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Implementation of national and international REDD mechanism under alternative payments for environemtal services: theory and illustration from Sumatra

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Abstract

This paper develops an analytical model of a REDD+ mechanism with an international payment tier and a national payment tier, and calibrate land users' opportunity cost curves based on data from Sumatra. We compare the avoided deforestation and cost-efficiency of government purchases across the two types of contracts–fixed price and opportunity cost, and across two government types– "benevolent" and "budget maximizing." Our paper shows that a fixed-price scheme is likely to be more efficient than an opportunity-cost compensation scheme at low international carbon prices, when the government is "benevolent," or when variation in opportunity cost within land users is high relative to variation in opportunity cost across land users. Thus, a PES program which pays local communities or land users based on the value of the service provided by avoided deforestation may not only distribute REDD revenue more equitably than an opportunity cost-based payment system, but may be more cost-efficient as well[1].

Keywords: Payment for Environmental Services, avoided deforestation, agricultural expansion, policy simulation.

[1]The authors thank Fabiano Godoy and Daniel Juhn from Conservation International for useful insights into the Sumatra database as well as participants to the 12th annual Bioecon conference (september 2010), and to the CERDI conference on "Environment and Natural Resources Management in Developing and Transition Economies" (November 2010). All errors remain ours.

1 Introduction

Slowing down deforestation in developing countries is one of the main priorities for the future of climate change mitigation. Indeed, tropical deforestation represents roughly 15 to 17% of anthropogenic emissions of CO_2 (Van der Werf et al., 2009; IPCC, 2007). Moreover, mitigating climate change by curbing deforestation in Southern countries has been estimated to be less costly than abating industrial emissions in Northern countries (Murray et al., 2009; Naucler and Enkvist, 2009). At the 13$^{\text{th}}$ Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) which took place in Bali in 2007, a number of tropical countries put a new mechanism on the negotiation table. This proposal is called Reduction of Emissions from Deforestation and forest Degradation (REDD)[2]. The main principle of REDD is simple: Northern countries provide financial transfers to the Southern countries which reduce their carbon emissions from deforestation below an agreed level, called the reference level. This North-South transfer is proportional to the difference between the reference level and the observed level of emissions from deforestation. Such a mechanism is an indirect way to give a monetary value to avoided carbon emissions by rewarding avoided deforestation, at a rate reflecting the market value of CO_2 emissions. Participation is voluntary, and in contrast to other North-South financial transfers such as development aid or structural adjustment programs, payments are based on observed outcomes rather than commitments to policy changes. At the 15$^{\text{th}}$ COP in Copenhagen in 2009, REDD was formally included in the Copenhagen Accord.

Implementation of REDD at the national level requires that participating Southern countries choose their own domestic policies to achieve their emission-reduction targets and to adequately avoid domestic emission displacements from areas where emissions are reduced to other areas. Amongst a wide array of deforestation-reduction policies, ranging from protected areas to control of illegal logging (Peskett el al., 2008), payments for environmental services (PES) are increasingly cited as an appropriate tool to reduce deforestation caused by agricultural activities in forest frontier area, which are estimated to be responsible for 75% of deforestation in developing countries (Angelsen, 2009), and to help achieve national REDD goals (Angelsen and Wertz-Kanounnikoff,

[2]The concept of REDD has since expanded to REDD+, which also includes conservation, sustainable management of forests, and enhancement of forest carbon stocks. This paper focuses on reduced deforestation rather than other elements of REDD+.

2008; Ogonowski et al., 2009; Angelsen, 2009; Bond et al., 2009). The underlying principle of PES is to “buy” from local land users a carbon sequestration and storage service provided by the reduction of their deforestation and forest degradation activities. There is a large variety of PES contracts, but the two main payment schemes include fixed-price contracts, in which a fixed payment is made to land users per hectare of avoided deforestation, and opportunity-cost contracts, in which payments are made to compensate opportunity costs of avoided deforestation, based on an evaluation of agricultural production losses incurred by land users when stopping deforestation. Southern countries wishing to participate to REDD will both have to decide on their deforestation goals (which will in turn set the international financial transfer they can expect) and the types of PES schemes they want to implement at the subnational level. These choices will depend on their preference in terms of budget management and agricultural surplus. In this paper, we will contrast the preferences of two types of governments: a benevolent government that maximizes national social welfare, and a budget-maximizing government that maximizes the net receipts from REDD (i.e. international REDD transfers minus internal payments to local landusers).

The aim of this paper is to compare for these two types of governments the outcomes of a fixed-price PES scheme and an opportunity cost PES scheme, for different prices of avoided CO_2 emissopns made by Northern countries. This analysis will provide insights on the strategic choices made by Southern countries, both in terms of deforestation objectives and in terms of domestic policies adopted to reduce deforestation. In section 2, we provide more insights into the policy issues discussed at the international level for REDD implementation. We then propose in section 3 a simple static optimization model capturing deforestation decisions by heterogeneous land users within a country. This model is used to compare the outcomes of two policy instruments to reduce domestic deforestation: an opportunity cost compensation PES scheme and a fixed-price PES scheme. We then simulate the policy choices made by a benevolent government and by a budget-maximizing government, as well as outcomes in terms of public budget surplus, local income, and total avoided deforestation. Section 4 provides a numerical simulation which helps to illustrate the sensitivity of these results to the characteristics of agricultural production functions in the country and enables us to compare the two schemes under different governmental preferences. In section 5, we use a GIS database on Sumatra’s opportunity costs of deforestation (Conservation International, unpublished), which enables us to measure the respective performance of the two PES schemes,

2 Reducing Emissions from Deforestation and Degradation and Payments for Environmental Services

Gibbs et al. (2010) estimate that 80% of recent tropical agricultural expansion is gained at the expense of primary or secondary forest, mainly through the activities of subsistence farmers, cash-crop small-holders and large companies, who clear forest to expand crops and cattle (Allen et al., 1985; Barbier and Burgess, 1997; Morton et al, 2006; Rudel, 2007, Angelsen, 2009). Prices, access to market, agricultural technologies, cost of conversion, land rights, and agro-ecological conditions are key factors in the decisions to cut down forests to expand agricultural land (Kaimowitz and Angelsen, 1998).

So far, the main policies used by governments of tropical countries to limit deforestation have been the setting-up of protected areas, with various consequences for land users who see the acess to the area severly restricted, and the control of illegal logging and clearing activities, which is costly and rarely efficient due to the poor definition of land use rights and the large area to be supervised (). The REDD scheme, by enabling developing countries to access new financial resources for avoiding deforestation, renders possible a new approach which is not based on command-and-control approach, but on incentives targeted land users. It consists in "buying" from them a service in terms of avoided deforestation through contracts like payments for environmental services (PES) (Wunder, 2009; Bond et al., 2009; Ogonowski et al., 2009). Wunder et al. (2008) give some evidence that well-designed PES schemes can result in efficient, cost-effective and equitable conservation of environmental services (ES).

A payment for environmental services scheme is based around a contract signed between providers and users of ecosystem services. The most widely-accepted definition of a PES is provided by Wunder (2005): it is (i) a voluntary transaction where (ii) a well-defined environmental service (ES) or a land use likely to secure that service (iii) is being bought by a (minimum one) service buyer and (iv) from a (minimum one) service provider (v) if and only if the provider continuously secures the provision of the service (conditionality). The underlying logic is simple: the providers of ES forego alternatives uses of land, and are compensated by the beneficiaries of the services (Bond et al., 2009). One of the key features of PES is the voluntary participation of ES providers: "PES schemes incorporate direct checks and balances on welfare and equity: if local people feel they will be disadvantaged by a conservation deal, they can simply decide not participate" (Wunder, 2009). Indeed, the contract is supposed to be a win-win agreement, where beneficiaries' payments are conditional on conservation performance. In theoretical terms, we expect that the payment must be at least equal to the minimum willingness-to-accept of ES provider, measured by its opportunity cost of ES provision, and at most equal to the maximum willingness-to-pay of the ES buyer, measured by its benefits of ES use. Within this range, a large spectrum of payment rules exists. In some schemes, ES buyers try to estimate the opportunity costs of each ES provider and establish individual payments offsetting these costs, as in Conservation International's Conservation Stewards Program (Niesten et al., 2010). Alternatively, ES buyers can establish a fixed payment per unit of ES provided. This is the policy implemented by the Government of Costa Rica to reward avoided deforestation, called Pago por Servicios Ambiatales (Pagiola, 2008; Wunder, 2009; Ogonowski et al., 2009). Other schemes also try to achieve equity or poverty alleviation objectives and establish other payments rules. For example, Brazil's Proambiente program involves paying a given share of minimum household income, while the Amazonas State Government's Bolsa Floresta program pays a fixed amount per family (Ogonowski et al., 2009). In this article, we will restrain our analysis to the first two types of payments: the opportunity cost compensation scheme and the fixed-price compensation scheme.

Angelsen and Wertz-Kanounnikoff (2008) and Angelsen (2009) liken the overall REDD architecture to a multi-level PES scheme: the main idea of REDD is to create a multilevel (global-national-local) system of payments for environmental services (PES) that will reduce emissions. The international REDD mechanism is clearly designed as a PES scheme, because developed countries (buyers) propose to pay governments in tropical forests countries (suppliers) for the supply of a global public good (avoided emissions from deforestation and degradation). Then, REDD income can be used by tropical country governments (buyers) to pay land users (suppliers) for on-the-ground emissions reductions through reduced deforestation and degradation activities.

Of course, such a PES/REDD scheme requires monitoring of performance within forest countries. It necessitates access to reliable deforestation data, which can be provided by satellite imagery, periodic on-site checks, and central database development (data on forest cover, forest biomass, soil carbon, tree health, illegal activities, infrastructures development, etc.) (Angelsen, 2009). This type of information is rarely available in tropical countries but those who wish to be eligible for REDD have joined a readiness phase for REDD, building their monitoring, reporting and verification (MRV) capacities, and strengthening institutions (reduction of corruption, clarification of land use rights and property rights, etc.) (Herold and Skutsch, 2009). The implementation of the first phase will be financed by Northern voluntary funds. In the Copenhagen accord established at the COP 15 in 2009, US, Australia, France, Japan, Norway and the UK promised USD 3.5 billion for fast-start funds to empower REDD. In the months following Copenhagen this figure surpassed USD 4.5 billion. In this article, we make the assumption that tropical countries have been able to pass the readiness phase successfully and have the capacity to implement PES schemes to reduce their deforestation. This means that they are able to estimate and report carbon emissions at national level, as set up in the IPCC Good Practice and Guidance (IPCC, 2003, 2006) for reporting at the international level, and that the necessary expenses for policy reform have been made to clarify land rights, improve the enforcement of law and eradicate corruption, facilitating the implementation of an effective, efficient and equitable REDD-PES mechanism at a meaningful scale (Gregersen et al., 2010; Angeslen, 2009). We assume therefore that they are in the implementation phase: a national reference level has been negotiated and their governments are implementing domestic policies actions in order to achieve deforestation reduction, financed by North-South transfer. We focus here on the PES policy instrument. .

3 Agricultural expansion and policy options to reduce deforestation: a multi-level PES scheme

This section provides a static model of deforestation decisions by land users, which is then used to identify optimal PES policy options by Southern governments. It is based on simple assumptions which help us to capture one of the important features of PES schemes: the structure of land users' opportunity costs.

Agricultural expansion in a business-as-usual deforestation

We consider a population of land users i, called "farmers" in the rest of the paper, practicing agriculture in frontier forest land. Each farmer i may need to extend his farmed land, choosing how much forest he will convert to agriculture. Under risk-neutrality, this choice takes the form of a profit maximizing problem:

$$\max_L \Pi_i = \max_L \lambda_i \, f\left(L\left(\lambda_i\right)\right) - \omega \, L\left(\lambda_i\right) \tag{1}$$

f is the agricultural revenue function of additional deforested land $L\left(\lambda_i\right)$. $f(L,z) = P \times y(L,z) - C(z)$. where y is the agricultural production funtion defining the output quantity as a function of deforested land L and the vector of all other inputs z, P is the price of output and $C(z)$ is the cost of all other inputs. We assume f to be twice differentiable and quasi concave $f' > 0$ and $f'' \leq 0$. λ_i is an efficiency factor characterizing each farmer i $(\lambda_i > 0)$. It encompasses both the productivity of deforested land, which depends mainly on its slope, elevation, or quality of soil(Kaimowitz and Angelsen, 1998); the farmer's technical capacity (which depends on its equipment and acces to technologies); and the difference between the local price and the national price of outputs and inputs (which may depend on the distance to main roads of farmer i and on his bargaining power). We assume that the set of farmers i is distributed uniformly along $\lambda_i \in \left[\underline{\lambda}; \overline{\lambda}\right]$. ω is the unit cost of land conversion. We assume, without loss of generality, that this cost is constant across land at the forest frontier.

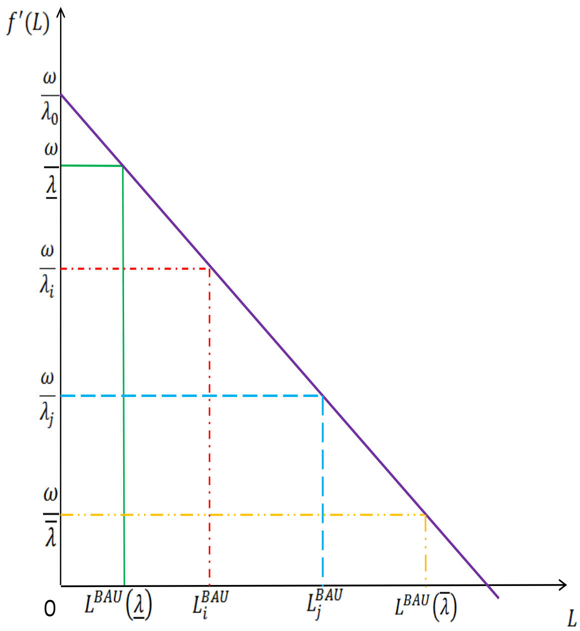
In the business-as-usual scenario (BAU), i.e. without any policy incentive to reduce deforestation, each farmer i chooses the level of deforestation $L_i^{BAU}\left(\lambda_i\right)$ maximizing his profit. The first-order condition is:

$$\frac{d\Pi_i}{dL} = 0 \iff \lambda_i \, f'\left(L\left(\lambda_i\right)\right) - \omega = 0 \iff f'\left(L\left(\lambda_i\right)\right) = \frac{\omega}{\lambda_i} \tag{2}$$

Since f' is strictly monotonically increasing, $L_i^{BAU}\left(\lambda_i\right) = \left(f'\right)^{-1}\left(\frac{\omega}{\lambda_i}\right)$.

We define $\lambda_0 = \frac{\omega}{f'(0)}$, for which $L_i^{BAU}(\lambda_0) = 0$. In the rest of the analysis we will only consider a population of farmers who deforest under the BAU scenario[3]. We assume therefore that $\underline{\lambda} > \lambda_0$. Under this condition, $L_i^{BAU}(\lambda_i) > 0$ for all λ_i. The deforestation behaviour is illustrated in Figure 1. For $\lambda_i < \lambda_j$ then $L_i^{BAU}(\lambda_i) < L_j^{BAU}(\lambda_j)$. All farmers deforest and total deforestation at the national level is L_T^{BAU} with $L_T^{BAU} = \int_{\underline{\lambda}}^{\overline{\lambda}} L_i^{BAU}(\lambda)\, d\lambda$.

Figure 1: Marginal revenue as a function of deforested area



The REDD scheme: a North-South transfer to avoid deforestation

Each tropical country that reduces its deforestation receives a REDD transfer T from developed countries, proportional to its avoided carbon emissions. For simplicity, we calculate the REDD transfer on the basis of avoided deforestation A, multiplied by a single proxy value for the quantity of carbon stored in one hectare of forest.A variety of methods have been proposed for setting the national reference level (Busch et al, 2009). We make the assumption in this paper

[3]There is in reality three cases, developed in appendix 1

that reductions are measured relative to a business-as-usual (BAU) deforestation level, i.e. the deforestation level if REDD were not put in place. In our model, the national reference level is thus the total BAU deforestation, $L_T^{BAU} = \int_{\underline{\lambda}}^{\overline{\lambda}} L_i^{BAU}(\lambda)\, d\lambda$. This reference level is compared to the observed deforestation under the PES contract, $L_T^P = \int_{\underline{\lambda}}^{\overline{\lambda}} L_i^P(\lambda)\, d\lambda$, each farmer i deforesting $L_i^P(\lambda_i)$ under the PES contract. The North-South transfer is T, calculated as:

$$T = t\,A = t\,(L_T^{BAU} - L_T^P)$$

t is the international transfer rate for saved CO_2 emissions. It reflects the value of avoided deforestation in terms of reduced emissions of carbon. $t = P \times EF$ where P is either the international carbon price, fixed by the market if forest carbon is introduced in the international carbon market, or an exogenous value chosen by Northern countries; and EF is the proxy carbon emissions factor, which converts deforestation into carbon emissions. In this paper, we do not consider differences of carbon density within a country's forest. Rather, we assume that EF is the same for all types of forests. We also assume that a country's level of aggregate deforestation can be observed without uncertainty due to the monitoring, reporting and verification capacities of the tropical countries, as described above.

National level: PES schemes

Southern government's optimal decisions to curb deforestation

The Southern country sets up a PES scheme to reduce deforestation, in order to join the international REDD scheme and obtain the transfer T described above from Northern countries. Such a PES/REDD scheme requires monitoring of performance within forest countries. In this article, we make the assumption that they have passed the readiness phase successfully. We consider two types of Southern governments: a "benevolent" government that maximizes social welfare, (measured here as total agricultural profit plus income from the international REDD transfer), and a "budget-maximizing" government that maximizes the difference between income from the international REDD transfer and payments made to farmers under PES schemes [4]. This

[4]For simplification, we do not consider the potential positive feedback effects on the budget of tax revenue from agriculture.We also assume that governments do not take into account in their utility function the environmental degradation associated with deforestation.

"budget-maximizing" type can capture the features of a corrupt government, wanting to divert public money to the benefit of a political elite, but it can also describe a government wanting to invest REDD income in other sectors (for education, health, infrastructure, or even agriculture). All linear combinations of these two extreme types describe the range of governmental behaviors that could be observed. The government maximizes its utility U, subject to budget constraint that total PES payments cannot exceed REDD transfers:

$$\begin{aligned} \max\ U &= T + \alpha\,(\Pi_T^{BAU} + \Pi_T^{P}) + (1-\alpha)\,(-E) \qquad (3) \\ s.t.\quad T &\geq E \end{aligned}$$

where T is the REDD transfer from Northern countries to the Southern government described above, Π^P is the total agricultural profit of all farmers participating in the national PES scheme, and Π^{BAU} is the total agricultural profit of all farmers who do not participate in the PES scheme and pursue their BAU agricultural activities. E is the total budgetary cost of the domestic PES scheme, corresponding to the payment from the Southern government to farmers participating to the PES. α describes the type of government: if $\alpha = 1$, the government is benevolent and maximises total welfare measured here as the sum of international transfers plus profits generated by agricultural activities [5]; and if $\alpha = 0$, it is budget maximizing.

Two PES schemes are considered in the following section[6]:

1) An "opportunity cost" compensation scheme in which each participating farmer is exactly compensated for his opportunity cost of reducing deforestation. In this scheme, we assume that participating farmers are required to abate deforestation to zero. The setting up of such scheme requires that the scheme manager (thereafter the government) acquires a good knowledge of individual farmer's agricultural profits.

2) A "fixed-price" scheme in which farmers are all offered the same fixed payment per hectare of avoided deforestation relative to their BAU deforestation. Under this scheme, farmers choose the

[5] PES payments to farmers are not included because they are considered domestic transfers: they are deducted from the public budget and added to farmers surplus. If we assume that PES have no transaction costs, then these payments are neutral in terms of total domestic welfare.

[6] These schemes align closely with the "quasi-auction scenario" and "per-ton carbon payment modality" described in Borner et al (2010)

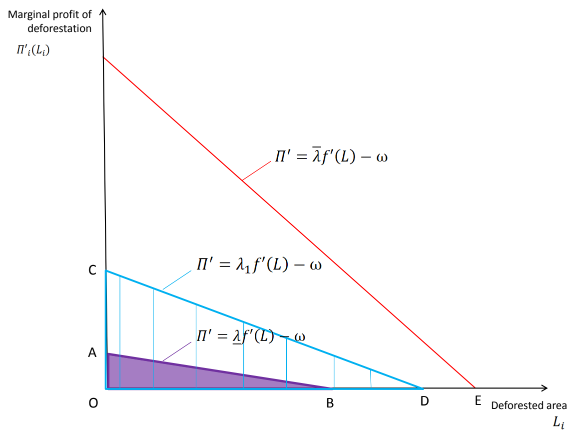
level of avoided deforestation they want to achieve. This is based on the assumption that public authorities can observe individual deforestation levels, both under BAU and under contract.

The opportunity cost compensation scheme

In the opportunity cost compensation scheme (OC) , we assume that the government can observe farmers' individual amounts of deforested areas under BAU, as well as farmers' opportunity costs. The government offers a compensation payment to farmers equal to their foregone revenue, if farmers agree to abate their level of deforestation to zero ($L_i^P(\lambda_i) = 0$ if i joins the scheme). In theory, farmers are indifferent between participating in the scheme in exchange for the foregone revenue, or pursuing their agricultural activities. We assume here that, if given the choice, farmers sign up and abate deorestation to zero. The government can thus select the farmers to whom a PES contract is proposed, and will choose those with the lowest opportunity costs.

The scheme is illustrated in Figure 2: in the BAU scenario, farmers $\underline{\lambda}$, λ_1 and $\bar{\lambda}$ deforest OB, OD and OE respectively. In the case where farmers $\underline{\lambda}$ and λ_1 are selected to participate in the OC scheme, farmer $\underline{\lambda}$ reduces deforestation to zero and gets paid OAB, farmer λ_1 also stops deforestation and gets a compensation OCD, and farmer $\bar{\lambda}$ is not invited to join the scheme, but deforests area OE.

Figure 2: Opportunity Cost Compensation Scheme



The government chooses the total level of deforestation which maximizes its utility, under the budget constraint that total payments to farmers are not greater than REDD transfers.

Farmers are invited to join the scheme, starting with the lowest opportunity cost farmer, up to the "marginal farmer" $\hat{\lambda}$, whose contribution to the scheme enables the government to achieve its chosen level of avoided deforestation. Farmer $\hat{\lambda}$ is thus the last farmer joining the OC scheme. He splits the group of farmers into two groups: those who are selected to participate, $\lambda \in [\underline{\lambda}, \hat{\lambda}]$, and stop deforesting $L_i^P(\lambda_i) = 0$ in exchange for an exact compensation of their opportunity costs, and those who do not participate, $\lambda \in [\hat{\lambda}, \overline{\lambda}]$, and continue to deforest as usual $L_i^{BAU}(\lambda_i)$.

Under this scheme, the benevolent government's maximization problem is:

$$\begin{aligned} \max_{\hat{\lambda}^B} U &= \max_{\hat{\lambda}^B} t \int_{\underline{\lambda}}^{\hat{\lambda}^B} L_i^{BAU}(\lambda) d\lambda + \int_{\hat{\lambda}^B}^{\overline{\lambda}} \Pi_i^{BAU}(L(\lambda)) d\lambda \\ s.t. \quad t \int_{\underline{\lambda}}^{\hat{\lambda}^B} L^{BAU}(\lambda) d\lambda &\geq \int_{\underline{\lambda}}^{\hat{\lambda}^B} \Pi_i^{BAU}(L(\lambda)) d\lambda \end{aligned} \tag{4}$$

while, the budget maximizing government's program is:

$$\begin{aligned} \max_{\hat{\lambda}^M} U &= \max_{\hat{\lambda}^M} t \int_{\underline{\lambda}}^{\hat{\lambda}^M} L_i^{BAU}(\lambda) d\lambda - \int_{\underline{\lambda}}^{\hat{\lambda}^M} \Pi_i^{BAU}(L(\lambda)) d\lambda \\ s.t. \quad t \int_{\underline{\lambda}}^{\hat{\lambda}^M} L^{BAU}(\lambda) d\lambda &\geq \int_{\underline{\lambda}}^{\hat{\lambda}^M} \Pi_i^{BAU}(L(\lambda)) d\lambda \end{aligned} \tag{5}$$

We can see that the two maximization problems are equivalent. Indeed, increasing $\hat{\lambda}$ has exactly the opposite impact on $\int_{\hat{\lambda}}^{\overline{\lambda}} \Pi_i^{BAU}(L(\lambda)) d\lambda$ and on $\int_{\underline{\lambda}}^{\hat{\lambda}} \Pi_i^{BAU}(L(\lambda)) d\lambda$. This is due to the uniform distribution assumption of the λs[7]. Therefore, the marginal agent for the benevolent case, identified by $\hat{\lambda}^B$, is the same as for the budget maximizing case $\hat{\lambda} = \hat{\lambda}^B = \hat{\lambda}^M$: it is the agent whose average opportunity cost of avoided deforestation is equal to t, $t = \frac{\Pi(L^{BAU}(\hat{\lambda}))}{L^{BAU}(\hat{\lambda})}$. This result, which is only valid for the OC scheme, is easily understood: the interests of the benevolent government (which maintains agricultural activity of high profit farmers) converge with the interests of the budget-maximizing government (which selects the lowest cost farmers to limit PES expenditures). Moreover, the budgetary constraint imposes that the minimum North-South transfer rate t be at least equal to the average opportunity cost of $\underline{\lambda}$: in this case $\underline{\lambda}$ is the only farmer joining the scheme and $t_{min} = \frac{\Pi\left(L^{BAU}(\underline{\lambda})\right)}{L^{BAU}(\underline{\lambda})}$. For more details about results, see Appendix 3.

[7] under the assumption that the λs are uniformly distributed

The fixed-price scheme

In the fixed-price (FP) scheme, the government offers a fixed-price K per unit of avoided deforestation. Each farmer i joining the scheme chooses the level of deforestation $L_i^P(\lambda_i)$ he wants to commit to, in order to maximize his income $R^P(\lambda_i)$. The government chooses the total deforestation level, which maximizes its utility: it sets the optimal $K*$ per hectare of avoided deforestation corresponding to the desired total avoided deforestation.

Figure 3 illustrates the fixed-price scheme: farmers $\underline{\lambda}$, $\breve{\lambda}$, $\overline{\lambda}$ join the scheme. Farmers $\underline{\lambda}$ and $\breve{\lambda}$ reduce deforestation to zero and get paid respectively OABC and OADE. Farmer $\overline{\lambda}$ reduces deforestation from OI to OH and gets paid FGHI.

The farmer's maximization program is:

$$\begin{aligned} \max_L \; R^P &= \lambda_i f(L(\lambda_i)) - \omega L_i^P(\lambda_i) + K\left(L_i^{BAU}(\lambda_i) - L_i^P(\lambda_i)\right) \\ s.t. \quad & L_i^{BAU}(\lambda_i) > L_i^P(\lambda_i) \text{ and } R^P(\lambda_i) \geqslant \Pi_i^{BAU}(L_i) \end{aligned} \tag{6}$$

The first-order condition is:

$$\frac{dR}{dL} = 0 \iff f'(L^p(\lambda_i)) = \frac{\omega + K}{\lambda_i} \tag{7}$$

Since $\frac{\omega+K}{\lambda_i} \geq \frac{\omega}{\lambda_i}$ and f' is a decreasing function, $L_i^P(\lambda_i) = f'^{-1}(\frac{\omega+K}{\lambda_i}) \leq L^{BAU}(\lambda_i)$ is always verified.

The benevolent government's maximization problem is:

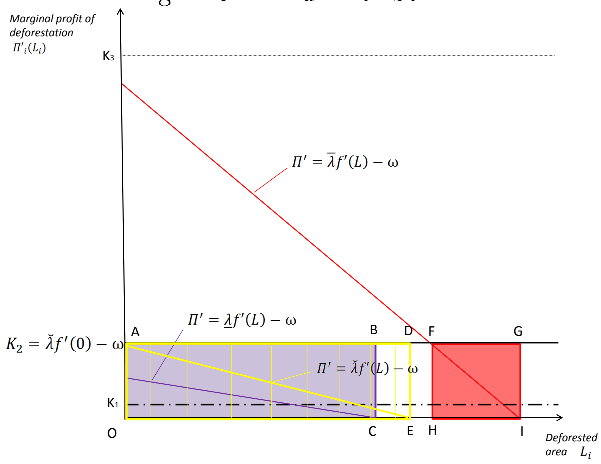
$$\begin{aligned} \max_{K^B} U\left(K^B\right) &= \max_{K^B} t \int_{\underline{\lambda}}^{\overline{\lambda}} \left(L_i^{BAU}(\lambda) - L_i^P\left(\lambda, K^B\right)\right) d\lambda + \int_{\underline{\lambda}}^{\overline{\lambda}} \Pi_i^P\left(\lambda, K^B\right) d\lambda \\ s.t. \quad t &\geq K^B \end{aligned} \tag{8}$$

while the budget-maximizing government's program is:

$$\begin{aligned} \max_{K^M} U\left(K^M\right) &= \max_{K^M} \left(t - K^M\right) \int_{\underline{\lambda}}^{\overline{\lambda}} \left(L_i^{BAU}(\lambda) - L_i^P\left(\lambda, K^M\right)\right) d\lambda \\ s.t. \quad t &\geq K^M \end{aligned} \tag{9}$$

We can see from equation 8 and 9 that the fixed price K^B influences positively the benevolent government's utility through higher payments to farmers, whereas the fixed-price K^M reduces the budget-maximizing government's utility.

Figure 3: Fixed-Price Scheme



In order to calculate total avoided deforestation and total PES budget, we need to distinguish between different levels of $K*$:

- Case 1: if $K*, < \underline{\lambda} f'(0) - \omega \Rightarrow L_i^P(\lambda_i) = f'^{-1}\left(\frac{\omega + K_1}{\lambda_i}\right)$, $\forall \lambda \in \left[\underline{\lambda}; \overline{\lambda}\right]$ when let's call $K* = K_1$, all farmers sign the contract and partially reduce their deforestation. Total deforestation is $L_T^P = \int_{\underline{\lambda}}^{\overline{\lambda}} L_i^P(\lambda)\, d\lambda$.

- Case 2 : if $\underline{\lambda} f'(0) - \omega \leq K* < \overline{\lambda} f'(0) - \omega, \Rightarrow \begin{cases} L_i^P(\lambda_i) = 0 & \text{for } \forall \lambda \in \left[\underline{\lambda}; \breve{\lambda}\right] \\ L_i^P(\lambda_i) = f'^{-1}\left(\frac{\omega + K_2}{\lambda_i}\right) & \text{for } \forall \lambda \in \left[\breve{\lambda}; \overline{\lambda}\right] \end{cases}$ then let's call $K* = K_2$, all agents join the PES scheme. We define $\breve{\lambda} = \frac{\omega + K_2}{f'(0)}$: farmers with $\lambda \in \left[\underline{\lambda}; \breve{\lambda}\right]$ stop deforestation altogether, whereas farmers with $\lambda \in \left[\breve{\lambda}; \overline{\lambda}\right]$ stop only partially deforestation. The total national level of deforestation is $L_T^P = \int_{\breve{\lambda}}^{\overline{\lambda}} L_i^P(\lambda)\, d\lambda$.

- Case 3: if $K* \geq \overline{\lambda} f'(0) - \omega$, then let's call $K* = K_3 \Rightarrow L_i^P(\lambda_i) = 0\ \forall \lambda \in \left[\underline{\lambda}; \overline{\lambda}\right]$, all farmers sign the contract and abate deforestation to zero. We assume that the government will give the lowest fixed-price $K = \overline{\lambda} f'(0) - \omega$, to avoid overpayments.

In all cases, the budget constraint imposes that $t \geq K$. For more details about the results see Appendix 3.

Comparison of the two schemes

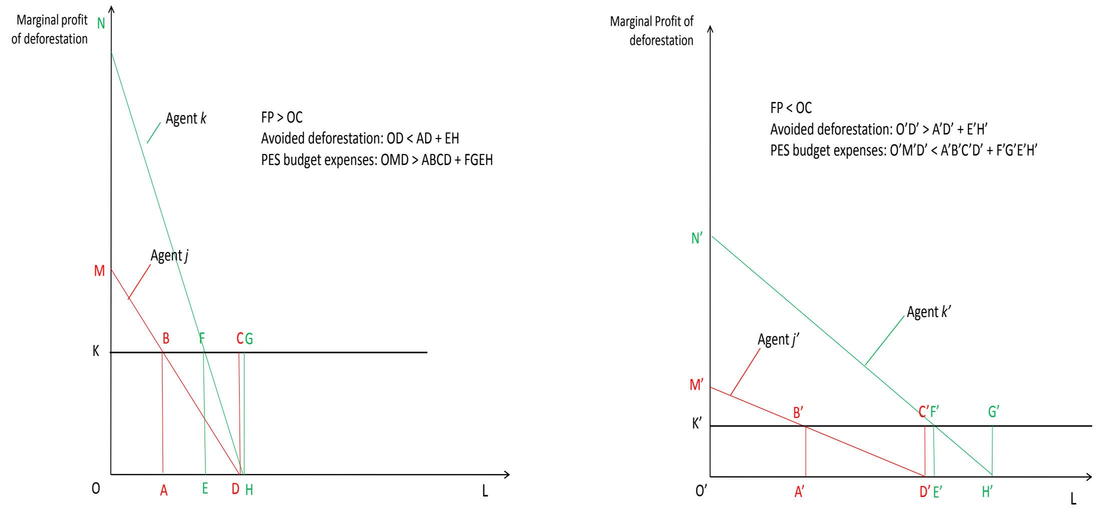
We choose to contrast these two schemes because they both have advantages and drawbacks. It is straightforward that the fixed-price scheme provides farmers with a positive net surplus since farmers are always paid more than their true opportunity costs per hectare (see figure 3). By contrast, in the OC scheme, farmers get no extra surplus. From a poverty alleviation viewpoint, the FP scheme is more desirable than the OC scheme. From a budgetary efficacy viewpoint, it might seem natural to suppose that the OC scheme would always perform better. But this is not always the case. Since farmers joining the scheme have to reduce deforestation to zero, the last units of avoided deforestation are costly, especially if the marginal opportunity cost curve of farmers is steep. Therefore there is a tradeoff between paying too much but targeting the least costly units of avoided deforestation in the fixed-price scheme, and just compensating the opportunity costs but also enrolling high cost units of avoided deforestation in the OC scheme. Thus when considering an OC scheme versus a FP scheme, it is necessary to consider the trade off between including the most profitable units of deforestation of agents deforesting the least in the OC scheme, and the least profitable units of deforestation by all agents in the FP scheme. Which scheme is more efficient hinges upon a comparison of the overall opportunity cost of the agents, and the steepness of their marginal profit curve.

Of course, the ideal scheme from an efficiency and efficacy viewpoint would be an OC scheme in which the regulator can also impose the individual deforestation abatement to each farmer. Such OC scheme would surpass the fixed-price scheme in all settings and there would be no interest in contrasting the two schemes. But such scheme would require perfect information both on farmers' types and behaviours.

To illustrate the trade-off, consider the extreme case of a society with only two famers j and k (see figure 4, case 1 and 2), who differ both in their total opportunity costs and marginal profit curves. In case 1, agents deforest about the same land area and the slope of their marginal profit curves are steep. In case 2, agents'marginal profit curves are flatter than in case one, and j' and k' do not deforest the same amount of land. In case 1, as the marginal profit curves are steeper than in case 2, so for an equivalent amount of total opportunity costs (ONH $\approx$ O'N'H'and ODM$\approx$O'D'N'), agent k and j deforest less than k' and j' (OH $<$ O'H' and OD $<$ O'D') so opportunity costs per hectare is higher for agent k than k' and for agent j tan j'.

We assume that the government arbitrarly selects agent j in case 1 and j' in case 2 for participaton to the OC scheme. Under this hypothesis, in case 1 (case 2), avoided deforestation area is OD (O'D') and total budget expenses are OMD (O'M'D'). Now consider that the government implements a fixed-price scheme with an arbitrary fixed-price of K in case 1, and K' in case 2. Under this scheme, in case 1 (case 2) avoided deforestation is AD+EH (A'D'+E'H') and total budget expenses are ABCD+EFGH (A'B'C'D'+E'F'G'H'). We see graphically that in case 1 the fixed-price scheme performs better in terms of avoided deforestation and it costs less than the OC scheme, while we observe the contrary in case 2. The OC scheme has a more efficient outcome than the fixed-price scheme in case 2, and vice-versa in case 1. Overall, this simple example shows that we can expect the fixed-price scheme to be more efficient - i.e. performing better in terms of avoided deforestation at lower cost - than the OC scheme, when the marginal benefit curves are steeper. It is explained by the trade-off described above between high payments for the least costly units of avoided deforestation in the fixed-price scheme, or just compensating the opportunity costs but also paying for high cost units of avoided deforestation in the OC scheme.

Figure 4: Comparison of the FP and OC schemes with two agents



Case 1 : Steep marginal opportunity cost curves   Case 2: Flat marginal opportunity cost curves

Indeed, the decision to compare these settings is also based in the structure of information and control costs (table 1). An OC scheme imposing abatment to zero is easier to control than an OC

Table 1: Needs of informations for each scheme

	OC scheme	Fixed-price scheme
Information on OC structure	necessary	not necessary
Information on BAU deforestation level	necessary	necessary
Information on individual deforestation level under PES	not necessary	necessary

sheme where each land user has a specific deforestation level allowed (table 1). In contrast, under the fixed-price scheme, the government does not need to know the opportunity costs structure of land users, it just needs information on deforestation level (table 1).

Gregersen et al. (2010) emphasize the fact that an opportunity costs approach may be inappropriate to implement equitable and effective REDD program in case notably of unclear property rights on land and carbon or other governance issues of corruption, enforcement of laws or weak MRV system. As we suggest before, we consider here that these issues are resolved in a readiness phase, previous the implementation phase. In case of the participants "have clear title to their deforest lan, opportunity cost would be a relevant indicator as a strating point for the negociations for REDD+ payments" (Gregersen et al., 2010). Of course, the implementation of such PES contracts have significant transactions and implementation costs (Gregersen et al., 2010) but the two schemes do not require the same information and monitoring costs (table 1). Since such costs are very difficult to estimate, we make the simplifying assumption that these costs are equivalent in average so in the following, we will not take them into account to compare the two schemes. We further assume that there is no price feedback effect and leakage. In other words, the reduction of deforestation by agents joining a PES scheme does not provide additional incentives to non contracting farmers to increase their deforestation levels. Moreover, we assume that the payment is additional therefore payments do not go to someone who would have not deforested in any case.

4 Comparison of PES schemes for the two different types of governments: numerical simulations

Analytical results with a quadratic function

Without an analytical expression of $f(L_i)$, results in terms of total avoided deforestation, welfare, and budgetary costs (available in Appendix 3), cannot be compared. In this section, we assume that $f(L_i)$ is a quadratic function: $f(L_i) = \frac{a}{2}L_i^2 + bL_i + c$, with $a < 0$, and $b, c > 0$. Thus $f'(L_i) = aL_i + b$ and the lower a is, the steeper the marginal curve is, which, as mentioned above, is a crucial element determining the relative budgetary efficiency of the two schemes.

The BAU deforestation rate for farmer i is thus $L_i^{BAU}(\lambda_i) = \frac{\omega}{a\lambda_i} - \frac{b}{a}$, and his profit is $\Pi_i^{BAU}(\lambda_i) = -\frac{\omega^2}{2a\lambda_i} + \left(c - \frac{b^2}{2a}\right)\lambda_i + \frac{b\omega}{a}$. To be consistent with section 2, we restrict parameter values in order to limit our analysis to a population of farmers having strict positive values of BAU deforestation: $L_i^{BAU} > 0 \Rightarrow \frac{\omega}{b} < \lambda_i$ and $\Pi^{BAU}(\lambda_i) > 0 \Rightarrow -\frac{\omega^2}{2a\lambda i} + \left(c - \frac{b^2}{2a}\right)\lambda_i > -\frac{b\omega}{a}$.

- Under the OC scheme, the benevolent and the budget-maximizing governments adopt the same target group of participating farmers. The marginal agent splitting the farmers' population into two groups is $\hat{\lambda}$:

$$\hat{\lambda} = \frac{b(\omega + t) + \sqrt{t^2b^2 + 2ac\omega^2 + 4ac\omega t}}{b^2 - 2ac}$$

With values of a, b, c, t, and ω such that $t^2b^2 + 2ac\omega^2 + 4ac\omega t > 0$.

- Under the fixed-price scheme, farmers maximize their income, choosing their level of deforestation $L_i^P(\lambda_i) = \frac{1}{a}\left(\frac{\omega+K}{\lambda_i} - b\right)$. Avoided deforestation by farmer i is $A = L_i^{BAU} - L_i^P = -\frac{K}{a\lambda_i} > 0$ and his income under the scheme increases: $R_i^P - \Pi_i^{BAU} = -\frac{K^2}{2a\lambda_i} > 0$. Avoided deforestation increases as K increases and is greater for low productivity farmers (low λ_i) and for flat opportunitu cost curves (low a). Moreover, there is a reinforcement effect: $\frac{\partial^2 A_i}{\partial\lambda_i\partial K} = \frac{1}{a\lambda_i^2} < 0$; When K increases, the gains in terms of avoided deforestation are lower for high productivity farmers with high λ_i.

As noticed before, agents are better off when the FP scheme is introduced. Moreover, note that the net gain in income is larger for farmers with low productivity and for farmers whose marginal profit curves are flatter: $\frac{\partial(R_i^P - \Pi_i^{BAU})}{\partial \lambda_i} < 0$ and $\frac{\partial(R_i^P - \Pi_i^{BAU})}{\partial a_i} > 0$.

As stated above, we may face three different cases depending on the optimal value of K^* chosen by each type of government. In case 1, where all farmers participate to the fixed-price scheme but nobody stops deforestation altogether, the benevolent government redistributes the total amount of North-South REDD transfer through the fixed-price scheme ($K^* = t$); while the budget-maximizing government redistributes only half of the international REDD transfer $\left(K^* = \frac{t}{2}\right)$. In case 2, where some farmers are encouraged to stop deforestation altogether and others continue partially with agricultural activity, we observe that K^{*B} and K^{*M} are distinct from each other, but without numerical analysis we cannot determine the value of the fixed-price chosen by each government (see appendix 3 for more details). In case 3, where all farmers stop deforestation altogether, we consider that the Southern government chooses the lowest fixed-price scheme possible, i.e. the marginal opportunity cost of the last unit of deforested area of $\overline{\lambda}$: $K^{*B} = K^{*M} = \overline{\lambda}\, b - \omega$.

Results of numerical simulations

In order to illustrate the different types of policy responses we can obtain, we choose two contrast sets of parameters, presented in Table 1.

Parameter	a	b	c	ω	$\underline{\lambda}$	$\overline{\lambda}$	$\Pi(\underline{\lambda})$	$\Pi(\overline{\lambda})$	L_T^{BAU}	$\frac{\Pi(\underline{\lambda})}{L_T^{BAU}}$	$\frac{\Pi(\overline{\lambda})}{L_T^{BAU}}$
Simulation 1	-53	53	57	30	30	900	2 475	75 000	868	2 500	75 000
Simulation 2	-5	160	15	400	3	35	260	78 000	827	49	2 620

Table 2: Parameter values in the two simulations

The two sets of parameters (simulations 1 and 2) lead to equivalent total deforestation under the BAU scenario (around 850). High profit farmers are also quite similar in the two simulations (the highest deforestation profit is 75000 under simulation 1 and 78000 under simulation 2).

whereas the farming population in simulation 1 displays a much wider range of opportunity costs per unit of deforestated area than the population of simulation 2 (the opportunity cost per unit of deforested area is between 2500 and 75000 under simulation 1, and between 49 and 2620 under simulation 2). The agricultural productivity factor is multiplied by 30 between the least productive and the most productive farmer in simulation 1, it is only multiplied by 12 in simulation 2. In simulation 1, the marginal opportunity cost curve is steeper than in simulation 2. Then two characteristics differ between both simulations: simulation 1 presents more heterogenous average oppportunity costs and steeper marginal profit curves, compared to simulation 2.

We calculate total avoided deforestation and total utility of Southern governments, under the two schemes, for the benevolent government and for the budget maximizing government[8]. Figure 5 to 8 present these results.

To analyze numerical results, we will focus on two policy issues:

1) What is the preferred PES scheme of the benevolent government and of the budget-maximizing government, for a given level of international transfer t? To answer this question, we assume that they choose PES scheme that provides the highest utility as define by equation 3 (figure 5 and 7).

2) If Northern countries had to select REDD countries, which ones would they choose? Since in our model, international payments are strictly proportional to avoided deforestation, Northern countries are supposed to be indifferent between targeting a single country or several countries for an equivalent total avoided deforestation. But we assume that setting up a REDD scheme and monitoring it is costly and that Northern countries prefer to limit the number of Southern countries joining REDD. Moreover, it is very likely that the purchase of emission reductions takes the form of bilateral agreement[9]. Therefore, they will select countries offering the highest deforestation abatement (figure 6 and 8). Do the preferences of Northern countries coincide with policy choices made by Southern countries?

We note that in simulation 2, the values of K are close to the t for the benevolent state and to $\frac{t}{2}$ for the budget-maximizing state. In contrast, in simulation 1, the values of K move away respectively from t and $\frac{t}{2}$. We note that for the highest values of t, the fixed-price of the benevolent state is inferior to the fixed-price of the budget-maximizing state.

[8]Under the OC scheme, the results in terms of avoided deforestation and budget expenses per unit of avoided deforestation are similar for the two types of governments, because they choose the same marginal farmer.

[9]Implementation phase could be based on bilateral agreement, between one Northern countries or an other buyers of REDD credits and developing countries. For example, California's private purchases are due to begin in 2012. California will likely only choose to contract a REDD agreement with only one or two countries and this choice will be partially guided by where they can reasonably expect that a sufficient number of high-quality offsets can be supplied.

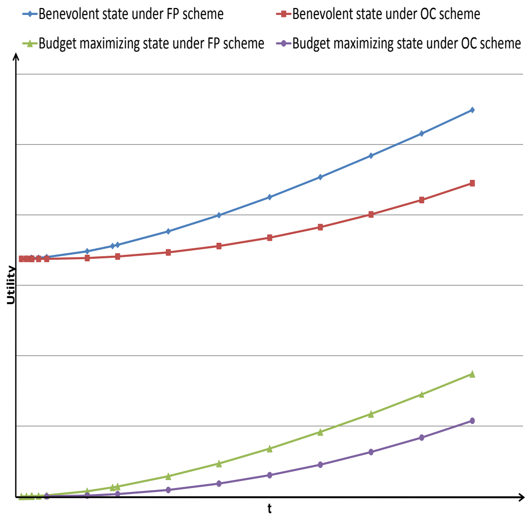


Figure 5: Simulation 1
Utility evolution as a function of t

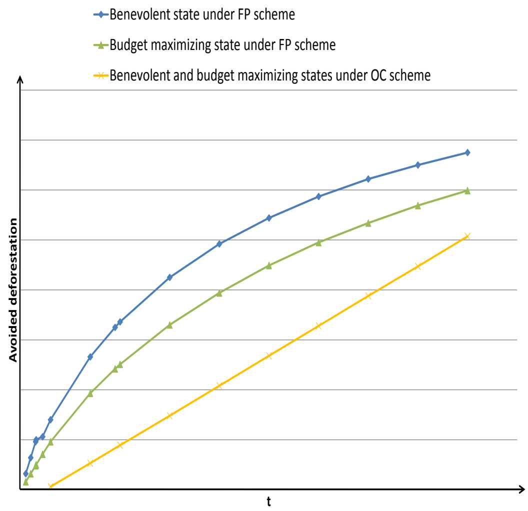


Figure 6: Simulation 1
Avoided deforestation as a function of t

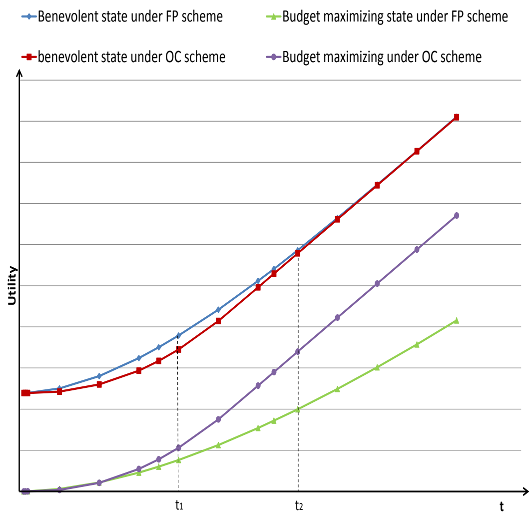


Figure 7: Simulation 2
Utility evolution as a function of t

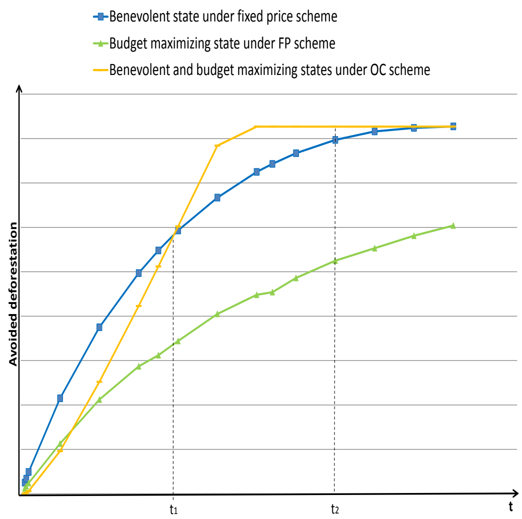


Figure 8: Simulation 2
Avoided deforestation as a function of t

Simulations 1 and 2 provide contrasted responses to these questions, according to the structure of the opportunity costs per hectare (see explanations in the previous analytical analysis).

- In simulation 1, the fixed-price scheme is clearly superior to the OC scheme for all levels of carbon price: it provides the highest government utility, both for the benevolent government and the budget maximizing government; it is also the scheme with the highest total deforestation, for both types of governments. Figure 5 shows that donor countries would select a benevolent-type government adopting a fixed-price scheme. In simulation 1, the marginal opportunity cost curves are steep: since the last units of avoided deforestation are costly, the fixed-price scheme is preferred to the OC scheme.

- Simulation 2 presents a more complex picture. For levels of $t < t_2$, the benevolent government prefers the fixed-price scheme to the opportunity cost scheme, whereas for $t > t_2$, there is no clear advantage of one scheme over the other. The benevolent government faces a trade-off between offering a high compensation to farmers (through a fixed-price sheme) and getting a high international transfer (obtained through an OC scheme which garantees larger area of avoided deforestation). Therefore, when the unit transfer t reaches the threshold t_2, the benevolent government becomes indifferent between the two schemes. The budget-maximizing government, on the contrary, will increasingly prefer the OC scheme when t increases. Does this coincide with Northern countries' preferences? For $t < t_1$, they would select a benevolent government with a fixed-price scheme. For $t > t_1$, they will prefer any type of government adopting an OC scheme. This indicates that for values of t between t_1 and t_2, Northern countries will select in priority budget-maximizing governments because for this range of t values, benevolent states prefer fixed-price schemes. In simulation 2 the opportunity costs per hectare are lower than in simulation 1. It explains why the budget-maximizing government prefers paying farmers their opportunity costs, even for the last, more expensive units, rather than a fixed-price.

Table 3: Outcome in simulation 2

Transfer rate	$t < t_1$	$t_1 < t < t_2$	t_2
Choice of the benevolent gouvernement	FP scheme	FP scheme	indifferent
Choice of the BM gouvernement	OC scheme	OC scheme	OC scheme
Choice of donor countries (North)	Benevolent gouvernement under FP scheme	BM gouvernement under OC scheme	BM or benevolent gouvernement under OC scheme

5 Illustrative case study: Northern Sumatra

Description of the data

To go beyond numerical analysis, we test our model in an empirical context. The Indonesian case is very interesting because this country has one of the highest deforestation rates in the world and Indonesia's government shows a willingness to get involved in REDD mechanism process. Indonesia's greenhouse gas emissions ranked at the fourth-highest in the world in 2005, following China, the United States and Brazil (CAIT, 2010). Over 70% of these emissions are due to conversion of natural forests and the associated burning and draining of peat lands (CAIT, 2010). Conversion is driven largely by lucrative production of export crops such as palm oil and coffee, with extractive logging often offering a source of up-front finance for agricultural conversion. Sumatra lost about 30% of this forest cover between 1985 and 1997 (FWI/GFW, 2002) and this trend has accelerated over the last ten years (FFI and Carbon Conservation, 2007). Progress toward national REDD readiness in Indonesia is well advanced relative to other countries. In 2007, Indonesia created the Indonesian Forest-Climate Alliance (IFCA), supported by several bilateral donors (for example GTZ, DFID, AusAID) and the World Bank built a national framework for long-term REDD implementation and identify the main methodological hurdles threaten the REDD mechanism (Murdiyarso, 2009). Different pilot projects have been identified, led by local governments, local NGO and private donors and companies. The main challenges for Indonesia for the 2009-2012 period is to specify the rights and responsibilities of local communities, to address issues of land insecurity of smallholders and the compensation of large landowners' forest rents, and to strengthen monitoring, reporting and verification capacities (Murdiyarso, 2009). Different tools are currently tried in Indonesia to implement REDD mechanism: protected areas

(FFI and Carbon Conservation, 2007), PES and concession purchases (Madeira, 2009). A number of studies have examined REDD+ scenarios in the Indonesian context (Gaveau et al., 2009; Venter et al., 2009; Koh and Ghazoul, 2010) but to our knowledge ours is the first to examine the implications of alternative payment distribution mechanisms.

To test the impact of different PES schemes on forest cover in Indonesia, we need to build a model of deforestation driven by agricultural profits. We use a GIS data set follows Gaveau et al. (2009) located in the Northern half of the Indonesian island of Sumatra. This portion corresponds to the forest cover of three provinces, which are divided into 37 districts. We study the forest cover evolution between 1990 and 2000 in these three provinces. Our objective is to estimate the BAU deforestation level and to compare this situation to a scenario where PES schemes would be implemented.

Data on forest cover observed for the years 1990 and 2000 was obtained from 30 m resolution change detection imagery (Conservation International, cit), aggregated to the 900 m level using a 50% forest cover threshold. Our database contains only land covered by old-growth forest in 1990, representing 7 160 800 hectares of forest, each cell of the database in 1990 corresponds to 100 hectares of forest. Between 1990 and 2000, the studied forest cover decreased, and we observed a loss of 867 900 hectares of forest (average annual deforestation rate of 1%). Oil palm production is the main driver of deforestation in Sumatra and the more profitable activity responsible of deforestation(FWI/GFW, 2002; Madeira, 2009), so we consider that deforestation between 1990 and 2000 are due to conversion for oil palm plantations, which allowed us to estimate opportunity cost ceiling for forest cover. The influence of driver variables on forest cover change between 1990 and 2000 was modelled using the logit regression. Explanatory variables are suitability for oil palm production, forest biomass, slope, and elevation. This modeled regression estimates was used to build an "effective opportunity cost", representing the profit from conversion to oil palm for each cell. Details on the econometric model and the construction of the opportunity costs are developed in appendix 5.

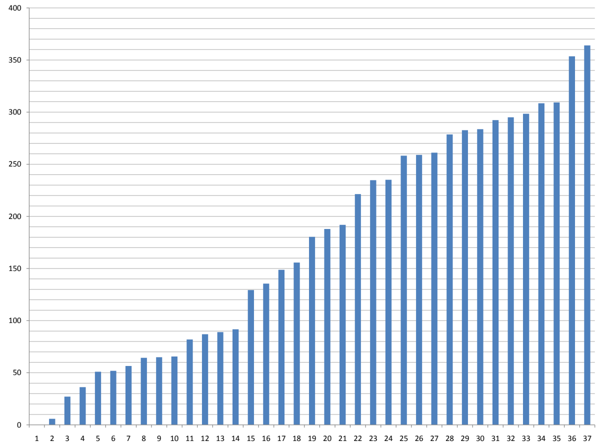
If the profit of one cell is positive, we consider that the cell should have been deforested between 1990 and 2000 under the BAU scenario. Thanks to this method, the total estimated deforested area between 1990 and 2000 is equal to the observed deforested area between 1990 and 2000 (867 900 hectares), and the distribution of deforested areas through each district is equivalent (the difference between deforested areas observed and estimated between 1990 and 2000, is inferior to 1% for each district). Data on above- and belowground forest biomass was obtained from Tier I IPCC estimates (Ruesch and Gibbs, 2008), and we observe that on average in the database, carbon density is 172 tC/ha, so we estimate that carbon emitted between 1990 and 2000 has reached 54.7 million tCO_2e/year on average. Deforestation for oil palm production between 1990 and 2000 yielded an average profit of 233USD/year. This total agricultural profit also corresponds to the amount of compensation that would have to be paid in order to conserve a unit of forest that would otherwise be converted to oil palm plantation. To have an idea about the budget needed to stop deforestation, if we made the simple assumption that we can pay the carbon/hectare at the opportunity costs/hectare, to completely avoid deforestation in the studied zone between 1990 and 2000, a average price of 4.25$/$tCO_2$is sufficient ($\frac{233}{54.7}$).

Simulation

We assume that a PES/REDD payment is paid to each district according to the two types of PES described before: OC scheme and fixed-price scheme. Whereas our analytical model was developed at the farm level, reductions in deforestation achieved under alternative PES policy scenarios in Sumatra were modeled at the district level (37 districts). We assumed that a district represents the aggregated decisions of all farmers living in the district. This hypothesis is closed to what happens in some REDD pilot projets in Sumatra, as those of the provincial government of Nanggroe Aceh Darussalam, supported by the NGO Fauna and Flora International and the Australian company Carbon Conservation Pty Ldt. This project was proposed in 2007 to justify land reclassification from production areas to conservation areas and community-managed low-impact areas, by using carbon finance. It was approved under Climate Community and Biodiversity Standards in 2008 by Rainforest Alliance[10]. It would be implemented by district's government, and communities have indicated a strong willigness to participate. In our simulation, the opportunity cost curve of a district is made of the ordered, from highest to lowest, estimated opportunity costs of each cell located in the district. We ranked districts from the lowest average opportunity cost district (equivalent to our $\underline{\lambda}$ farmer in the section 3 model) to the highest (equivalent to farmer $\overline{\lambda}$) (figure 5). Of course the distribution of district profits is not continuous

[10]http://www.climate-standards.org/projects/index.html

Figure 5: Distribution of the average opportuniy costs per hectare of deforested areas per year and per district



but it is closed to a uniform distribution.

The government will receive a transfer T from the North proportional to his avoided deforestation: $T = t \times A$. t is the international rate for saved carbon emissions: $t = P \times CD \times 3.67$ where P is the international carbon price, CD is the average carbon density in the country and 3.67 is the atomic ratio of carbon dioxide to carbon (ton CO2e/ton C). Here, we assume that the North knows the average carbon density of the studied forest cover area (172 tC/100ha). Benevolent government utility is the sum of the North-South transfer and the agricultural profits from conversion of forest cover of the districts, while the utility of the budget-maximizing state is the difference between the North-South transfer and the total budgetary cost of the domestic PES scheme. We vary the carbon price to observe the evolution of governments' utilities and the avoided deforestation under the different schemes.

- Under the OC scheme, we assume that the government chooses the deforestation level that maximizes its utility and then selects the districts (equivalent to our farmers in the model) with the lowest average agricultural profit when the scheme is proposed. In the previous section, we demonstrated that the marginal agent h is defined such that $t = \frac{\Pi_h^{BAU}}{L_h^{BAU}}$. All districts with an average opportunity cost per hectare of deforested areas per year lower than h, join the OC scheme. They are exactly compensated and stop deforestation altogether. The other districts carry on with BAU deforestation.

- Under the fixed-price scheme, the government offers a price K by 100 hectares of avoided deforestation. Each district can join the scheme and choose the cells in which to abate deforestation. Cells of 100 hectares where the opportunity cost of avoided deforestation is greater than K are deforested; cells where the opportunity cost of avoided deforestation is lower than K remain forested and receive a compensation K. To facilitate the simulation, we consider that $K = t$ for the benevolent government, and that $K = \frac{t}{2}$ for the budget maximizing government (according to the results found in case 1, table 3).

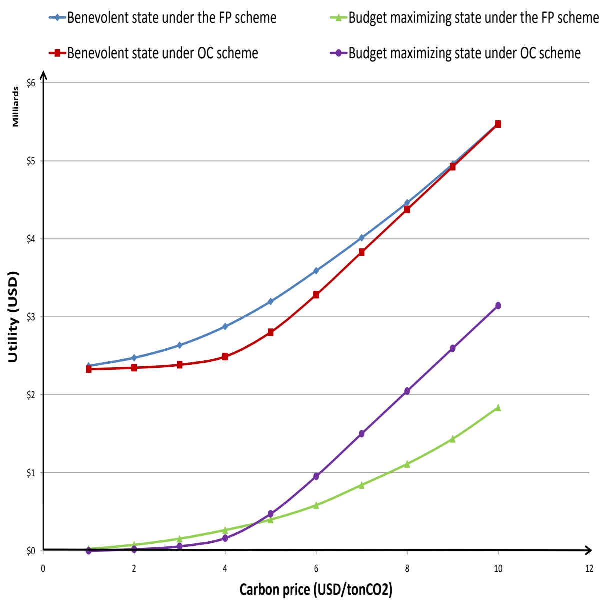


Figure 9: Governments' utility as a function of carbon price

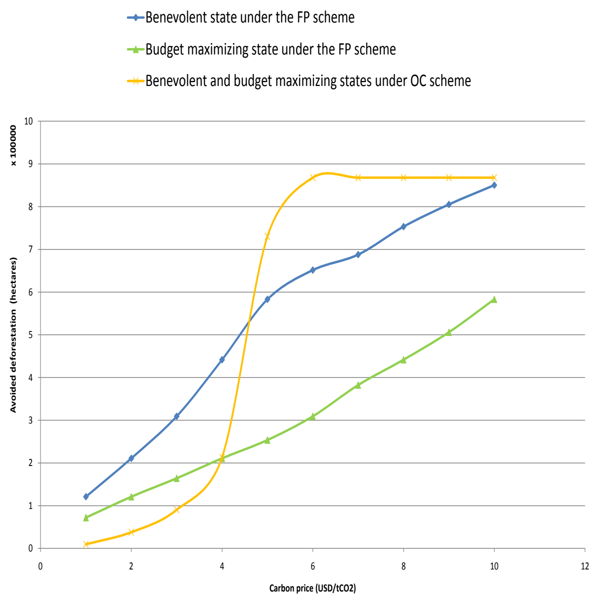


Figure 10: Avoided deforestation as a function of carbon price

If the government can be compared to our theoretical "budget-maximizing" government, then we expect that for low carbon prices (below 4-5 USD/tonCO_2), it will choose the fixed-price scheme and it reverts to an OC scheme for greater values of t (figure 9, table 3 and table 4). If the government can be compared to our "benevolent" government, then it will be indifferent the fixed-price scheme and the OC scheme for a carbon price above 6 USD/tonCO_2. For carbon prices below 6 USD/tonCO_2, it will prefer a fixed-price sheme (figure 9, table 3 and table 4).

We observe in figure 10, table 3 and table 4, that all deforestation is abated under an OC scheme for a carbon price of 6 USD/tonCO_2. The fixed-price scheme is more efficient in terms of avoiding deforestation than the OC scheme, from carbon prices below 4-5 USD/tonCO_2 For

Table 4: Results for a carbon price equal to 3 USD/tonCO_2

Type of government	Benevolent	BM	Benevolent	BM
Type of PES scheme	OC		Fixed-price	
Deforestation without REDD (ha/10 years)	867 900			
Deforestation with REDD/PES (ha/10 years)	777 600		558 700	703 700
Avoided deforestation (ha/10 years)	90 300		309 200	164 200
Budget expenses for PES scheme (million USD/10 years)	113		585	155
North-South REDD transfer (million USD/10 years)	171		585	310
Government's surplus (million USD/10 years)	58		0	155
Government's utility (million USD/10 years)	2 386	58	2 636	155

carbon price above 4-5 USD/tonCO_2, the OC scheme is more efficient.

Table 5: Results for a carbon price equal to 7 USD/tonCO_2

Type of government	Benevolent	BM	Benevolent	BM
Type of PES scheme	OC		Fixed-price	
Deforestation without REDD (ha/10 years)	867 900			
Deforestation with REDD/PES (ha/10 years)	0		180 000	485 500
Avoided deforestation (ha/10 years)	867 900		687 900	382 400
Budget expenses for PES scheme (million USD/10 years)	2 328		3 036.5	844
North-South REDD transfer (million USD/10 years)	3 831		3 036.5	1 688
Government's surplus (million USD/10 years)	1 503		0	844
Government's utility (million USD/10 years)	3 831	1 503	4 014	844

6 Conclusion

Designing an efficient international scheme to reduce deforestation is a key challenge in international post-2012 climate change negotiations. As an international REDD+ mechanism emerges, forest countries are readying policy frameworks to effectively reduce deforestation. PES programs, in which national governments pay local actors for their forests' climate services, and in turn receive international payments through a REDD+ mechanism, are expected to be a mainstay in these policy frameworks. Forest countries face a choice whether to structure payments in national PES programs to be based on forest services provided by land users, or land users' estimated opportunity costs.

Literature on payment designs for REDD have commented that fixed-price schemes retain a greater share producer surplus within local communities, and avoid complicated mechanisms for eliciting supplier willingness-to-accept. Such studies have typically assumed that an opportunity-cost compensation scheme is more cost-efficient for government purchasers than a fixed-price scheme, since purchasers would pay suppliers for less consumer surplus. However, a fixed-price scheme has a commonly overlooked advantage which is not possible under an all-or-nothing opportunity cost contract: a fixed-price scheme allows suppliers to self-identify low-cost areas for conservation, while maintaining productive land for agriculture.

In this paper we develope and calibrate an analytical model of a REDD+ mechanism with an international payment tier and a national payment tier, to compare the avoided deforestation and cost-efficiency of government purchases across the two types of contracts–fixed price and opportunity cost. Our model is voluntarily simple and do not consider important issues of REDD implementation, such as additionality issues, transaction and monitoring costs and property right issues (see Borner,). Nevertheless we give the interesting insight that a fixed-price scheme can be more efficient than an opportunity-cost compensation scheme at low international carbon prices, when variation in opportunity cost within land users is high relative to variation in opportunity cost across land users. Thus, a PES program which pays land users based on the value of the service provided by avoided deforestation may not only distribute REDD revenue more equitably than an opportunity cost-based payment system, but may be more cost-efficient as well. A crucial issue of policy making is then to assess the distribution of opportunity costs, both accross and within farmers.

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REFERENCES

Allen J.C. and D.F. Barnes, 1985. The causes of deforestation in developing countries. Annals of the Association of American Geographers, Vol. 75, No. 2 (Jun., 1985), pp. 163-184

Angelsen, A., 2009. Policy Options to reduce deforestation. In Angelsen, A., (eds) Realising REDD: National Strategies and Policy Options. Center for International Forestry Research (CIFOR), Bogor, Indonesia: 125 - 138

Angelsen, A., and Wertz-Kanounnikoff, S., 2008. What are the key design issues for REDD and the criteria for assessing options? In A. Angelsen (ed.) Moving ahead with REDD: Issues, Options and Implications. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Barbier E.B., Burgess J.C., 1997. The Economics of Tropical Land Use Options. Land Economics 73 (2) 174-195

Bond I., M. Grieg-Gran, S. Wertz-Kanounnikoff, P. Hazlwood, S. Wunder and A. Angelsen, 2009. Incentives to sustain forest ecosystems services. A review and lessons for REDD. Natural Resources n°16. International Institute for Environment and Development, London UK, with CIFOR, Bogor, Indonesia, and World Resources Institute, Washington D.C., USA.

Busch, J., Strassburg, B., Cattaneo, A., Lubowski, R., Bruner, A., Rice, R., Creed, A., Ashton, R., Boltz, F., (2009). Comparing climate and cost impacts of reference levels for reducing emissions from deforestation. Environmental and Research Letters, 4.

Climate Analysis Indicators Tool (CAIT) Version 7.0. 2010. World Resources Institute, Washington, DC.

FWI/GFW. 2002. The State of the Forest: Indonesia. Bogor, Indonesia. Forest Watch Indonesia, and Washington DC: Global Forest Watch. 118 p.

Herold, M., and Skutsch, M., 2009. Measurement, reporting and verification for REDD+. Objectives, capacities and institutions. In Angelsen, A., (eds) 2009. Realising REDD: National Strategies and Policy Options , Center for International Forestry Research (CIFOR), Bogor, Indonesia: 85 – 100.

Gregersen, H., El Lakany, H., Karsenty, A., and White, A., 2010. Does the opportunity cost approach indicate the real cost of REDD+? Rights and realities of paying for REDD+. Rights and Resource Initiative, CIRAD. http://www.rightsandresources.org

IPCC, 2003.Good practice guidance for land use, land-use change and forestery. Penman, J., et al. (eds). National Greenhouse Gas Inventories Programme, Institute for global Environmental Strategies, Kangawa, Japan

IPCC, 2006. IPCC guidelines for national greenhouse gas inventories. Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (eds). National Greenhouse Gas Inventories Programme, Institute for global Environmental Strategies, Kangawa, Japan.

IPCC, 2007 Fourth Assessment Report (IPCC AR4) (Geneva: Intergovernmental Panel on Climate Change), 22 p.

Gaveau, D.L.A., Wich, S., Epting, J., Juhn, D., Kanninen, M., and Leader-Williams, N., 2009. The future of forests and orangutans (Pongo abelii) in Sumatra: predicting impacts of oil palm plantations, road construction, and mechanisms for reducing carbon emissions from deforestation. Environmental Research Letters, 4 (3), 12 p.

Gibbs, H.K., Ruesch, A.S., Achard, F., Clayton, M.K., Holmgren, P., Ramankutty, N., and Foley, J.A., 2010. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. PNAS, 107 (38), 5 p.

Kaimowitz D., Angelsen A., 1998. Economics Models of Tropical Deforestation. A Review. Centre for International Forestry Research, Bogor, Indonesia

Koh, L.P., and Ghazoul, J., 2010. Spatially explicit scenario analysis for reconciling agricultural expansion, forest protection, and carbon conservation in Indonesia. PNAS, 5 p.

Naucler and Enkvist, 2009. Version 2 of the global greenhouse gas abatement cost curve. Draft

Niesten, E., Zurita, P., and Banks, S., 2010. Conservation agreements as a tool to generate direct incentives for biodiversity conservation. Biodiversity, special Knowledge, Conservation, Sustainability, 11, p. 5 – 8.

Madeira, E.M., 2009. REDD in design: assessment of planned first-generation activities in Indonesia. Resources for the future, RFF DP 09-49

Morton, D.C., DeFries R.S., Shimabukuro, Y.E., Anderson, L.O., Aral, E., del Bon Espirito-Santo, F., Freltas, R., and Morisette, J., 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. PNAS, 103 (39), 4 p

Murray, B.C., Lubowski, R. and Sohngen, B., 2009. Including International Forest Carbon Incentives in Climate Policy: Understanding the Economics NI R 09-03 Nicholas Institute for Environmental Policy Solutions Duke University, Durham, NC, 63 pages.

Ogonowski M., L. Guimaraes Haibing, M. D. Movius, J. Schmidt, 2009. Utilizing Payments for Environmental Services for Reducing Emissions from Deforestation and Forest Degradation (REDD) in Developing Countries: Challenges and Policy Options. Center for clean air policy, Washington. 23p.

Peskett, L., Huberman, D., Bowen-Jones, E., Edwards, G., and Brown, J., 2008. Making REDD work for the poor. Report for the Poverty Environment Partnership (PEP), 78 pages. http://www.iucn.org/about/work/programmes/economics/?2052/Making-REDD-Work-for-the-Poor

Pagiola, S. 2008. Payments for environmental service in Costa Rica. Ecological Economics (65) pp. 712-724

Rudel, T.K., 2007. Changing agents of deforestation: From state-initiated to enterprise driven processes, 1970-2000. Land Use Policy 24 pp. 35-41

Ruesch, A.S. and H.K. Gibbs (2008). New IPCC Tier-1 global biomass carbon map for the year 2000. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN, USA. http://www.cdiac.ornl.gov

Venter, O., Laurance, W.F., Iwamura, T., Wilson, K.A., Fuller, R.A., and Possingham, H.P., 2009. Harnessing carbon payments to protect biodiversity. Science, 326, 1 p.

Van der Werf, G. R., Morton, D. C., DeFries, R. S., Olivier, J. G. J., Kasibhatla, P. S., Jackson, R. B., Collatz, G. J., and Randerson, J. T., 2009. CO2 emissions from forest loss. Nature Geoscience, 2 : 737 – 738.

Wunder, S., 2005. Macroeconomic Change, Competitiveness and Timber Production: A Five-Country Comparison. World Development 33: 65-86

Wunder, S., Engel, S. and Pagiola, S. 2008. Taking stock: a comparative analysis of payments for environmental services progams in developed and developing countries. Ecological Economics 65 (4): 834-8520

Wunder, S., 2009. Can payments for environmental services reduce deforestation and forest degradation? In Angelsen, A., 2009. Realising REDD: National Strategies and Policy Options.

Center for International Forestry Research (CIFOR), Bogor, Indonesia: 214 – 223.

Appendix 1: The different options for BAU deforestation

If we consider a heterogeneous population living in the frontier area, we have to distinguish three cases:

1. If $f'(0) > \frac{\omega}{\underline{\lambda}} \Longrightarrow L_i^{BAU}(\lambda_i) = f'^{-1}\left(\frac{\omega}{\lambda_i}\right) \Longleftrightarrow L_i^{BAU}(\lambda_i) > 0,\ \forall\lambda \in \left[\underline{\lambda};\overline{\lambda}\right]$, all farmers expand deforest and total deforestation at the national level is L_T^{BAU} , $L_T^{BAU} = \int_{\underline{\lambda}}^{\overline{\lambda}} L_i^{BAU}(\lambda)\, d\lambda$.

2. If $\frac{\omega}{\overline{\lambda}} \leq f'(0) < \frac{\omega}{\underline{\lambda}} \Longrightarrow \begin{cases} L_i^{BAU}(\lambda_i) = 0 & \text{for } \lambda \in [\underline{\lambda}; \lambda_0] \\ L_i^{BAU}(\lambda_i) = f'^{-1}\left(\frac{\omega}{\lambda_i}\right) & \text{for } \lambda \in \left[\lambda_0; \overline{\lambda}\right] \end{cases}$, farmers whose $\lambda_i \in ([\underline{\lambda}; \lambda_0])$ do not deforest and farmers whose $\lambda_i \in \left(\left[\lambda_0; \overline{\lambda}\right]\right)$do deforest: Total deforestation amounts to $L_T^{BAU} = \int_{\lambda_0}^{\overline{\lambda}} L_i^{BAU}(\lambda)\, d\lambda$.

3. If $f'(0) \leq \frac{\omega}{\overline{\lambda}} \Longrightarrow L_i^{BAU}(\lambda_i) = 0,\ \forall\lambda \in \left[\underline{\lambda};\overline{\lambda}\right]$, there is no deforestation : $L_T^{BAU} = 0$.

In our analysis we consider only agents who deforest, so we set the first case, with $f'(0) > \frac{\omega}{\underline{\lambda}}$.

ix 1: The different options for BAU deforestation

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Appendix 3: Description of the two types of scheme for the two states

Appendix 4: Optimal value of the fixed-price K

Benevolent State	Budget Maximizing State
Case 1	
$K^B = t$	$K^M = \frac{t}{2}$
Case 2	
$\frac{\omega^2 - {K^B}^2}{2a\left(\omega + K^B\right)} + \frac{K^B - t}{a}\left(ln\left(\overline{\lambda}\right) - ln\left(\breve{\lambda}\right)\right) + \frac{2t-\omega}{a} - \left(c - \frac{b^2}{2a}\right)\frac{\omega + K^B}{b^2} = 0$	$-\frac{1}{a}\left(\left(t - K^M\right)\left(ln\left(\overline{\lambda}\right) - ln\left(\breve{\lambda}\right)\right)\right) - \frac{\left(\omega\left(ln\left(\overline{\lambda}\right) - ln\left(\underline{\lambda}\right)\right) - \left(\omega + K^M\right)\left(ln\left(\overline{\lambda}\right) - ln\left(\breve{\lambda}\right)\right) + b\left(\underline{\lambda} - \breve{\lambda}\right)\right)}{a} = 0$
Case 3	
$K^B = \overline{\lambda}\, b - \omega$	$K^M = \overline{\lambda}\, b - \omega$

Appendix 5: Construction of the opportunity costs in North-Sumatra

We construct an index of "effective opportunity cost" based on observable variables, estimating the influence of driver variables on forest cover change between 1990 and 2000, using a logit regression:

$$y_i = logit\left(\beta_0 + \beta_1 G_i + \beta_2 S_i + \beta_3 Vi + \beta_4 C_i\right) \tag{10}$$

With y_i, a dichotomous variable capting observed forest cover change between 1990 to 2000. All cells introduced in our database are covered by forest in 1990. If the forest cover is maintained in 2000, $y_i = 0$ in 2000, but if the cell is converted in arable land, $y_i = 1$ in 2000. G_i is the agricultural revenue per hectare (US$/ha), S_i, is the the average slope per hectare (%), and V_i, is the average elevation per hectare (m), are proxies for the cost of accessing forest. C_i, the average above- and belowground forest biomass per hectare[11] (tC/ha), is a proxy for the cost of converting natural forest. A single, monetized "effective opportunity cost" for each cell was constructed from the driver variables using the following formula:

$$Oi = \frac{\hat{\beta}_0 + \hat{\beta}_1 G_i + \hat{\beta}_2 Si + \hat{\beta}_3 Vi + \beta_4 \hat{C}_i - \hat{H}}{\hat{\beta}_1} \tag{11}$$

Where $\hat{\beta}$ represents modeled regression estimates, O_i is the effective opportunity cost for cell$i$, and H is a hurdle added to the modeled intercept such that total modeled deforestation is equal to total observed deforestation;

$$\sum_i \hat{y}_i = \sum_i y_i$$

where forest cover is maintained when the opportunity costs is negative $(\hat{y}_i = 0 \; if \; O_i \leq 0)$, and deforestation takes place if opportunity cost is positive $(\hat{y}_i = 1 \; if \; O_i > 0)$. Deforestation is more likely to occur on land with higher estimated oil palm revenue potential, and is less likely to occur on land with greater slope, higher elevation, or greater biomass.

[11] Data on belowground and aboveground forest biomass was obtained from Tier I IPCC estimates

Table 6: Regression Results

Logistic regression			Number of observations = 71609		
LR$\chi^2(4) = 17711,91$					
Prob> $\chi^2 = 0$					
Log likelihood= $-17589,882$			Pseudo-R^2= $0,3349$		
Forest cover loss (%/10yrs)	Coef.	Std. Err	z	$P > \|z\|$	[95% Conf. Interval]
Oil palm gross revenue ($/ha)	0,0005	0,000018	27,6	0	$[0,00046; 0,00053]$
Slope (%)	-0,027	0,0023	-11,73	0	$[-0,031; -0,022]$
Elevation (m)	-0,0007	0,000045	-15,79	0	$[-0,00079; -0,00062]$
Biomass (tC/ha)	-0,014	0,00021	-64,32	0	$[-0,014; -0,013]$
Constant	-2,032	0,15	-13,64	0	$[-2,32; -1,74]$

Documents de Recherche parus en 2011[1]

DR n°2011 - 01 : Solenn LEPLAY, Sophie THOYER
« Synergy effects of international policy instruments to reduce deforestation: a cross-country panel data analysis »

DR n°2011 - 02 : Solenn LEPLAY, Jonah BUSCH, Philippe DELACOTE, Sophie THOYER
« Implementation of national and international REDD mechanism under alternative payments for environemtal services: theory and illustration from Sumatra »

[1] La liste intégrale des Documents de Travail du LAMETA parus depuis 1997 est disponible sur le site internet : http://www.lameta.univ-montp1.fr

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