Unveiling information on opportunity costs in REDD: who obtains the surplus?

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Abstract

Improving information about individual opportunity costs of deforestation agents has the potential to increase the efficiency of REDD when it takes the form of a payment for environmental services scheme. In this paper, we show that the impact of increasing this type of information depends on the type of policy maker. If the policy maker is an environmental agency, providing such information may increase the amount of forest conserved under REDD. By contrast, if the policy maker aims at maximizing net income from REDD, improving information may not increase forest but only change the distribution of the surplus. For a development agency aiming to improve agents' welfare, providing information makes no difference to forest outcomes or welfare. These results are illustrated with data collected on opportunity costs in Amazonas state, Brazil.

Keywords: deforestation, REDD, payment for environmental services, information, opportunity costs.

1 Introduction

With tropical deforestation accounting for up to a fifth of global, anthropogenic CO_2 emissions, (van der Werf et al. (2009), IPCC (2007)) Reducing Emissions from Deforestation and Degradation (REDD) has been positioned as a potentially cost-effective climate change mitigation strategy (Stern, 2007; Eliasch, 2008; Palmer and Engel, 2009). Incentive payments or payments for environmental services (PES) schemes are often promoted as a means of supplying REDD benefits (Angelsen, 2010; Pattanayak et al.„ 2010; Palmer, 2011).[1] While long-term finance continues to be subject of discussion among REDD stakeholders, such schemes could be financed through an international carbon market and/or voluntary funds (see Neeff and Ascui, 2009). One of the major selling points of incentive payments is their cost-effectiveness compared to other policy options (Ferraro and Kiss, 2002; Ferraro and Simpson, 2002; Muller and Albers, 2004; Groom and Palmer, 2010). Moreover, they are often proposed as efficient policy tools for achieving REDD in developing countries (e.g. Angelsen (2008), Leplay et al. (2011)).

Increased knowledge about the opportunity costs of avoiding deforestation is often cited as a prerequisite to the efficient implementation of payment schemes to curb deforestation (e.g. Pagiola and Bosquet (2009)). In this paper, we investigate the impacts of improving information on the opportunity costs of deforestation agents, and on business-as-usual deforestation. A simple model of payments to reduce deforestation is developed in which a policy maker offers a price to deforestation agents in order to reduce deforestation. The policy maker can be of three types: a development agency aiming at maximizing the well-being of a country's citizens; an income-maximizing government maximizing net income from REDD, or an environmental agency maximizing the amount of forest prevented from being deforested. It can then either sell the carbon credits derived on an international carbon market or can be retributed though an international REDD fund.

Agricultural households, logging companies, and the agro-businesses obtain diverse benefits from deforesting, and thus have very different opportunity costs of not deforesting. Thus, some agents can provide environmental services from not deforesting at lower costs than others. Moreover, agents are likely to have better information about the size of these costs than the policy maker. This type of information asymmetry, known as hidden information (or adverse selection), can lead to inefficiencies in payments schemes. If the payments are too high, then uniform contracts - the

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[1] Wunder (2005) defines PES as a voluntary transaction between at least one buyer and at least one seller in which payments are conditional on maintaining an ecosystem use that provides well-defined environmental services.

norm in many payments schemes around the world (see Engel et al., 2008) - can be a costly way of inducing agents to participate. Yet such contracts can improve welfare. This is particularly relevant in developing countries where donors and international agencies may be looking for a double dividend of reducing poverty and increasing environmental services provision at the same time (Bulte et al. (2008)).

To prevent informational rents accruing to low-cost agents, separating contracts can be used to separate the low- from the high-cost agents.[2] While offering a menu of contracts may be more efficient than a uniform contract, they are rarely used in practice (Ferraro, 2008). Informational requirements on the part of the policy maker may be substantial and the menu of contracts that would be offered in the presence of complete information may not be incentive compatible in the presence of information asymmetries (Arguedas and van Soest, 2011). Instead of offering a menu of contracts, procurement auctions have been proposed and used in practice as a means of extracting informational rents from agents (e.g. Stoneham et al., 2003). Thus, improving information on agents' opportunity costs is possible, although debate continues about the relative efficiency of separating contracts vis-a-vis auctions.

In our framework, we explore the trade-offs between improving agents' welfare and increasing the supply of benefits from REDD as a result of improving information on agents' opportunity costs. The policy maker knows the distribution of BAU levels of deforestation among deforestation agents and the distribution of agents' opportunity costs. However, it may not infer the individual agents' BAU levels of deforestation nor their opportunity costs. The innovation of our framework is to examine trade-offs and the impact of improvements in information according to the type of policy maker. It can either aim at maximizing its citizens well-being, net income from REDD, or quantity of avoided deforestation. While this simplifies often complex decision-making processes, such processes will remain essentially unobservable to international sources of REDD finance. Yet important differences in outcomes emerge, particularly if actual policy objectives are different from stated ones. Tropical forest policy processes are often characterized by patronage politics and the presence of powerful interest groups close to national policy makers, which obscures the true motivations of policy makers (Mayers and Bass, 1998). Indeed, the recent finding government officials in Liberia were bribed by carbon investors to secure carbon rights to a forest concession at below-market values suggests that corruption is already playing an unwelcome role in REDD policy

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[2]For classic examples of separating contracts as applied to agri-environmental schemes, see Smith (1995), Wu and Babcock (1995,1996).

(Financial Times, 2010). Our framework accounts for possible rent-seeking and demonstrates how improving information could exacerbate the problem.

We show that under incomplete information about the individual opportunity costs, the three types of policy maker set the same level of REDD payment resulting in the same environmental outcome. When information is improved, the development agency sets the same payment and obtains the same outcome as in the incomplete information case. The income-maximizing policy maker achieves the same outcome in terms of avoided deforestation as in the incomplete information case. But this policy maker uses the information to increase its surplus, potentially to benefit powerful interest groups. Finally, with improved information about agents' opportunity costs, the environmental agency is able to get a better outcome in terms of avoided deforestation while their welfare remains unchanged.

These results are illustrated with data collected on households' opportunity costs in the Brazilian state of Amazonas. Land use is characterised by low agricultural productivity, which occurs through the conversion of forest of high carbon content. We show that, as expected, the environmental agency is able to buy up almost all the land that would otherwise be converted to agriculture, more than either of the other two policy maker types. Under incomplete information, the environmental agency achieves the highest aggregate welfare gain for agents. These naturally dissipate once information is made available on their opportunity costs of keeping land in forest.

Overall, the impact of improving information about opportunity costs on welfare and avoided deforestation depends on the type of policy maker. If the policy maker is a development agency, improving information has no real impact, since citizens and the government have the same objective of improving well-being. If the policy maker aims at maximizing profit from REDD, improving information allows it to bind agents to their opportunity costs. Improving information thus reduces well-being but with no change in avoided deforestation. For an environmental agency, improving information improves scheme efficiency. Less money is spent on agents with low opportunity costs and more is allocated to agents with higher opportunity costs. In this case, improving information improves the outcome in terms of avoided deforestation.

In the remainder of the paper, Section 2 presents the incomplete information case while Section 3 shows the implications of improving information about agents' opportunity costs. Section 4 illustrates the main points of the model with policy simulations using data collected in Amazonas, Brazil. Section 5 concludes and discusses the policy implications, including the potential screening benefits that a fund may provide compared to a global carbon market.

2 Payments for reducing deforestation with incomplete information

In this section, we present an incentive payment scheme for reducing emissions from deforestation under a situation of incomplete information. We first present the deforestation agents and the Business-As-Usual (BAU) deforestation baseline before moving to the payment scheme. Several types of policy maker are considered and the equilibrium payment policy is inferred.

2.1 Deforestation agents and Business-As-Usual scenario

We consider a country in which deforestation agents, e.g. agricultural households, logging firms, $i \in [0, N]$, are distributed according to $f(i)$. The deforestation agents obtain some private benefit (or net income) $Y_i \in [\underline{Y}, \overline{Y}]$ from deforestation $D_i \in [\underline{D}, \overline{D}]$. We implicitly assume that opportunity costs and deforestation levels have the same order: agents with high income from deforestation have high individual deforestation levels while low-income agents have lower ones. Where forest clearing requires investment, high-income agents are more likely to have the capacity to clear forest (Angelsen and Kaimowitz, 1999).[3] Yet we do not discriminate among types of agent. Instead, we only differentiate according to income. Thus, we assume that poorer agricultural households, for example, obtain relatively low benefits from deforestation and thus have low individual levels of deforestation. Palm oil firms, on the other hand, may obtain large profits from land conversion and thus have higher individual levels of deforestation. Agents are also assumed to have no outside options in the the form of off-farm income opportunities. This is a strong assumption that while allowing for analytical crispness does not hold in our Brazilian case.

In our model, D_i is the individual level of deforestation of agent i, and $D^{BAU} = \int_0^N D_i f(i) di$ is total deforestation in a BAU scenario. Moreover, agent i obtains private benefits Y_i from deforestation D_i, which are assumed to be known by the agent. Total benefits from deforestation are given by $Y^{BAU} = \int_0^N Y_i f(i) di$ in a BAU scenario, which can also be interpreted as an aggregate measure of deforestation agents' welfare.

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[3]We note, however, that empirical evidence on the link between poverty and deforestation is mixed. For example, Zwane (2007) presents evidence from a household-level analysis in Peru showing that land clearing is positively correlated with income but at a decreasing rate.

2.2 Introducing payments for reducing emissions from deforestation

The policy maker in the REDD host country establishes an incentive payment or PES scheme to reduce emissions from deforestation. While it has knowledge of the distribution of deforestation levels and incomes among all agents, it cannot observe their opportunity costs of land use, i.e. is unable to distinguish between those with low or high opportunity costs. In response to this, it offers a fixed, uniform payment as an incentive to avoid deforestation against the BAU baseline. As noted in the introduction, this is a common feature of payment schemes around the world.

Any agent i may accept or refuse the offer. If it accepts, agent i reduces its deforestation from D_i to D_i^{PES}. For simplicity, we assume that $D_i^{PES} = 0$ (in this sense, we consider D^{BAU} as the quantity of deforestation that is avoided). We assume perfect monitoring of deforestation levels under the payment scheme, for example, using a combination of remote sensing data and ground surveys. In exchange for avoiding deforestation the agent receives a fixed payment L. If it declines participation in the scheme, agent i keeps receiving its BAU income Y_i. Agent i accepts the offer if and only if it makes it better off: $L \geq Y_i$.

2.3 The Policy Maker

The policy maker has incomplete information about the agents' individual opportunity costs. Since neither these nor the BAU deforestation rates of individual agents can be discerned, a fixed payment L is offered to all agents. Agent i enters the scheme if and only if: $L \geq Y_i$.

In our framework, the indifferent agent $\tilde{i}$ is the one that separates total population, and is defined as follows: $\tilde{Y} = L$. Agents with a low opportunity cost ($i \in [0, \tilde{i}]$) participate in the scheme while agents with a high opportunity cost ($i \in [\tilde{i}, N]$) choose to stay out.

Total income, total deforestation levels under the payment scheme, and avoided deforestation are given by:

$$Y^{PES} = \int_{\tilde{i}}^{N} Y_i f(i) di + \int_{0}^{\tilde{i}} L f(i) di \qquad (1)$$

$$D^{PES} = \int_{\tilde{i}}^{N} D_i f(i) di \qquad (2)$$

$$AD = D^{BAU} - D^{PES} = \int_{0}^{\tilde{i}} D_i f(i) di \qquad (3)$$

A situation of incomplete information implies that the policy maker only has to set the amount of the payment L, which determines the indifferent agent and the number of agents entering the scheme $i \in [0, \tilde{i}]$. It cannot discriminate among deforestation agents. Thus, it follows that the policy maker cannot capture the surplus from the REDD mechanism. Participants are assumed to

comply and deliver the benefits associated with their REDD contracts. Implicitly, there is perfect and costless monitoring of REDD contracts through monitoring, measurement and verification (MRV) procedures established in the REDD host country.

In our framework, third-party finance for REDD can be accessed by the policy maker from the REDD host country. There are two options for channeling REDD finance. First, verifiable avoided deforestation could create carbon (offset) credits, which can then be sold on an international carbon market at price r. Alternatively, the country could be retributed through an international REDD fund established by developed countries. In this case, r would represent the price offered by the fund in exchange for a given, verified amount of avoided deforestation. The policy maker may be of three types. First, we consider a development agency that aims to maximize the welfare of a country's citizens before considering one that aims to maximize net income from REDD. Finally, the policy maker is an environmental agency that aims to maximize the size of the forest to be protected under REDD.

2.3.1 Development agency

The development agency only cares about the community welfare. The policy maker thus implements its payments scheme such that the deforestation agents' welfare is maximized compared to the BAU baseline, subject to a budget constraint, i.e. it cannot make a loss from implementing the scheme:

$$\max_{L} W_A \;\; = \;\; Y^{PES} - Y^{BAU} = \int_0^{\tilde{i}} (L - Y_i) f(i) di \tag{4}$$

$$s.t \quad \int_0^{\tilde{i}} (r D_i - L) f(i) di \geq 0 \tag{5}$$

The development agency tends to set the highest possible payment level. The equilibrium payments scheme thus takes the form:

$$
\begin{cases}
L = r\tilde{D} \; \forall i \in [0, N] \\
\tilde{i} : \frac{\tilde{Y}}{\tilde{D}} = r \\
\int_0^{\tilde{i}} (r D_i - L) di = 0
\end{cases}
\tag{6}
$$

2.3.2 Policy maker maximizing net income from REDD

In the second case, the policy maker maximizes net income derived from REDD. It might prefer to increase social welfare by utilizing the income obtained from REDD rather than distributing it to deforestation agents. Thus, income from REDD could be used to fund public services such as

education, health, and infrastructure, or even redistributed to the population at large. The latter could apply in a situation where the social cost of public funds is small enough, i.e. implying that the policy maker can improve social welfare using REDD finance for public services rather than directly distributing it to agents. Alternatively, income could be redistributed to rent-seeking groups through the policy maker's client-patron networks.[4]

The maximization program of the policy maker is:

$$\max_{L} \pi_{PM} = rAD - \int_0^{\tilde{i}} Lf(i)di = \int_0^{\tilde{i}} (rD_i - L)f(i)di$$

Since the policy maker cannot discriminate among agents according to their opportunity costs, it cannot make a profit. There is not enough information available to claim the agents' surplus. With zero profit, we assume that the policy maker implements the policy that maximizes the amount of deforestation avoided subject to the budget constraint.

Due to incomplete information, the income-maximizing policy maker is constrained to implement the same level of payment as the development agency. As shown in Section 2, with an income-maximizing policy maker, incomplete information results in the same environmental outcome as is achieved under complete information. However, the distribution of REDD rents is different. Indeed, since the policy maker cannot discriminate among deforestation agents, the surplus from REDD remains with deforestation agents.

2.3.3 Environmental agency

The environmental agency has the objective of maximizing the quantity of avoided deforestation. Its program is:

$$\max_{L} AD \quad = \quad D^{BAU} - D^{PES} = \int_0^{\tilde{i}} D_i f(i)di \tag{7}$$

$$s.t \quad rAD - \int_0^{\tilde{i}} Ldi = \int_0^{\tilde{i}} (rD_i - L)f(i)di \geq 0 \tag{8}$$

Again the policy maker is unable to discriminate among agents. Overall, the equilibrium payments scheme is the same as in the two previous cases (equation (6)). Asymmetric information about agents' opportunity costs prevents it from being able to redistribute the surplus from REDD. Note that deforestation agents are better off under incomplete information. Indeed they benefit from the asymmetric information about opportunity costs and increase their welfare relative to the BAU baseline.

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[4]Therefore, we do not consider explicitly how the net income from REDD is used, whether it is in a positive (public services) or negative (rent-seeking) way.

Figure 1 presents the payments' outcome for the three policy maker types in an incomplete framework. Figure (i) presents the distribution of average opportunity costs Y_i/D_i; Figure (ii) presents the distribution of opportunity costs Y_i; Figure (iii) presents the distribution of deforestation levels D_i. Due to incomplete information about individual opportunity costs, the policy maker sets the same policy whatever its type. A uniform payment is implemented and deforestation agents self-select into the scheme.

The policy maker sets $L = r\tilde{\tilde{D}}_{B,P,E}$ (figure (ii)), and the indifferent agent is the one represented by $\tilde{\tilde{Y}}_{B,P,E}/\tilde{\tilde{D}}_{B,P,E} = r$. deforestation agents increase their welfare relative to the BAU baseline by the amount shown in zone 1 in Figure (ii). While they receive L for not deforesting, they would generated $Y_i < L$ for not deforesting. The amount of deforestation avoided is described in zone 2 of figure (iii). Finally, the REDD payments scheme binds the budget constraint since the payment L is sold at $r\tilde{\tilde{D}}_{B,P,E}$ to the carbon buyer participating either in the international carbon market or the REDD fund.

3   The impact of improving information

In this section, we consider the impact of improvements in information about agents' opportunity costs, e.g. from auctions. As a result, the policy maker can infer these and payments may be implemented in a more flexible way. More precisely, the policy maker is able to discriminate agents according to their opportunity costs. The payment now consists of a price p_i to the deforestation agent i per hectare of avoided deforestation. The indifferent agent $\tilde{\tilde{i}}$ is the one that separates total population, and is defined as follows: $\tilde{\tilde{Y}} = \tilde{\tilde{p}}\tilde{\tilde{D}}$. Agents with a low opportunity cost ($i \in [0,\tilde{\tilde{i}}]$) participate in the scheme while agents with a high opportunity cost ($i \in [\tilde{i}, N]$) opt out.

Total income, total deforestation levels under the payments scheme, and avoided deforestation are then:

$$Y^{PES} = \int_{\tilde{i}}^{N} Y_i f(i)di + \int_{0}^{\tilde{\tilde{i}}} p_i D_i f(i)di \tag{9}$$

$$D^{PES} = \int_{\tilde{i}}^{N} D_i f(i)di \tag{10}$$

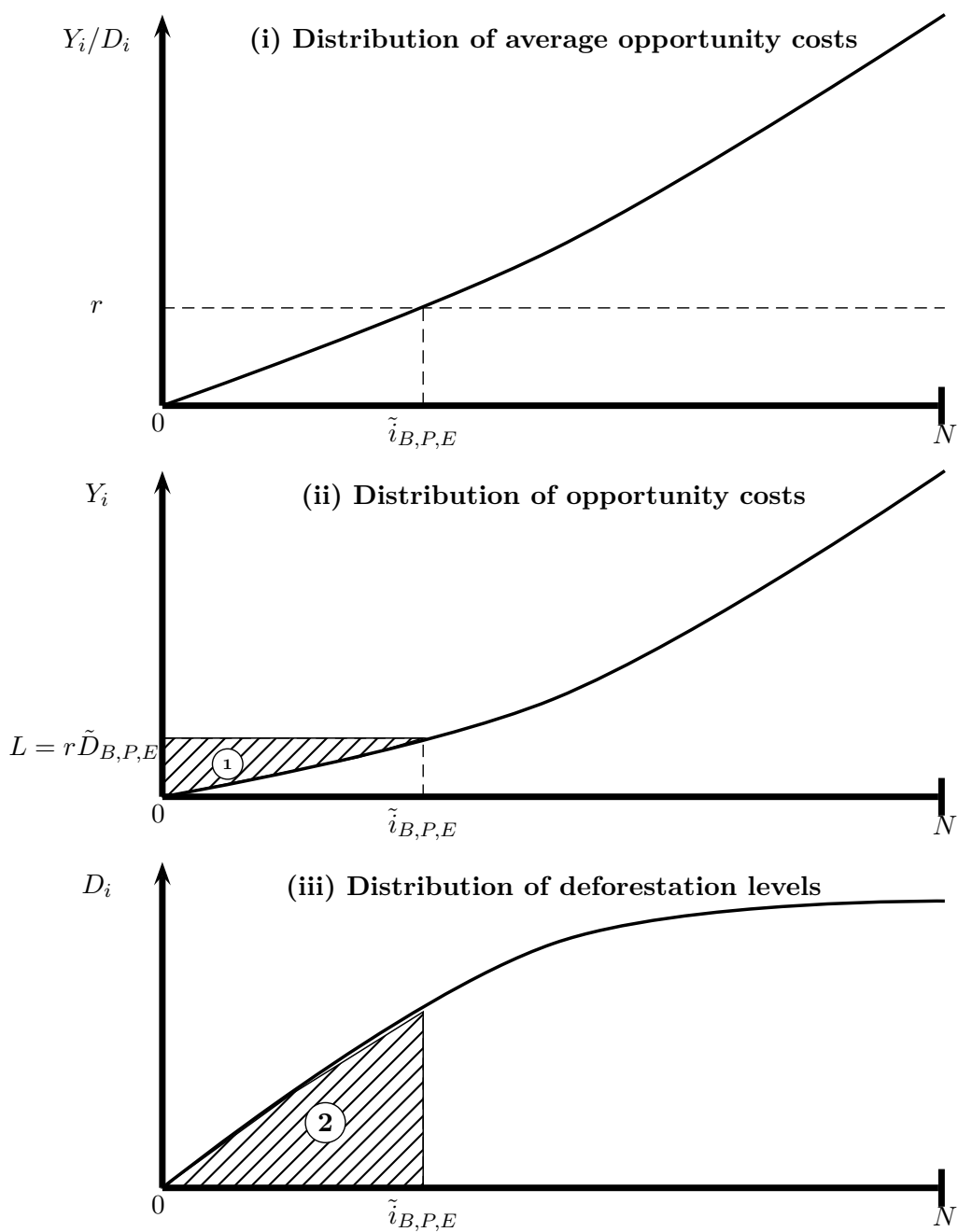$$AD = D^{BAU} - D^{PES} = \int_{0}^{\tilde{\tilde{i}}} D_i f(i)di \tag{11}$$

Figure 1: Payments scheme for REDD in an incomplete information framework

When setting the price schedule p_i of the scheme, the policy maker has to make two choices. First, it chooses the indifferent agent $\tilde{\tilde{i}}$, which is the final agent to participate in the scheme, setting $p_{\tilde{\tilde{i}}}$. Second, it decides how much to pay agents entering the scheme, setting p_i for agents $i \in [0, \tilde{\tilde{i}}]$.

The choice of the indifferent agent determines the quantity of avoided deforestation: AD. The price level determines how the surplus from REDD is distributed between the policy maker and deforestation agents. Setting $p_i = Y_i/D_i$ implies that agents are retributed according to their opportunity costs, which means that the surplus from REDD is entirely captured by the policy maker. In other words, agents' welfare remains as in the BAU baseline case. Setting $p_i > Y_i/D_i$ implies that some share of the REDD surplus is distributed to deforestation agents. Thus, they are better off under the scheme than in the BAU baseline case.

3.1 Development agency

The development agency maximization program becomes:

$$\max_{p_i} W_A \quad = \quad Y^{PES} - Y^{BAU} = \int_0^{\tilde{\tilde{i}}} (p_i D_i - Y_i) f(i) di \tag{12}$$

$$s.t \qquad rAD - \int_0^{\tilde{\tilde{i}}} p_i D_i f(i) di = \int_0^{\tilde{\tilde{i}}} (r - p_i) D_i f(i) di \geq 0 \tag{13}$$

When choosing the payment schedule, it is easy to see that this policy maker's objective function is strictly increasing in price offered to the deforestation agents. Moreover, so long as the offered price p_i is strictly larger than agent i's opportunity cost, i will be better off under the scheme. The policy maker then sets the highest possible price schedule that binds its budget constraint. Moreover, it has no interest in offering more than the international price r to the agents. This is because it would be unable to respect its budget constraint or would need to obtain rent from other agents, i.e. paying them a lower price.

The equilibrium payments scheme thus takes the form:

$$\begin{cases} p_i = r \; \forall i \in [0, N] \\ \tilde{i} : \frac{\tilde{Y}}{\tilde{D}} = r \\ \int_0^{\tilde{i}} (r - p_i) D_i f(i) di = 0 \end{cases} \tag{14}$$

The policy maker sets a uniform price to all agents, which is similar to the incomplete information case. Low opportunity cost agents accept the payment, which improves their well being (they lose Y_i but get $rD_i > Y_i$). The policy maker then sells the avoided deforestation credits at the same price r, and is thus able to finance the policy without loss. Note here that agents with a high opportunity cost obtain the same welfare as in the BAU baseline.

It can be seen that the indifferent agent is the same as in the incomplete information case. Then the outcome in terms of deforestation is also the same. Moreover, the complete information case brings a uniform price to avoided deforestation when the policy maker is a development agency ($p_i = r$). Both welfare and the quantity of avoided deforestation are identical to that achieved in the incomplete information case. This is due to the fact that the policy maker and the deforestation agents have the same objective, which is to maximize agents' welfare. Therefore, improving information about agents' true opportunity costs has no real impact on either outcome, whether the quantity of avoided deforestation or agents' welfare.

3.2 Policy maker maximizing net income from REDD

The policy maker's maximization program is:

$$\max_{p_i} \pi_{PM} = \int_0^{\tilde{\tilde{i}}} (r - p_i) D_i f(i) di \tag{15}$$

In this case, it is straightforward to see that the policy maker will pay deforestation agents so long as it makes profit on the scheme. Note that the price offered must remain lower than the international price r. Moreover, it will pay them as little as possible. In the context of improved information about agents' opportunity costs, this means that it will bind them to these costs.

The equilibrium scheme is thus:

$$
\begin{cases}
p_i = \begin{cases} \frac{Y_i}{D_i} \ \forall i \in [0, \tilde{\tilde{i}}] \\ r \ \forall i \in [\tilde{\tilde{i}}, N] \end{cases} \\
\tilde{\tilde{i}} : \frac{\tilde{\tilde{Y}}}{\tilde{\tilde{D}}} = r \\
\int_0^{\tilde{\tilde{i}}} (r - p_i) D_i f(i) di > 0
\end{cases} \tag{16}
$$

Note that since the indifferent agent is the same, the profit-maximizing policy maker achieves the same outcome in terms of avoided deforestation as the development agency. The only difference is that, with complete information, the policy maker can bind agents to their opportunity costs, which implies a different distribution of the surplus from REDD. The welfare of deforestation agents is then exactly the same as in the BAU baseline case, and lower than in the incomplete information case.

3.3 Environmental agency

This policy maker's program is:

$$\max_{p_i} AD \quad = \quad \int_0^{\tilde{\tilde{i}}} D_i f(i) di \tag{17}$$

$$s.t \quad \int_0^{\tilde{\tilde{i}}} (r - p_i) D_i f(i) di \geq 0 \tag{18}$$

In contrast to the two previous cases, the environmental agency may have an interest to offer a price larger than the international carbon price to some agents. Indeed, it may prefer to make some profit on agents with a low opportunity cost by paying them a price lower than the international price. This profit can then be used to give incentives to agents with a high opportunity cost. The environmental agency thus binds agents to their opportunity costs.

Overall, the equilibrium payments scheme takes the form:

$$\begin{cases} p_i = \begin{cases} \frac{Y_i}{D_i} \ \forall i \in [0, \tilde{\tilde{i}}] \\ r \ \forall i \in [\tilde{\tilde{i}}, N] \end{cases} \\ \tilde{\tilde{i}} : \int_0^{\tilde{\tilde{i}}} (r - p_i) D_i f(i) di = 0 \\ \int_0^{\tilde{\tilde{i}}} (r - p_i) D_i f(i) di = 0 \end{cases} \tag{19}$$

In this case, making a profit on some deforestation agents enables the policy maker to pay agents with opportunity costs larger than the international carbon price. Thus, the quantity of avoided deforestation is higher than the quantity achieved either with the development agency or the income-maximizing policy maker. Deforestation agents' welfare is the same as in the BAU case.

Proposition 1: *When implementing a PES scheme with the option of selling the benefits from avoided deforestation to a REDD fund or international carbon market and with complete information about agents' opportunity costs and deforestation levels, the development agency and the income-maximizing policy maker obtain the same level of avoided deforestation while the environmental agency achieves a higher level. Regarding welfare, the development agency increases the deforestation agents' welfare with PES while the income-maximizing PM and the environmental agency bind deforestation agents to their opportunity costs, which prevents them from being better off under REDD.*

Proposition 2: *In comparison to the incomplete information scenario, when improving information about individual opportunity costs and deforestation levels:*

- *The development agency sets the same level of payment, which results in the same outcome, both in terms of avoided deforestation and welfare impacts.*

- *The profit-maximizing policy maker can profit from low opportunity cost agents, which results in the same avoided deforestation outcome while the surplus from REDD is switched from the deforestation agents to the policy maker.*

- *The environmental agency redistributes REDD rent from low opportunity cost agents to agents with higher opportunity costs; the amount of deforestation avoided is larger while the welfare of deforestation agents decreases.*

3.4   Graphic illustration

Table 1 and figure 2 illustrate the payments schemes and associated outcomes for the three types of policy maker under complete information. As in figure 1, Figure (i) presents the distribution of average opportunity costs Y_i/D_i; Figure (ii) presents the distribution of opportunity costs Y_i; Figure (iii) presents the distribution of deforestation levels D_i.

The policy maker can now discriminate among deforestation agents. The development agency sets $p_i = r$, for all agents (figure (i)). As a result, the indifferent agent is $\tilde{\tilde{i}}_{B,P}$. Their welfare increases by the amount given in zone 1 (figure (ii)). This is the difference between the amount received under the scheme and the amount received in the BAU baseline case ($rD_i - Y_i$). The amount of deforestation avoided is illustrated in zone 3 in figure (iii). The scheme breaks even since the amount spent ($p_i \tilde{\tilde{D}}_{B,P}$) equals the amount received from international REDD finance (rAD), as shown in zone 1 (figure (ii)).

The income-maximizing policy maker sets $p_i = Y_i/D_i$, up to $p_i = r$ (figure (i)). As a consequence, the indifferent agent remains $\tilde{\tilde{i}}_{B,P}$, although the agents' welfare is the same as under BAU. Avoided deforestation is still equal to zone 3 in figure (iii). However, the scheme makes some profit as illustrated in zone 1 (figure (ii)). The policy maker buys avoided deforestation at price Y_i/D_i and sells the credit at price $r > Y_i/D_i$.

Finally, the environmental agency also makes some profit on low opportunity cost agents (zone 1 in figure (ii)). However, this profit is redistributed to agents with higher opportunity costs. The indifferent agent here is $\tilde{\tilde{i}}_E$, such that the area in zone 1 equals the area in zone 2 (figure (ii)), that is the scheme makes no profit. A larger number of indifferent agents increases the amount of avoided deforestation equivalent to both zone $3 + 4$ (figure (iii)).
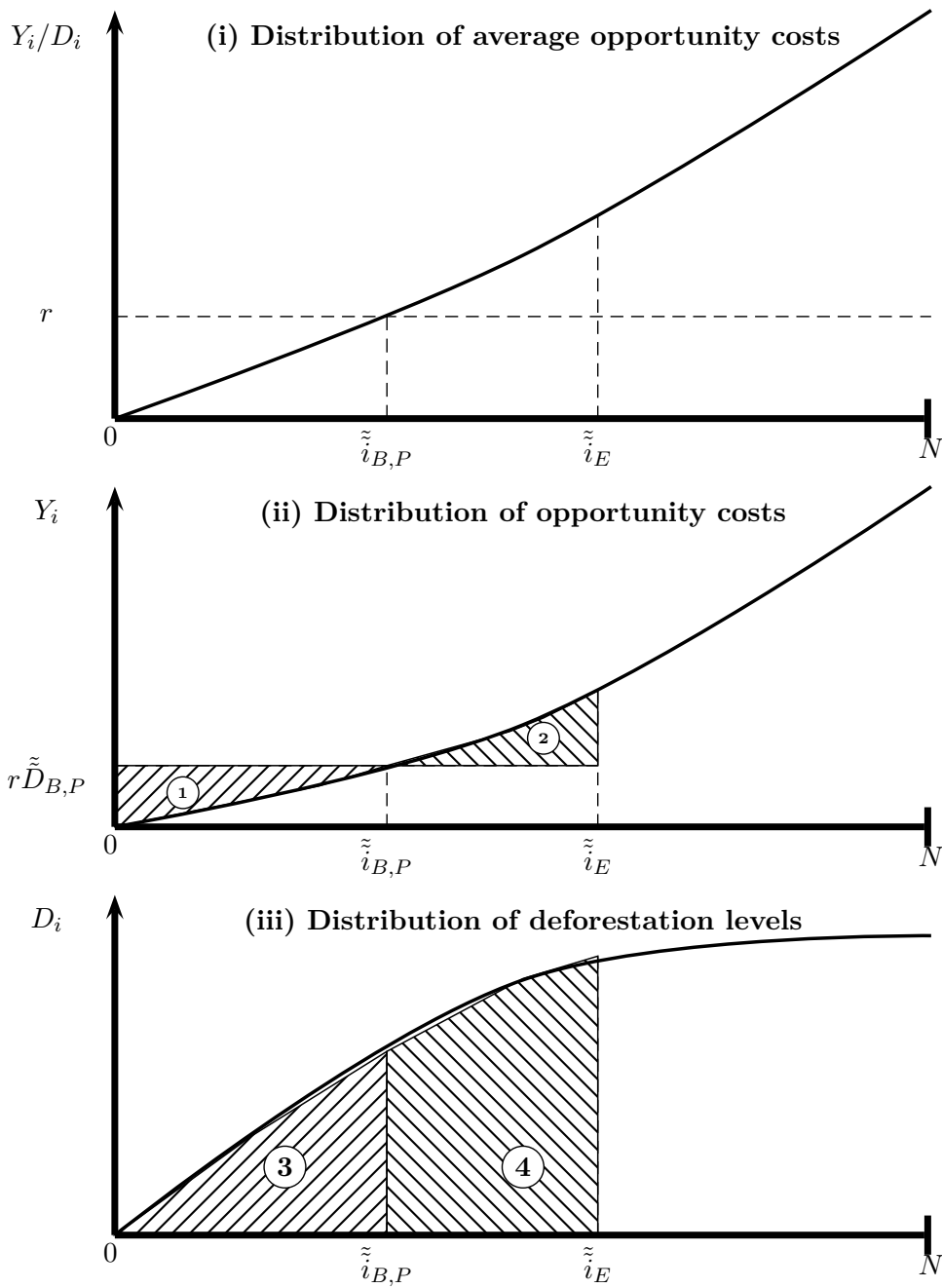
Figure 2: PES Scheme and avoided deforestation in a complete information framework

Table 1: PES Outcome in the complete information case

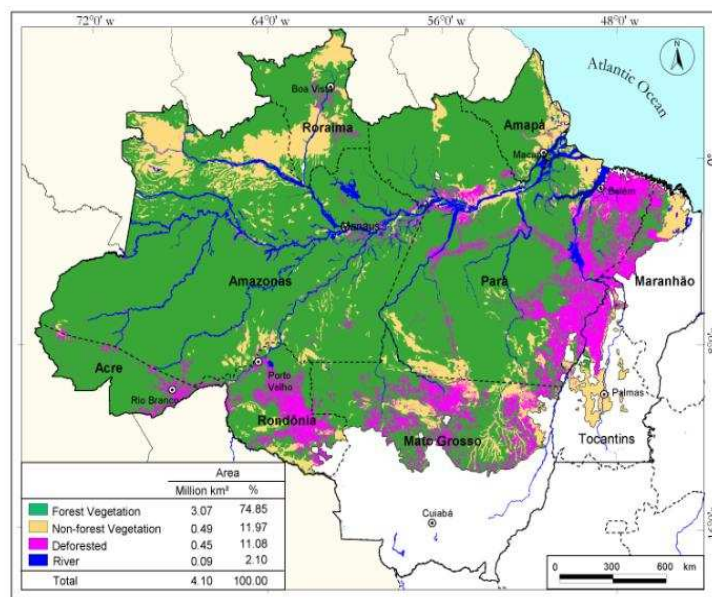|	Indifferent Agent $\tilde{i}$	Agents Welfare W_A	REDD Net Income π_{PM}	Avoided Deforestation AD
Development agency	$\tilde{\tilde{i}}_{BP}$	1	0	3
Income-maximizing PM	$\tilde{\tilde{i}}_{BP}$	0	1	3
Environmental Agency	$\tilde{\tilde{i}}_{E}$	0	$1 - 2 = 0$	$3 + 4$

4   Simulations on Brazilian data

4.1   Case study presentation

Brazil is a priority for REDD activities. The country hosts two thirds of the world's largest forest, the Amazon biome, which covers 6.4 million square kilometers. This contains the equivalent of 15 years of current (CP: ANNUAL?) worldwide anthropogenic emissions (Soares-Filho et al, 2006; May et al 2011). Absolute deforestation rates in Brazil are also the highest in the world, representing approximately one-fifth of global CO2 emissions from land-use change (Borner et al 2010). In recent decades, frontier expansion has occurred along the 'Arc of Deforestation', which stretches from the northeast of the states of Para, Tocantins, Maranhão, down to Mato Grosso and west to Rondônia, ending in the state of Acre (Figure 3). New frontiers have begun to emerge, including the southern border of Amazonas state (May et al 2011).

The state of Amazonas is one of 10 states comprising the Legal Amazon (Amazonia Legal), covering 61 percent of the country. Households in all areas not designated as reserves are bound by the Brazilian Forest Code, which, during the study period, required at least 80 percent of their land to be under forest cover. Surveyed households were randomly chosen from a selection of villages both inside and outside two reserves, Uatuma and Juma. The simulations utilized data collected from 96 households outside the two reserves (50 outside Uatumã and 46 outside Juma), and not those surveyed inside the reserves. This is to avoid confounding the simulation results through the use of data from households who were already receiving incentive payments for conservation and were subject to tighter restrictions on land use inside the reserves.

Figure 3: Forest Vegetation and Deforestation

Area		
	Million km²	%
Forest Vegetation	3.07	74.85
Non-forest Vegetation	0.49	11.97
Deforested	0.45	11.08
River	0.09	2.10
Total	4.10	100.00

Source: http://www.globalforestwatch.org. The baseline for the Human Pressure analysis was a dataset that combines vegetation (IBGE 1997) and deforestation as of 2001 (INPE 2003).

4.2 Estimation of opportunity costs and BAU deforestation

Opportunity costs are estimated from the household survey, which included information on household income earned and assets held in the year prior to the survey. Socio-demographic data such as household composition, age, and education were collected as well as data on land clearing, extraction behavior and household well-being. The shares of annual income sources at the aggregate, sample level are given in Table 2. They highlight the general importance of livestock and agricultural incomes to households in the study areas.

Table 2: Annual income shares for households outside the reserves

	Non land-based income			Natural resource based income		
				Extractive	Land use based income	
Total income shares	Business	Salary	Other	Forest	Net agriculture	Net livestock
Outside Juma	0.06	0.20	0.15	0.12	0.17	0.29
Outside Uatuma	0.02	0.14	0.15	0.23	0.33	0.11

Outside Juma, the predominant income source and land-use activity is livestock, mainly cattle while agriculture (cassava and fruits) dominates outside Uatumã. Opportunity costs per hectare of forest land are first calculated using agriculture and livestock income at the household level since they are the primary land uses after forest is cleared in the area (SDS 2009, 2010). This is then divided by the sum of land currently under cropland or pasture as well as early fallow in order to obtain Y_i/D_i.

However, while all of this area is in production, it does not correspond to a single year of deforestation behaviour at the household level. To account for the periodicity of agriculture, we estimated an annual land clearance figure (D_i) by dividing the sum of cropland, pasture and early fallow by ten years. According to Vosti et al (2002), agricultural production (annual crops) in the Amazon is generally viable for two years after which fields are left to fallow for around three years before fields are planted again. Alternatively, fields can be converted to pasture, which are viable for 15 years. In our measure of net agricultural and livestock productivity per hectare on current land in production and recently fallowed land, we assume a static income flow and ignore the diminishing returns to land over time as a result of decreasing soil and land productivity.

The aggregate productivity of one hectare was estimated for each household by dividing the net income derived from agriculture and livestock and animal product sources by the total land dedicated to each of these activities (cropland, pasture and early fallow).

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Table 3: Descriptive statistics for households outside the reserves

Measures	N of households active	Mean	Std. Dev	Min	Max
Net productivity*	91	1,396	2,23	-289	11,59
Net agricultural income (BRL /year)	85	5,951	9,74	-4,8	75,08
Net livestock and animal product income (BRL /year)	76	4,997	13,66	-13,167	72,546
Forest income (BRL /year)	74	5,029	17,442	-5,24	146,283
Business income (BRL /year)	10	7,961	18,639	-5,04	58,848
Salary income (BRL /year)	62	5,391	7,008	0	33
Miscellaneous Income (BRL /year)	72	4,066	3,512	144	13,2
Land use over past 4 years (hectares)	96	29,52	65,76	0	472
- Total cropland	92	2.25	3.35	0	25
- Total pasture	92	23.93	56.59	0	352
- Early fallow	92	4.61	13.45	0	120

* agricultural and livestock/animal income per hectare of cropland/ pasture/ early fallow (BRL/hectare per year)

Summary statistics of the net productivity in Brazilian Real (BRL) are presented in Table 3, showing the value of per hectare of cropland, pasture and early fallow.[5] Mean incomes are also provided in BRL. These also vary widely among individual households (CP: WHY ARE SOME MIN INCOME VALUES IN TABLE 3 NEGATIVE? DUE TO HIGH COSTS?). The mean area under cropland is much smaller than the area under pasture. Thus, income per hectare is on average much higher for agriculture than for livestock, the latter being an extensive but land intensive activity.

4.3 Setting a carbon payment level

In order to generate a feasible international payment for avoiding deforestation (r), several factors need to be considered. First, a carbon price needs to be determined. Assuming that REDD markets will likely be based on the sale of temporary credits (Borner and Wunder, 2008), we have opted to use the crediting structure as used by afforestation and reforestation projects in the Clean Development Mechanism (CDM). These projects allocate temporary Certified Emissions Reductions (tCERs), which typically fetch a price lower than that of permanent CERs. A conservative estimate of 10 €/tCO2 is used. Second, a discount rate is chosen that will affect the value of tCERs against permanent CERS. We opted to vary the discount rate between 5 and 15 percent, as seen in Table 3. The relationship between the price of a tCER, P_0^{tCER}, and that of a permanent CER, P_0^{CER}, is given by (see Dutschke et al. 2005):

$$P_0^{tCER} = P_0^{CER} - \frac{P_T^{CER}}{(1+\rho)^T} \tag{20}$$

where ρ is the discount rate and $T = 5$. We convert this price into the corresponding annuity over the five years before obtaining the eligible amount of CO2 per hectare (see below and Table 4). This enables a comparison with our estimates of annual per hectare opportunity costs.

Carbon content per hectare varies widely in the Amazon. We apply a conservative estimate of 110 Mg C/ha, corresponding to 403 tCO2 /ha (Houghton, 2001). In the calculations shown below, we present payments for net carbon stock, of around 81.5 t C / ha (equivalent to around 75% of gross stocking per ha).[6]

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[5]One household claimed a total area of land, which seemed unreasonably small for the amount of agricultural production, and is therefore excluded from the sample. Another four households who either had no recorded agricultural or livestock income, or recorded land were also excluded.

[6]The carbon content of 110Mg C (t) / ha includes the carbon content of secondary regrowth based on Fearnside's (1996) average biomass figure of 28.5 t C per hectare for all deforested areas in the Amazon.

Table 4: Discount rate and corresponding payments

Discount rate, ρ	5%	10%	15%
Price of permanent CER, €/tCO2	10	10	10
Price of 5-year non-permanent tCER, €/tCO2	2.16	3.79	5.03
Annual payment, €/tCO2	0.48	0.95	1.43
Annual payment, BRL/tCO2	1.10	2.19	3.29
Annual payment, BRL/hectare = r	442	883	1,325

4.4 Simulation results

Figure 5 identifies the total and marginal hectare purchased under the REDD payment scheme, at each level of r and for the alternative cost estimations. The x-axis shows the distribution of land, which is ordered by households' increasing opportunity cost per hectare deforested. The y-axis shows the price r and the annual opportunity cost per hectare. High cost hectares were truncated in this figure as they are very few and very expensive. Nonetheless, they are included in the simulations since they are representative of projected land pressures in the area. Clearly, it can be seen that irrespective of discount rate used, REDD payments could, in principle, induce the participation of the majority of households in this area. This is largely due to the relatively large but also extensively managed livestock land-holdings, the generally low productivity of agricultural and livestock production, and the high carbon content of the Amazon.

Table ?? outlines the measures of agents' welfare (W_A), REDD net income (π_{PM}) and hectares of avoided deforestation (AD). First, with incomplete information the amount of avoided deforestation is identical across all policy-maker types. None succeed in buying up all the hectares in this sample of households. (CP: we should comment on agents' welfare gain but there looks to be a mistake in this (fifth) column among the different policy makers in the uninformed case). With complete information, policy makers with the development and income maximization objectives cannot buy out all the hectares even at differing tCER prices. Only the policy maker with the environmental objective can buy out almost all hectares in our sample at the tCER price with a 5% discount rate and all hectares at the higher rates. Changes in agents' welfare are as expected, i.e. according to the model.

Table 5: Distribution of rents accross government and housholds and the area contracted

Information state	Policy maker	ρ	tCER cost	Agents' total welfare gain	REDD net income	$\sum Di$
			BRL/ha	W_A, BRL/year	π_{PM}, BRL/year	AD, ha
Informed	Development agency	5%	331	58,469	0	218.8
		10%	663	137,231	0	240.2
		15%	994	222,239	0	255.8
	Income-maximizing	5%	331	0	58,469	218.8
		10%	663	0	137,231	240.2
		15%	994	0	222,239	255.8
	Environmental agency	5%	331	0	0	277.8
		10%	663	0	0	283.4 (all area)
		15%	994	0	0	283.4 (all area)
Uninformed	Development agency	5%	331	58,469	0	218.8
	Income-maximizing	10%	663	137,231	0	240.2
	Environmental agency	15%	994	222,239	0	255.8

5 Discussion and conclusion

In this paper, we develop a simple incentive payments framework for investigating the impacts of improving information about agents? opportunity costs on agents? welfare and the level of deforestation avoided. With growing interest from policy makers and practitioners in policies to Reduce Emissions from Deforestation and Degradation (REDD), we focus on the claim that improving information could lead to increased efficiency. First, an incentive payment is offered by a policy maker in a REDD host country conditional on deforestation agents not deforesting. Second, the carbon services supplied from avoided deforestation may be sold by the host country either on an international carbon market (in the form of carbon credits) or to a fund, at a fixed price. We then consider two cases: incomplete and complete information about individual agents? opportunity costs and their deforestation levels. In both cases, the distribution of opportunity costs and BAU deforestation are known to the policy maker.

We find that the results largely depend on the objective of the policy maker implementing the payments scheme. It may be one of three types: development agency, income-maximizing or an environmental agency. Under complete information, the environmental agency performs the best in terms of the quantity of deforestation avoided as illustrated with the simulations performed using household data collected in Brazil. Indeed, it uses the information on opportunity costs to generate profit on low-cost agents, paying them less than the international price. This profit is then used to retribute agents with larger opportunity costs who also deforest more. We note, however, that by paying these agents more than the international price, such payments could be construed as 'inefficient'. Yet the net effect aggregated across all deforestation agents is more deforestation avoided for a given price.

The income-maximizing policy maker uses improved information on opportunity costs to increase its income, which could be redistributed to the wider population. Alternatively, it could retain rents from REDD for distribution among patron-client networks. The development agency performs better than the other types of policy maker in terms of welfare improvements. In this case, it pays as much as possible to deforestation agents setting a uniform price equivalent to the international price. Note that agents are no better off under the scheme than in the BAU case. In contrast, agents? welfare is the same as in the BAU case when the policy maker is income-maximizing or an environmental agency due to binding agents to their opportunity costs.

An important point concerns the utility of improving information about individual opportunity costs. Improving information in our framework only increases the efficiency of the REDD policy

if the policy maker is an environmental agency, that is setting the policy to maximize avoided deforestation. In this case, improving information increases avoided deforestation. If the policy maker is income maximizing, improving information allows it to capture the surplus from REDD, which decreases the agents? welfare without increasing avoided deforestation. Thus, improving information has no real environmental impact when the policy maker only aims at maximizing the welfare of deforestation agents. Given the demands of stakeholders in the REDD policy debate to improve the well-being of (often poor) forest dwellers, this is an important insight.

The model presented in this paper is, of course, very simple. For instance, we ignored any possible types of transaction costs, which are likely to reduce the incentives for agents to participate. Yet it demonstrates some of the possible trade-offs involved and hence, opens the door for thinking about the real desirability of improving information about individual opportunity costs in the context of REDD. Our results suggest that the actual motivations of the policy maker is key to determining whether or not improving information will increase efficiency. But while obtaining information about opportunity costs is obviously challenging, our results also raise the question of ever knowing about policy makers? true motivations. First, whether it could be identified as welfare, income or environmental service maximizing and second, for the income maximizers to whom the rents from REDD might be distributed. Given endemic corruption among the natural resource sectors of many developing countries, this latter point is particularly pertinent.

In our framework, we only assume that there is some international price for forest carbon sinks that would otherwise be deforested. Funding for REDD could be obtained by the host country either through an international (regulated) carbon market and/or some kind of (voluntary) fund. Where the policy maker?s objective can be discerned (at least to some extent), the source of international funding becomes relevant. An international market, like any market, will be indifferent to the objective of the policy maker and hence, will not discriminate accordingly. A fund, on the other hand, may have the ability to discriminate among types of policy maker. For example, it may choose to avoid REDD host governments with a record of corruption or focus on those with well-run environmental agencies. With this flexibility, a fund-based financing mechanism may be better placed than a market to choose among competing policy objectives particularly if REDD is not to focus only on maximizing forest carbon services alone.

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