welfare of the local community is indicated by its profits derived from agriculture and forest conservation ($\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) - C(\theta)$) and, for SODEFOR by profits from forest conservation ($(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})$). Thus, the optimal stock of forest is supposed to be greater in this case than another where there is no joint management arrangement. Indeed, they do more forest conservation since they reap some benefits from forest conservation activities.

4 JM stands for joint management.

5.1.2 Discussion about α and β

With $\alpha = \beta$, the forest authority's incentive for forest conservation has not been changed compared to the one under the state management regime (see equation 8c). In contrast to that result, the local community's incentive for forest conservation is high (see equations 11c, 9 and the welfare expression) in this joint management regime. Under joint management policy, the optimal stock of forest increases when $\alpha < \beta$.

From the welfare expression, we note that SODEFOR and the local community have more conservation incentives, with profit derived from secondary activity. Thus, the optimal stock of forest (more conservation) would show more significant increases under the joint management regime than before. The local community does more forest conservation (monitoring) activity than agricultural activity.

5.1.3 No joint management case where α=β=0

Considering the state management situation where α=β=0, condition (11b) will only be satisfied with an optimal anti-infiltration effort of zero. Thus, the local community applies no anti-infiltration effort in that regime, i.e., $\theta^{*NJ} = 0$[5]. In this context, protected forest will disappear as long as it has zero existence value for the local community, according to equation (11a). Indeed, the local community does not care about forest conservation in that case, since its welfare $R(q_{2t}) - C(\theta)$ is not dependent on the forest as a resource. There are no incentives for the local community to exert any conservation activities. In the same way as previously determined, we obtain the optimal variables q_{1t}^{*NJ}, q_{2t}^{*NJ}, x_{1t}^{*NJ}, x_{2t}^{*NJ} and θ^{*NJ} by setting α=β=0.

5.1.4 Comparison of the two cases and policy implications

Under the joint management regime, the local community derives additional profit from forest resource use. Under joint management the optimal anti-infiltration effort is positive, as shown by conditions (11a) and (9). Thus, the local community has a greater incentive to monitor the protected forest. The higher the share of revenue from secondary activity, the greater the anti-infiltration effort on the part of the local community. The non-zero effort level of θ^{*JM} ($\theta^{*JM} > (\theta^{*NJ}=0)$) gives room for designing JMP aimed at enlisting the support of the local community in forest preservation, through the use of economic incentives (Fernandez-Puente, 1996). It must be the case that when community-based forest conservation schemes are put in place, they are structured so as to sufficiently reward the local community to exert anti-infiltration effort. Thus, the local community should be adequately rewarded in order to attain its cooperation in forest conservation (Nguinguiri, 1999). The highest optimal anti-infiltration effort is obtained when β is close to unity.

Local community cooperation in forest conservation is mainly aimed at reducing the level of infiltration and enhancing the stock of forest. Thus, the impact of anti-infiltration effort $\theta^{*JM} > \theta^{*NJ}$ under joint management will result in more conservation, i.e., ${x_{1t}}^{*JM} > {x_{1t}}^{*NJ}$. In that case, the local community performs more forest conservation activities than agricultural activities ${q_{2t}}^{*NJ} > {q_{2t}}^{*JM}$. This result makes room for the implementation of forestry community programmes where the forest management is entrusted to the local community. In addition, the non-zero share $1-\beta$ (see equation 11c) going to the forestry authority can be seen as supporting this structure in carrying out training programmes (fire protection, greenbelt establishment, etc.) and extra extension services to strengthen the local community's ability to sustainably manage the forest. Indeed, the local community's conservation activities should be regulated by the forestry authority, and should assist it in its management plan design.

5.2 The solution to the social planner problem

We solve the social planner's problem using Pontryagin's maximum principles.

$$\underset{(q_{1t},q_{2t},\theta)}{Max}\ \pi^{Social} = \int_0^\infty [\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) + B(x_{1t}) - C(\theta) + (1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})]e^{-\delta t}dt \qquad (5)$$

s/c

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) \qquad (2)$$

$$\dot{x}_{2t} = g_2(x_{2t}) - q_{2t} \qquad (3)$$

Considering the current value Hamiltonian, we have

$$H^c = [\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) + B(x_{1t}) - C(\theta) + (1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})] + \mu_{4t}(g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta)) + \mu_{5t}(g_2(x_{2t}) - q_{2t})$$

$$\frac{\partial H^c}{\partial \theta} = 0 \Leftrightarrow -C'(\theta) - \mu_{4t}I'_\theta = 0 \Rightarrow \mu_{4t} = \frac{C'(\theta)}{-I'_\theta} \qquad (15)$$

$$\frac{\partial H^c}{\partial x_{2t}} = -\dot{\mu_{5t}} + \delta\mu_{5t} \Leftrightarrow \mu_{5t}g'_{2x_{2t}} = -\dot{\mu_{5t}} + \delta\mu_{5t} \qquad (16)$$

$$\frac{\partial H^c}{\partial q_{1t}} = 0 \Leftrightarrow R'_{q_{1t}} - \mu_{4t} = 0 \Rightarrow \mu_{4t} = R'_{q_{1t}} \qquad (17)$$

$$\frac{\partial H^c}{\partial q_{2t}} = 0 \Leftrightarrow R'_{q_{2t}} - \mu_{5t} = 0 \Rightarrow \mu_{5t} = R'_{q_{2t}} \qquad (18)$$

$$\frac{\partial H^c}{\partial \mu_{4t}} = \dot{x_{1t}} \Leftrightarrow g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) = \dot{x_{1t}} \qquad (19)$$

$$\frac{\partial H^c}{\partial \mu_{5t}} = \dot{x_{2t}} \Leftrightarrow g_2(x_{2t}) - q_{2t} = \dot{x_{2t}} \qquad (20)$$

$$\frac{\partial H^c}{\partial x_{1t}} = -\dot{\mu_{4t}} + \delta\mu_{4t} \Leftrightarrow R'_{x_{1t}} + B'_{x_{1t}} + \mu_{4t}\left(g'_{1x_{1t}} - I'_{x_{1t}}(.)\right) = -\dot{\mu_{4t}} + \delta\mu_{4t} \qquad (21)$$

Considering equations (17) and (15) we get

$$R'_{q1t} = \frac{C'(\theta)}{-I'_{\theta}} \tag{22}$$

Considering the steady state where $\dot{\mu}_{4t} = \dot{\mu}_{5t} = 0$ equation (21) leads to

$$\mu_{4t} = \frac{R'_{x1t} + B'_{x1t}}{(\delta - (g'_{1,x1t} - I'_{x1t}))} \tag{21a}$$

Considering equations (21) and (17) we get

$$R'_{q_{1t}} = \frac{R'_{x_{1t}} + B'_{x_{1t}}}{\delta - (g'_{1x_{1t}} - I'_{x_{1t}}(.))} \tag{21b}$$

Considering steady state solution, equations (15) and (21) lead to

$$\frac{C'(\theta)}{-I'_{\theta}} = \frac{R'_{x1t} + B'_{x1t}}{(\delta - (g'_{1,x1t} - I'_{x1t}))} \tag{21c}$$

From equation (16) assuming steady state where $\dot{\mu}_{5t} = 0$ we get

$$g'_{2,x2t} = \delta \tag{23}$$

The necessary conditions for maximising the social planer problem are reduced to equations 15–23. From equations (15) and (21) we can get θ^{*s} [5] and x_{1t}^{*S} considering equation (17) and assuming steady state. Equations (16) and (20) solve for x_{2t}^{*S} assuming steady state. q_{1t}^{*S} and q_{2t}^{*S} are obtained from equations (19) and (20) assuming steady state.

Condition (21c) implies that the anti-infiltration effort of the social planner is positive and greater than the levels obtained previously in the two market-based regimes, i.e., $\theta^{*S} > \theta^{*JM} > \theta^{*NJ}$. In addition, the social planner has a positive valuation of the protected forest which is greater than those of the local community and SODEFOR, as long as $B'(x_{1t})>0$. This high level of forest resource valuation requires a high level of effort from the local community, as depicted in equations (21a) and (21c). Therefore, the social planner solution requires a higher effort level than other two market solution regimes. The social planner's optimal solution shows a greater anti-infiltration effort and an extra term $B'(x_{1t})$ (the marginal public good effect) compared to the market-based solution. Thus, the socially optimal stock of forest would be greater than the joint management market situation level.

In this perspective, social welfare would improve if a financial reward is designed that fully compensates the effort of the local community. All these results are summarised in Table 1, where the effort level and welfare scenarios are presented according to internal and external economic incentives.

5 S stands for social planner solution.

Table 1: Economic incentives, effort level and social welfare scenarios

α tends to \ β tends to		0	1
0	without external financial support	S^1 : no effort	S^2: effort level with little welfare improvement
	with external financial support	$S^{1'}$: no effort	$S^{2'}$: highest effort level with welfare improvement
1	without external financial support	S^3: no effort but welfare improvement	S^4: effort level with more welfare improvement
	with external financial support	$S^{3'}$: no effort but welfare improvement	$S^{4'}$: greater effort level with more welfare improvement

Source: author

Scenarios S^1 and $S^{1'}$ describe the situation of current forest management where there are no incentives and there is no welfare improvement. S^2 describes the situation where more incentives are provided to the local community to apply more effort in conserving the forest. But, the highest effort level is obtained when external financial support is considered, as in $S^{2'}$. This scenario is best as far as joint management is concerned. In S^3 and $S^{3'}$ scenarios, no incentives are provided, but there is welfare improvement of the local community. These cases (especially $S^{3'}$) illustrate the situation of ongoing joint forest management projects promoted by NGOs where some socioeconomic infrastructure is provided, but the forest is still under pressure. Scenario S^4 provides fewer incentives compared to $S^{2'}$ and $S^{4'}$ but improves the welfare of the local community, and describes community forestry initiatives. In terms of welfare improvement, scenario $S^{4'}$ with external funding is best. Globally, the level of effort is higher with external financial support.

5.3 Economic policy measures

Policy measures follow from the adjustment of market solutions to the social planner’s solution. Considering the case where $B'(x_{1t}) = 0$, the adjustment requires that all profits from secondary activity should be given to the local community, that is, α tends to 0 and β tends to 1. This result suggests that activities related to the exploitation of forest by-products (charcoal, rafters, planks, beams, etc.) should be managed by the local community (Fernandez-Puente, 1996) while the logging activity is undertaken by SODEFOR, but with the forest management plan jointly designed. This would bring about social optimality. However, when considering the public good effect of forest ($B'(x_{1t}) > 0$), the policy measure that will help save the protected forest is to increase the value of secondary activity. In this way, both SODEFOR and the local community have more incentives for forest conservation. But, in relative terms, if SODEFOR's main activity is more valuable than the secondary one, then conservation will improve as the time preference is mitigated. Thus, increasing the share of secondary activity profit going to the local community is expected to increase the stock of protected forest. In addition, in the context of global warming, where forests play an important role, the need for greater conservation requires financial contributions on the part of the international community, in the form of Pigouvian subsidy to the local community. The extra term $B'(x_{1t})$ in this joint management justifies the external financial support for forest conservation.

6 Conclusion

The persistence of peasant encroachment on protected forest has raised the main question of whether the joint management policy initiated by SODEFOR has been properly implemented. To this end, we formulated a bio-economic model with two agents (local community and SODEFOR) and two activities (agriculture and forest conservation) to analyse the JMP using dynamic optimisation techniques in continuous time. The study provided information that could be used to strengthen policies aimed at improving the level of forest conservation and helping the local community grow out of poverty.

The main finding of this study is that JMP and equitable sharing of forest income to benefit the local community will improve the management of protected forests by mitigating the peasants' encroachments. Indeed, the article investigated what policy could stimulate forest conservation. First, the results show that increasing the share of SODEFOR's profit from its secondary activity going to the local community, and increasing the value of that activity, are expected to conserve the forest, since it will increase the stock of forest. Indeed, the highest optimal anti-infiltration effort supplied by the local community is obtained when that profit share is close to unity. Second, the study proposed that SODEFOR's main activity should be relatively more valuable than the secondary one, as long as it mitigates the time preference. Third, the study also noted that the natural growth rate of non-protected forest must be equal to the discount rate (opportunity cost of capital). Lastly, the article revealed the need for international support to sufficiently account for the existence and option values of the forest (i.e., its public good effect).

Globally, the article recommends the joint management initiative with profit sharing. This profit is related both to SODEFOR's protected forest activity and the international community's financial support. Beyond these recommendations, the results of this study allow room for the implementation of communal forest management policy, much as in Cameroon, the Gambia and Zimbabwe, where people living on communal land are given legal rights and technical assistance to sustainably manage their natural resources. Under this scheme, the local community uses profits derived from the exploitation of these resources for rural development, while at the same time contributing to forest conservation. Indeed, the government's ownership right over the forest resource since the colonial period not only failed to bring about better management, but has in fact contributed to the impoverishment of the rural population. In fact, with the full implication of local community, this approach constitutes an opportunity for income source diversification that limits the degree of vulnerability of the rural poor. Besides many shortcomings (such as lack of human, financial and material resources) of the former approach being solved by this participative approach, it can employ traditional knowledge and skills to improve the level of forest conservation. Therefore this new approach to forest management will help achieve the millennium development goals of reducing poverty in rural areas especially.

However, the effectiveness of these economic incentives depends on the reinforcement of the institutional framework within the international context of institutional decentralisation and democratisation.

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