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Designing Contracts for Reducing Emissions from Deforestation and Forest Degradation

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Abstract

Reduction of carbon emissions from deforestation and forest degradation has been identified as a cost effective element of the post-Kyoto strategy to achieve long-term climate objectives. Its success depends primarily on the design and implementation of a financial mechanism that provides land-holders sufficient incentives to participate in such scheme. This paper proposes self-enforcing contracts (relational contracts) as a potential solution for the constraints in formal contract enforcement derived from the stylized facts of the implementation because relational contracting relies upon mutual private self-enforcement in a repeated transaction framework. The paper derives an opportunity cost function for land use and characterizes the optimal self-enforcing contract as well as provide the parameters under which private enforcement is sustainable. The optimal payment scheme suggests that all payments should be made contingent on the carbon offsets delivered, that is, at the end of the contracting period. Thus, the optimal contract does not observe any ex ante payment. Self-enforcement is more difficult to sustain the higher the opportunity cost of forest conservation is relative to the value of the carbon offsets from the contract. Necessary extensions to the relational contracting model are also discussed.

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Designing Contracts for Reducing Emissions from Deforestation and Forest Degradation *

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1 Introduction

Deforestation and forest degradation account for about 5.8 billion tons of carbon dioxide (CO2) released into the atmosphere each year, representing approximately twenty percent of greenhouse gas emissions (GHG) (Holloway and Giandomenico, 2009). The potential reduction of emissions from deforestation and degradation (REDD) has been present in the global debate under the United Nations Framework Convention on Climate Change (UNFCCC). However, previous initiatives such as the Kyoto Protocol contained few incentives for reforestation and even less for forest conservation. Furthermore, developing countries were excluded from the existing initiatives primarily because of concerns about the establishment of baselines, effectiveness of monitoring and enforcement of carbon reductions.

Despite these facts there is recognition that a successful reduction of emissions involves large-scale mitigation efforts from the global community, and that developing countries should be included in the REDD scheme as they control an important share of the global forest. Moreover, deforestation and forest degradation (DD) is only marginally profitable, therefore reducing emissions from forest conservation may be more cost-effective than other mitigation alternatives while it can lead to additional benefits such as positive impacts in biodiversity and on economic development (Angelsen, 2008; Sohngen and Beach, 2008).

Nevertheless, the success of REDD in a post-Kyoto protocol regime depends primarily on the design and implementation of a financial mechanism that is feasible and effective in providing the right incentives to land-holders to manage forests in a sustainable manner that contributes to climate goals. Designing REDD contracts not only involves properly rewarding those who reduce emissions from DD, but must also consider technical issues such as permanence of carbon offsets and equitable distribution of payments as well as financial and institutional issues including enforcement of contracts.

While such contracts may be crucial in implementing REDD policies, little is known about how such contracts can be structured to maximize the likelihood of seller participation and performance, particularly for long-term contracts featuring sellers in environments where contracts may be difficult to monitor and enforce. Unfortunately there is limited extant research to guide the formulation of such contracts. Furthermore, the bulk of contract theory has been developed for situations in which contracts are perfectly enforceable and involve only one-time interactions. This paper proposes a relational contracting approach as a new framework to examine the implementation of REDD contracts. Because of the variety of institutional frameworks present in the many countries where REDD contracts are potentially implemented, self-enforcing contracts are more desirable to overcome different legal systems, enforcement structures and weak governance. If the optimal contract is self-enforcing, providers of carbon sinks must perform because the contract is structured in a way where contractual performance (forest conservation) is in their personal best interest. Then, participants privately enforce the contract and third-party enforceability becomes less important.

We consider a principal/agent model where the principal is a buyer of carbon offsets and the agent is a seller that has the option of providing the service by keeping land in forest. We derive an opportunity cost function for the seller's land use that reflects the returns from alternative economic activities and the payments from participating in REDD. We assume that at the beginning of each period parties agree on an initial baseline of tons of carbon dioxide sequestered in the forest land controlled by the seller. The buyer offers a contract with a two-part tariff including a base price and a contingent payment to induce the seller to avoid changing the land use and releasing the carbon to the atmosphere for a particular period of time. The seller is not credit constrained. We assume an imperfect enforcement regime; therefore, after accepting the contract, parities decide to adhere to or renege on the terms of the contract. We derive the optimal contract under these circumstances and for comparison, we also provide the optimal contract structure when there is perfect contract enforceability. In this paper, the optimal contract is derived under the assumption that its unique objective is achieving carbon sequestration and we do not consider any co-benefits of REDD.[1]

The model suggests that when REDD contracts are perfectly enforceable, the buyer pays a base payment to the seller equivalent to the opportunity cost of forest conservation. The payment can be made at the beginning or during period t and the seller maintains the forest. This happens because a formal mechanism enforces the contract. The buyer receives the benefits of full conservation of carbon offsets and the seller gets zero economic profits as when she chooses the non-forest activities.

When REDD contracts are imperfectly enforceable, we assume that only the base price is perfectly enforced. In this case, the total payment is found to have the same total compensation as that of the perfect enforcement regime. However, they differ in how the payment is structured. In the perfect enforcement regime, the total payment is made in a single payment at any point of the contracting period. In the imperfect enforcement regime, the payment is structured such as the complete payment is made contingent on performance. As the base payment does not provide the seller incentives to perform, the optimal incentive provision in a REDD context is characterized with larger contingent payments and base payments equal to zero.

Cooperation is negatively related to the opportunity cost of forest conservation, e.g. the total payment to the seller, and positively related to the value of the forest to the buyer from the contract. The higher the opportunity cost of forest conservation is relative to net value of the carbon sinks in the forest contracted, the harder is to sustain cooperation and achieve forest conservation. Additionally, if the benefit that the buyer accrues from the carbon sinks delivered by the contract is close to the benefits of getting carbon credits from

[1] In this paper we apply the relational contracting model to address the pure objective of carbon sequestration as a first application. See Cordero Salas and Roe (2012) for a version that includes a framework with other REDD co-benefits often included in REDD+ such as distributional issues.

alternative sources, cooperation is also difficult to sustain. In these cases, self-enforcement requires both parties to have sufficiently high valuation of the future so that it is optimal to cooperate. On the other hand, cooperation is easier to sustain when the value to the buyer of the carbon sinks —the foregone opportunity cost of other means to achieve compliance with GHG emissions limits— is higher.

This paper is of interest because it serves the objective of generating new ideas to tackle the described issues and for drawing conclusions about the optimal contract design to guarantee participation of private sellers and mutual self-enforcement of participants, a necessary condition to ensuring long-term performance of forest conservation and carbon sequestration when formal institutions to enforce contracts may be unavailable. These ideas will also benefit practitioners charged with implementing carbon sequestration contracts around the world and of academic interest as the field of relational contracting is still evolving and has not studied many of the practical barriers described in the REDD context.

The structure of the paper is as follows. Section two discusses some relevant details about REDD and the use of relational contracts as a potential tool to overcome some of the issues related to the REDD characteristics. Section three presents the relational contracts model in the context of REDD. Section four presents the benchmark case of perfectly enforceable contracts. Section five derives the optimal relational contract and discusses the sustainability of self-enforcement under a REDD context. Finally, section six presents some conclusions and future extension of this work.

2 Highlights of REDD and the Potential for Relational Contracts

REDD is conceptualized as a cost-effective climate change mitigation mechanism (Kindermann et al., 2008; Sohngen and Beach, 2008) that is based on the idea of rewarding individuals, communities or countries that reduce greenhouse gas (GHG) emissions from forests (compared with a reference level). REDD can also produce additional environmental benefits including biodiversity conservation and watershed protection (Pagiola, Bishop, and Landell-Mills, 2002) and may also be a potential source for social benefits such as poverty reduction (Angelsen, 2008). However, because of the nature of carbon sinks and the absence of a well-established market for carbon offsets, several issues arise as potential challenges for the successful implementation of an effective REDD mechanism. The challenges include various technical, financial and institutional considerations.

First, REDD is conceived as a multi-level mechanism which includes international and national actors that interact through a payment scheme for environmental services (Angelsen, 2008). At the international level, the buyers are those who seek to earn credits within the framework of multinational agreements as part of voluntary reduction schemes or compliance markets, or governments of developed countries such as Norway that seek to reach climate goals, while the sellers are national or other organizations/governments supplying forest conservation. The signing of an agreement between a carbon credit buyer and government or agency promising forest conservation is only the beginning of a potentially protracted struggle to ensure the initiation and permanence of critical carbon emission mitigation efforts (Capoor and Ambrosi, 2008). At the national level, governments or local agencies must entice individual land holders, usually through many individual contracts, to 1) initiate costly land use, land-use change and forestry projects and then 2) fulfill the contractual promise for many years even if, say, rising prices for forestry products or a costly family illness makes such an action individually undesirable.

The presence of multiple players and the delegation of contract implementation and verification create several layers of principal-agent problems. Consequently, unless contracts provide sufficient incentives to all parties to participate and perform, contracts will fail to meet the REDD goals.

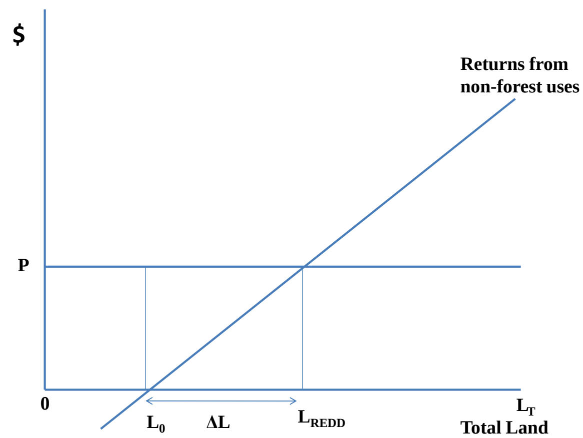

Figure 1: Land use choice with and without REDD payments

A second consideration relates to the technical characteristics for an ideal mechanism that implements REDD. The ideal mechanism would be carbon effective, cost efficient and socially equitable. An effective mechanism results in emissions reductions that are additional and permanent. Additionality means that carbon offsets are additional to the business-as-usual scenario. That is, a REDD mechanism gives incentives to land-owners to avoid DD that would occur in the absence of such incentives. Figure one shows the land-use choice determined by the returns from non-forest economic activities and the payments for REDD (Pfaff, Robalino, and Sanchez-Azofeifa, 2008) and illustrates this additionality property. The horizontal axis represents total land area where the land is ordered according to potential returns. The land at the origin is the least productive and has the lowest returns in productive activities such as agriculture and timber harvesting. The vertical axis represents the monetary value and the diagonal line represents the returns from the non-forest activities of each unit of land.

In the absence of payments for forest conservation, land is deforested as long as the returns from the alternative activity are positive. In the figure, land in the interval $[L_o, L_T]$ generate positive returns from non-forest activities. Therefore, in the absence of any REDD payments, land in that interval is deforested. In contrast, land located in the interval $[0, L_o]$ is never deforested because the returns from the non-forest activities are non-positive.

When REDD payments are introduced, the choice concerning land-use is potentially affected because the REDD payments offset some part of the opportunity cost of keeping the forest in its carbon-sequestering state. Land-holders decide to maintain the forest land if they are compensated for the forgone returns of the non-forest activity. However, only land that is under a threat of deforestation or forest degradation generate additionality for a REDD mechanism.

The horizontal line that goes through P in the figure represents the simplified REDD payment. The price does not reflect a single price from a competitive market for REDD credits. Instead it just illustrates a maximum REDD payment given the buyers' willingness to pay. In the context of this paper, the focus of the modeling is on individual bilateral contracts with perfect information in which the opportunity cost of the land determines the individual payment. As the model is of complete information, any economic rents dissipate because the sellers' individual rationality constraint binds. If there was a single price for REDD, all sellers accrue economic rents with the exception of the one for which the single price equals her opportunity cost of the land.

The point L_{REDD} where the REDD payment line intersects the returns of the non-forest activities line represents where the marginal benefit of REDD equals the marginal cost of it. If a REDD payment is made to a land owner in the interval $[L_{REDD}, L_T]$, the cost of forest conservation is higher than the payment for the carbon sinks generated. Therefore, REDD payments in this interval are inefficient. If a REDD payment is implemented for land in the interval $[0, L_o]$, the payment is also inefficient because land in this location would never have been slated for forest degradation or deforestation as the returns of the non-forest activities are not positive. Therefore, forest conservation in this land does not generate any additional reduction from the business-as-usual scenario. Finally, a REDD payment is efficient if it compensates land owners in the interval $[L_o, L_{REDD}]$ such as they participate in forest conservation. This interval represents the additionality of the REDD mechanism as this land is deforested in the absence of REDD payments.

The next requirement for effectiveness of REDD contracts is that the carbon offsets must be permanent. Permanence refers to fact that conserved forests should not be lost in the future and therefore carbon sinks must exist for long periods of time. The optimal REDD mechanisms has to give enough incentives to the land owner to keep participating in the REDD mitigation effort in the long-term (permanent) and has to be incentive compatible by compensating the seller for changes in the opportunity cost of forest conservation.

Finally, a key issue for contracts that implement REDD is the capacity to monitor, report and verify. In this context, contract enforcement is a key element for sustainability and permanence of REDD projects. However, enforceability is very complex given the institutional constraints. For instance, even though industrialized nations committed to list emission reduction targets and direct funding to help developing countries at the 2009 United Nations Climate Change Conference, the "Copenhagen Accord" is not legally enforceable (UNFCCC, 2009). Additionally, sellers in areas with sensitive ecosystems are of particular interest because their efforts may yield greater marginal benefits. However, many of these sellers reside in countries where contracts are difficult to enforce due to lack of formal courts, a weak institutional framework and weak governance, or high costs of enforcement. Furthermore, effort and outcomes described in such contracts including important technical aspects from REDD are difficult to monitor and enforce, specially under weak governance.

While such contracts may be crucial in implementing REDD policies, little is known about how such contracts can be structured to maximize the likelihood of seller participation and performance, particularly for long-term contracts featuring sellers in environments where contracts may be difficult to monitor and enforce. Because the limitations and characteristics of the context under which REDD contracts have to be implemented, an explicit contract would be incomplete and difficult for a third-party to enforce. Therefore, REDD contracts need to be self-enforcing; i.e., sellers must perform because the contract is structured in a way where contractual performance (forest conservation) is in their personal best interest. Without carbon payments, sellers adopt those land use and management practices that maximize economic returns. Therefore, the contract has to give incentives to sellers to choose forest conservation as part of their optimization program.

The power of relational contracts comes from the emergence of informal enforcement mechanisms that support incentives even when explicit contracts are incomplete. Relational contracts (also called self-enforcing contracts) rely upon the concept that, when parties are involved repeatedly in a relationship, the promise of future payoffs can sustain performance today while the threat of termination can serve as a partial substitute for explicit incentives in disciplining rent seeking, hold-ups and underinvestment problems. In the case of REDD, as buyers of carbon credits promise to pay for the performance of the suppliers today, tomorrow and so on, the suppliers look at their stream of future payoffs and have incentives to maintain forest stocks and reduce degradation. In the next section a first step is taken to apply the relational contract framework to a REDD environment with the objective to address enforcement issues.

3 The Model

Consider two risk-neutral parties, a buyer and a seller who have the opportunity to trade carbon emissions offsets at dates $t = 0, 1, 2, 3 \ldots$. Trading can be on an international or on a national level. If trading is on an international level the buyer may be attempting to comply with obligations to reduce GHG emissions, e.g., governments of industrialized countries. The seller may be governments of developing countries, local governments or project developers and NGOs interested in reducing carbon emissions. If trading is on a national level the buyer may be the government of the recipient country or project developers and NGOs such as Conservation International. The seller could be an individual land-owner, farmer or a local community who has the possibility of maintaining carbon stocks in the forest for specific periods of time.

The seller possesses forest land $\overline{q}$ at the beginning of the period. She is interested in adopting the land use and management practices that maximizes her economic returns and she has the option to conserve the forest and maintain the carbon stocks, $q \in (\underline{q}, \overline{q}]$, or she can change the land use to a non-forest activity such as agricultural and timber harvesting resulting in carbon emissions. In the absence of REDD payments, the seller allocates $\underline{q}$ of her land to forest and $(1 - \underline{q})$ to other economic activities. Let $U_0 = \omega(\overline{q} - \underline{q}) - c(\overline{q} - \underline{q})$ be the profit of the alternative economic activity where ω is the return of the activity and $c(\overline{q} - \underline{q})$ is the cost. The cost is assumed to have the following properties: $c_1(\overline{q} - \underline{q}) \geq 0$ and $c_{11}(\overline{q} - \underline{q}) \geq 0$. The seller chooses $\underline{q}$ by maximizing U_0 which leads to the first-order condition: $\omega = c_1(\overline{q} - \underline{q})$. When a seller faces the opportunity to participate in a REDD scheme, she can place some land in forest, $q \in (\underline{q}, \overline{q}]$, receive a payment $P(q)$ and receive returns from alternative land use for some of the land: $\omega(\overline{q} - q) - c(\overline{q} - q)$ if $q \neq \overline{q}$. Her total profits in this case are: $U_{REDD} = P(q) + \omega(\overline{q} - q) - c(\overline{q} - q)$. The landholder participates in the REDD program if $U_{REDD} \geq U_0$. By rearranging, the expression leads to $P(q) \geq \omega(q - \underline{q}) - c(\overline{q} - \underline{q}) + c(\overline{q} - (q - \underline{q}) - \underline{q})$. Let $C(q) = \omega(q - \underline{q}) - c(\overline{q} - \underline{q}) + c(\overline{q} - (q - \underline{q}) - \underline{q})$ be the opportunity cost function. Because $\omega = c_1(\overline{q} - \underline{q})$ and $q \in [\underline{q}, \overline{q}]$, the opportunity cost of keeping land in forest is increasing and convex—$dC/dq \geq 0$ and $d^2C/dq^2 \geq 0$[2] —and $C(\underline{q}) = 0$.

[2]Note that $dC/dq = \omega - c'(\overline{q} - \underline{q} - (q - \underline{q}))$ and $\omega \geq c'(\overline{q} - \underline{q} - (q - \underline{q}))\ \forall\ q \in [\underline{q}, \overline{q}]$.

The buyer is interested in obtaining credits for reducing greenhouse gas emissions from deforestation and degradation. Thus, he is willing to pay the seller to avoid changing the current land use and to maintain the carbon stock captured in the forest for a given period of time, t. That is the buyer is willing to pay for forest conservation.

Figure 2 shows the timing of actions and decisions. At the beginning of period t, the buyer and the seller agree on an initial baseline of tones of carbon stocked in the forest land owned by the seller. Once the initial forest baseline is established, the buyer proposes a compensation scheme to the seller that she is entitled to if she does not change the land-use and keeps the forest initially agreed, q^*. Compensation consists of a base payment p_t and a contingent payment $b_t : Q \to \Re$, where Q is the observed forest. Forest conservation is observable by both parties but they are not enforceable by a neutral third-party because of weak court systems and weak governance in the developing country. Consequently, the desired forest conservation, q^*, may differ from the delivered quantity, q_t. Let $q_t \in Q = [\underline{q}, \overline{q}]$ denote the set of forest delivered in period t, where $\overline{q}$ represents the forest at the beginning of the period given the initial land use. $\underline{q}$ represents the level of forest when the land use is completely changed to a non-forest activity.

The base payment, p_t, is paid independently of the final outcome , therefore it is enforceable. The contingent payment is considered as a *bonus* and it is used to reward complying with the baseline and avoiding deforestation and forest degradation. Since the contingency payment depends on an unenforceable measure, it is not a legally binding obligation.

After observing the compensation scheme, the seller decides whether or not to accept the buyer's offer. If the seller accepts, she receives p, observes the returns of alternative land uses including non-forest activities and decides to adhere to the contract or to change the land use and breach the contract.

If she decides to avoid DD, she performs under the contract and incurs the opportunity cost for forest protection which is given by the opportunity cost function, $C_t(q_t)$. The seller's

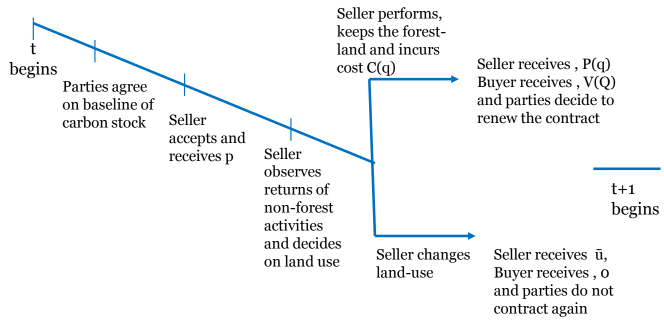

Figure 2: Timing line

economic profit is $U_t = P_t(q_t) - C_t(q_t)$, where $P_t(q_t) = p_t + b_t(q_t)$ is the total payment actually made from the buyer to the seller. At the end of period t and upon delivery, the seller's forest generates a direct benefit for the buyer, $V_t(q_t)$, where $V'(.) > 0$, $V''(.) \leq 0$, and $V(\underline{q}) = 0$. $V_t(q_t)$ represents the buyer's value of the carbon credits generated by the forest conservation. It can be interpreted as the buyer's direct cost of doing his own carbon emission mitigation, and it can also reflect the buyer's value for non-carbon objectives such as biodiversity conservation. The buyer also chooses whether or not to pay $b_t(q_t)$ and his profits are given by $\Pi_t = V_t(q_t) - P_t(q_t)$. Also, $V'(.) > C'(.)$ for all $q \in Q$, so it is socially efficient and Pareto optimal to maintain the forest land and trade carbon sinks $q = \overline{q}$, since $\overline{q}$ maximizes the total joint surplus defined by $S(q_t) = V(q_t) - C(q_t)$.

If the seller rejects the contract, trade does not occur, the seller does not incur the opportunity cost of the land and the buyer receives $\overline{\pi}$ which is equivalent to the alternative source of carbon credits; for example, the buyer can get CDM credits from other projects or alternatively implement a REDD project in another country. Trading is more attractive than these options, but the options are desirable to the parties if there are insufficient incentives for the parties to trade. The net social surplus is given by $S(q_t) - \overline{\pi}$, where $S(q_t) - \overline{\pi} > 0$

for all $q \in (\underline{q}, \overline{q}]$, and $S(\overline{q}) > S(\underline{q}) \geq 0$.

This sequence of events repeats in each period t, and over the course of repeated interactions the parties know only the past actions of the trading partners with whom they have traded allowing for the creation of relationships in which cooperation is an important characteristic. In addition, the party's objective is to maximize the future discounted stream of payments, where the common discount factor is $\delta \in (0, 1]$. Specifically, the objective of the seller is to maximize her present discounted profit, given as

$$\sum_{t=0}^{\infty} \delta^t \left\{ d_t(P_t(q_t) - c(q_t)) + (1 - d_t)\overline{u} \right\} \tag{1}$$

and the buyer's objective is to maximize his present discounted profit

$$\sum_{t=0}^{\infty} \delta^t \left\{ d_t(V(q_t) - P(q_t)) + (1 - d_t)\overline{\pi} \right\} \tag{2}$$

where $d_t = 1$ if the seller accepts the contract and trade occurs in period t, and $d_t = 0$ if the seller rejects and no trade occurs.

4 REDD Contracts under Perfect Enforceability

If forest conservation was perfectly third-party enforceable, the contract could explicitly include the amount of forest and a single base payment in exchange of the carbon delivered. Contingent payments are not necessary because a formal court enforces the contract. If parties breach the contract, they will incur a formal penalty assumed large enough to motivate performance. Consequently, the buyer proposes a contract defined as $y_t = \langle P_t, q_t \rangle$ that maximizes his stream of future payoffs subject to the participation of the seller in the contract. The seller accepts the contract and avoids DD if and only if the economic returns she obtained from the contract U^* are non-negative. This situation is given by inequality 3:

$$U^* = P_t - C(q_t) \geq 0. \tag{3}$$

The left-hand side represents the seller's gains from the contract. She receives P_t in exchange of avoiding changing the land use and incurs the opportunity cost for forest conservation. Inequality 3 just indicates that seller gets compensated for the forgone returns of the other economic activities which need to be non-negative to be individually rational for the seller to participate; i.e., the individual rationality constraint (IRC). The buyer's maximization program is

$$\begin{aligned} &\max_{P,q} \left(\frac{V(q) - P}{1-\delta}\right) \\ &\text{subject to} \quad P = C(q) \\ &\text{and} \quad q \in [\underline{q}, \overline{q}]. \end{aligned} \tag{4}$$

Substituting the seller's IRC into the buyer's profit option, we obtain the following first order condition

$$V'(q) \;\; = C'(q) \tag{5}$$

Because $V'(.) > C'(.)$ for all $q \in Q$ it is socially efficient and Pareto optimal to maintain the forest land and trade $q = \overline{q}$. The optimal contract is given in Proposition 1.

Proposition 1. *If REDD contracts are perfectly enforceable, the buyer pays a base payment to the seller equal to $P = C(\overline{q})$ during date t, the seller maintains the forest and gets non-negative economic profits, $U^* = 0$, while the buyer gets the surplus from forest conservation,* $\Pi^* = \frac{V(\overline{q}) - C(\overline{q})}{1-\delta}$.

A formal mechanism enforces the optimal contract which implements full conservation of the forest land. The buyer obtains the benefits of the carbon sink's storage in the forest. The seller is compensated for the opportunity cost of the land and she gets the same economic profits as she gets when choosing the alternative land use including for instance agricultural and timber harvesting.

5 Relational Contracts and REDD

Because of the weak governance in the developing country, forest conservation is not enforceable by a formal court of law. As a consequence, parties must rely upon relational contracting as a private enforcement mechanism. This means that parties rely on informal incentives and good faith to self-enforce agreements. However, the contingent payments are just a promise, therefore parties have the temptation to deviate from the contract as they do not incur in a formal penalty for reneging the original agreement.

If parties were to interact just one time, the buyer can only make the base payment credible as it is paid independently of forest conservation. Because this payment does not include any additional incentives to the seller to continue to sequester the carbon, avoiding carbon emissions from DD cannot occur in a static equilibrium. Consequently, trade does not occur.

In contrast, the ongoing interaction sustains the equilibrium by allowing the parties to support future terms of trade contingent on the satisfactory performance of present trade. The parties cooperate if the history of play in all periods has been cooperation, where cooperation is defined as both parties fulfilling the contract. The parties break-off trade forever if any deviation is observed. Following Levin (2003) we assume assume that deviation causes the parties to break-off trade forever because this outcome never happens in equilibrium. Furthermore, it can be assumed that after any deviation parties behave as they would in one-time interactions in which the buyer offers a contract in which there is no performance incentives and the seller responds by changing the land use. If the seller changes the land use, the buyer will not be interested in trading with such a seller anymore as she does not have forest conservation to offer. On the other hand, if the buyer deviates, the seller loses trust in the buyer and responds by changing the land use to a non-forest activity. Again, the forest is destroyed along with the opportunity of future trade.

Additionally, parties cannot renegotiate the trading decision after carbon sinks are observed. The reason for this is that if a self-enforcing contract is optimal given any history, then the contract is strongly optimal. This strongly optimal contract has the property that parties cannot jointly gain from renegotiating a new self-enforcing contract even off the equilibrium path. A behavior off the equilibrium path implies deviation. Following the same argument as before, if either party deviates, forests are destroyed and with them the social surplus. Therefore there is no gain from renegotiation.

Finally, each period is played following a Nash equilibrium and parties use a stationary contract, in which the buyer always offers the same payment scheme, the seller always takes the same action, and the rents to the relationship are attractive enough for parties to self-enforce the contract and stay in the relationship (Baker, Gibbons, and Murphy, 1994; MacLeod, 2006; MacLeod and Malcomson, 1989, 1998). Moreover, repetition allows players to maintain a Sub-game Perfect Nash Equilibrium (SPNE) where parties honor the contract and maintain long-term relationships.

These assumptions allow for self-enforcing contracts — relational contracts — since it contains a complete plan for the relationship that describes behavior on and off the equilibrium path. On the equilibrium path, both parties fulfill the contract, the seller avoids DD and incurs the opportunity cost of forest conservation. As an example, a party interested in carbon sequestration, e.g. Conservation International (CI) or a government, promises a forest-land manager, i.e. a party the owns the right to use the land, to pay p_t regardless of performance plus a bonus, $b_t(q_t)$, conditioned on the forest-land manager's satisfactory forest conservation. The forest-land manager can choose to shirk or conserve the forest by forgoing the returns of alternative land uses. If she decides to provide forest conservation, at the delivery date, since the forest conservation is not enforceable by a third party, then CI or a government has to decide to fulfill the initial agreement or to shirk. If he honors the agreement he pays $b_t(q_t)$ additional to the p , then trade continues overtime. If he decides to shirk then he does not pay $b_t(q_t)$.

5.1 Characterization of Self-enforcing Contracts

Because third-party enforcement is imperfect, the buyer must offer a contract $y = \langle p, b(q) \rangle$ through which he provides additional incentives for the seller to avoid DD. The buyer pays p as a base payment regardless of what the seller's performance is, and the contingent payment takes the form of a bonus that the buyer promises to pay as long as the seller does not shirk. Because enforcement is imperfect after the seller accepts a contract y, parties may renege without a formal penalty. The seller decides on how to use the land and it may differ from the desired use induced by the contingent payment rule in the contract. She can cooperate and choose $q_t \geq q^*$, or can shirk by choosing a non-forest activity.

The buyer, after observing the forest conservation delivered, may cooperate by paying $P_t(q_t) = p_t + b_t(q_t)$. Or he may renege the contract by choosing the most profitable deviation, reneging on the payment of the bonus, $b(q) = 0$. The buyer participates in the REDD contract if the benefits from such contract are greater than his alternative source of carbon reduction. This is given by the buyer's IRC

$$V(q) - p - b(q) \geq \overline{\pi} \tag{6}$$

In addition, the buyer's offer has to meet the seller's IRC, i.e., the offer has to provide a credible incentive to perform in each period. Note that P is now given by $p + b(q)$ in inequality (3). Because of the imperfect enforcement a dynamic incentive compatibility constraint (DICC) for each party has to be fulfilled to self-enforce the contracts. The DICC is necessary to reach the optimal contract because it requires the parties to prefer to behave according to the contract over time instead of reneging. The seller's and the buyer's DICC are given by (7) and (8) respectively. A seller cooperates if and only if:

$$\frac{p + b(q) - C(q)}{1 - \delta} \geq p - C(\underline{q}) \tag{7}$$

The left hand side is the discounted payoff of the seller for cooperating and maintaining the carbon stock $q_t \geq q^*$ at the end of each date t. It represents the discounted gains from the relationship for the seller. She receives p during period t and the contingent payment $b(q)$ after delivering the carbon stocks established in the contract and she incurs the opportunity cost of forest conservation. The right hand side represents the payoff if she shirks. Note that the most profitable deviation for the seller is to change the land-use completely and to not incur the opportunity cost for forest conservation which would cause the principal, after observing the carbon stocks delivered, to not pay the bonus. If the seller does so, she incurs $C(\underline{q})$ and receives p.

Additionally, participation for the buyer in the long-term relationship is optimal if his DICC given by (8) is satisfied. A buyer cooperates if and only if the left hand side payments from cooperation are greater than the right hand side payments from deviation. If he cooperates he gets the long-term benefits of forest conservation net of the payments he makes. If he deviates he gets the benefits of the carbon storage minus the price that is enforceable. Then in all future periods, he guarantees himself the benefits of the alternative options for carbon credits.

$$\frac{V(q) - p - b(q)}{1-\delta} \geq V(q) - p + \frac{\delta}{1-\delta}\overline{\pi} \tag{8}$$

A contract is self-enforceable if the parties find cooperation to be the optimal strategy. For instance, in REDD contracts, the long-term returns from the current relationship have to be at least as good as the present value of the returns from other alternative uses of land so that the seller remains trading with the same buyer, and vice versa. Then, since both parties can deviate from the contract, the contingent payment must be sufficient to ensure a self-enforcing contract. It follows that the compensation scheme is bounded by the future gains of the relationship. The buyer optimization program is now given by

$$\begin{aligned} &\max_{p,b(q),q} \left(\frac{V(q) - p - b(q)}{1-\delta}\right) \\ &\text{subject to} \quad p + b(q) = C(q), \\ &\qquad \tfrac{p+b(q)-C(q)}{1-\delta} \geq p - C(\underline{q}), \\ &\qquad \tfrac{V(q)-p-b(q)}{1-\delta} \geq V(q) - p + \tfrac{\delta}{1-\delta}\overline{\pi}, \\ &\text{and} \quad q \in [\underline{q}, \overline{q}]. \end{aligned} \tag{9}$$

As the buyer makes a take-it-or-leave-it offer that gives just enough incentives for the seller to participate, the seller's IRC can be rearrange as

$$p = C(q) - b(q) \tag{10}$$

and expression (7) can be restated as,

$$p \geq C(\underline{q}) + \frac{C(q) - C(\underline{q}) - b(q)}{\delta} \tag{11}$$

By substituting p from (10) in (11), we get the minimum bonus that needs to be offered in a REDD relational contract: $b(q) \geq C(q) - C(\underline{q})$. The presence of the performance payment allows the buyer to offer a lower base payment. By isolating $b(q)$ in (10) and substituting in (11), we get the upper bound on the base payment, p, for inducing long-term seller cooperation: $p \leq C(\underline{q})$.

In the same way, the buyer's IRC and DICC impose limits into the payment structure. To see this note that the buyer's DICC is binding while the IRC is not binding.[3] By substituting p from (8) into (6), we get the lower bound of a bonus that satisfies the buyer's constraints: $b(q) > 0$. Finally, by substituting p in the same way we get that $V(q) - \overline{\pi} > p$.

Note that the minimum bonus derived from the seller's constraint satisfies the minimum bonus derived from the buyer's constraints; therefore, the minimum bonus from the seller's constraints binds in the contract. In the same way, the maximum price from the seller's constraints binds as $C(\underline{q}) < V(q) - \overline{\pi}$. Thus, the optimal distribution of the total compensation among the base payment and the performance bonus is established. The optimal stationary REDD contract is defined in Proposition (2).

Proposition 2. *If contract enforcement is imperfect and parties repeatedly interact, and assuming δ high enough, an optimal stationary REDD contract $\langle p^*, b^*(q^*)\rangle$ that implements conservation of the forest land $\overline{q}$, must satisfy (3),(6), (7), and (8), where (3) and (8) bind, and the compensation scheme is characterized by:*

$$b(\overline{q}) \geq C(\overline{q}) - C(\underline{q}) \ , \tag{12}$$

$$p \leq C(\underline{q}) \ , \ \textit{and} \tag{13}$$

$$p + b(\overline{q}) = C(\overline{q}). \tag{14}$$

[3]If the IRC binds $V(q) - p - b(q) = \overline{\pi}$ and substituting in the DICC, we get that $p > V(q) - \overline{\pi}$ which violates the buyer's IRC. The IRC then does not bind. If the DICC binds, $V(q) - p - b(q) = (1-\delta)(V(q) - p) + \delta\overline{\pi}$. By substituting it in the IRC we get that $V(q) - \overline{\pi} > p$, which is possible, the DICC then binds.

and in each period the buyer receives profits equal to $\Pi = R(\overline{q}) - C(\overline{q})$ *while the seller gets economic profit* $U = 0$.

Equality (14) identifies the total compensation that the buyer offers the seller in the contract. Inequality (13) gives the maximum base payment that the seller receives regardless of performance and inequality (12) gives the size of the minimum bonus that the buyer promises to pay at the end of the period to induce the seller to not change the land-use.

Recalling the assumptions about the opportunity cost of forest conservation, $C(\underline{q}) = 0$, the base payment included in the optimal REDD contract is non-positive. That means that under the optimal relational contract the seller does not get paid through an enforceable base price. The contingent payment includes the full payment equivalent to the opportunity cost of the alternative land use. This is intuitive because if the seller deviates from the contract and changes the use of land, the buyer does not pay the performance payment and furthermore he does not trade again with her. As a consequence she cannot get any future benefits from the relationship. This happens even with the smallest change in the land use as the carbon sinks differ from the baseline established at the beginning of the period and renegotiation is not credible under the assumptions of the optimal relational contract. Therefore, if the seller deviates from the contract she chooses the most profitable actions which include not incurring any opportunity cost for forest conservation and converting all land to agricultural or timber activities. Because an ex ante base payment does not give incentives to the seller to remain in the relationship as it is not conditioned on performance, the buyer needs to provide large enough additional incentives to the seller to perform under imperfect enforceability of forest conservation. Moreover, because the contingent payments are limited by the future gains from the relationship and because the buyer's profit decreases when the base payment is positive, then all compensation is shifted to the contingent payment so that the seller has enough incentives to perform. The result is highlighted in the following corollary.

Corollary 1. *For imperfect enforcement regimes, all compensation is paid as a performance payment upon delivery of forest conservation, and the payment is weakly increasing on the returns of alternative activities.*

The total compensation is weakly increasing in the returns of non-forest activities — the opportunity cost of forest conservation— because the contingent payment is limited by the gains from the relationship. If the returns of other activities are too high, then the future gains from the relationship may not be enough to provide incentives to the parties to perform and self-enforce the contract. This result is examined in more detail in the next section.

5.2 Sustainability of Self-enforcing Contracts

Self-enforcing contracts are sustainable if parties find the optimal strategy is to cooperate in every period. The cooperation decision depends on each party's discounted payoff stream from the contract. The discounted payoff stream represents the value of the relationship and depends on how much each party values the future relative to the present (discount factor). If parties hold a very low discount factor, δ near to zero, the value of the relationship shrinks and it becomes less attractive to comply with the obligations of the contract. Therefore, it is more difficult to sustain cooperation and enforce contracts privately. As a consequence, social efficiency is potentially offset by the lack of formal enforcement.

In the case of the optimal REDD contract described in Proposition 2, parties find cooperation (self enforcement) to be the best strategy if they value the future relationship enough. The valuation is given by each party's dynamic incentive compatibility constraints. Combining the dynamic constraints for both parties given by (7) and (8) yields the discount factor necessary to achieve cooperation under the optimal REDD contract.

Proposition 3. *Let* $\underline{\delta} > 0$*. Cooperation under the optimal REDD contract is achievable*

$\forall\ \delta \in [\underline{\delta}, 1),\ where\ \underline{\delta} = \frac{C(q)-C(\underline{q})}{V(q)-C(\underline{q})-\overline{\pi}}.$

Proposition 3 reports the range of discount factors that can support a cooperative equilibrium under the optimal REDD contract. It predicts that parties that have a discount factor greater or equal to the parameter $\underline{\delta}$ find attractive to cooperate in the REDD context. Recalling again the assumption that $C(\underline{q}) = 0$, the parameter $\underline{\delta}$ can be rewritten as

$$\underline{\delta} = \frac{C(q)}{V(q) - \overline{\pi}} \tag{15}$$

The term in the numerator includes the total payment the buyer has to make to the seller to avoid carbon emissions from DD. The payment represents the full cost of forest conservation under a REDD contract. The denominator represents the value of the carbon sinks from the contract. That is, the buyer's value of the carbon sinks net of the outside option to get carbon credits from an alternative source.

The higher the total payment is relative to the net value of the carbon sinks in the contract the closer to one is the discount factor needed to maintain cooperation. As a consequence, only parties who value the future nearly as much as the present find cooperation to be the optimal strategy.

A high discount factor threshold emerges when the returns of the non-forest activity are too high. The latter implies a higher opportunity cost for the land use. Therefore, it will be more difficult for the seller to forgo alternative returns for the land use.

On the other hand, for any given REDD payment, when the benefit that the buyer accrues from the carbon sinks delivered by the contract is similar to the benefits of getting carbon credits from other alternative sources, the discount factor needed for cooperation is also very high and cooperation is harder to sustain. Accordingly, contract sustainability requires that both parties have sufficiently high discount factors to prevent any party from shirking on contract obligations and to continue cooperation.

In contrast, the lower the opportunity cost of forest conservation is relative to the difference of returns from the carbon delivered under the contract and the alternative source of carbon credits, the smaller is the discount factor need to self-enforce the contract. That is, the higher is the buyer's own cost of compliance as represented by $V(q)$ relative to other alternative carbon credits different than the individual contract with the seller; the lower is the critical value of the discount rate and the easier is cooperation to sustain. In these situations, REDD contracts are more likely to achieve their objective. We end by summarizing these insights in Corollary 2.

Corollary 2. *Cooperation under the optimal REDD contract is more likely to occur when the opportunity cost of maintaining carbon stocks is low, the outside options for buyer are low and when the buyer's value of carbon credits is high.*

6 Conclusions and Future Extensions

Reducing emissions from deforestation and forest degradation has been identified as a cost-effective measure to mitigate global climate change. However, REDD contract implementation is challenging because of technical, financial and institutional considerations, including the verifiability and monitoring of carbon sinks and forest conservation. These elements make contract enforceability a key issue for the implementation of a REDD mechanism. Previous research on REDD contracts assumes that there exists some probability of enforcement (Palmer, Ohndorf, and MacKenzie, 2009). However, because of the multiple institutional frameworks in which REDD is potentially embedded, this may not be the case. In this paper, we propose the use of informal incentives and good faith as key elements to enforce contracts and overcome incomplete enforcement. We have derived the optimal REDD contract and shown how the optimal level of incentive provision is characterized. We have also derived the parameters under which self-enforcement and cooperation are sustainable.

In the benchmark case, where contracts are fully enforced by a formal court, we have shown that the buyer achieves optimal forest conservation and the seller participate in the contract when the seller is paid the opportunity cost of the land. The total payment includes a single payment that can be made at any time during the trading period because it is formally enforced.

More interestingly, when contract enforcement is lacking, the model predicts that the optimal contract includes a payment structure in which the base payment is set to zero and the contingent payment includes the total value of the compensation. As the base payment does not provide the seller incentives to perform, the optimal incentive provision in a REDD context is characterized with larger contingent payments and the absence of base payments. Furthermore, we show that cooperation is difficult to sustain when the total cost of forest conservation is too high relative to net value of the forest conservation contracted, and when the benefit that the buyer accrues from the carbon sinks delivered by the contract is close to the benefits of getting carbon credits from alternative sources. As a consequence, self-enforcement requires both parties to have sufficiently high discount factors and REDD goals are more difficult to achieve.

This paper takes a first step to apply the relational contract framework to a REDD environment. The results provide insights on the power of informal enforcement mechanisms that support incentives even when REDD explicit contracts are incomplete. Thus, there are several issues that need to be incorporated in future extensions of this work to reflect additional particulars of REDD and objectives of REDD+. Such extensions include the presence of credit constrained sellers, distributional issues, moral hazard and adverse selection, stochastic variation of the alternative land-use, subjective and objective performance, as well as the existence of delegation and monitoring issues.

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