Designing Contracts for Reducing Emissions from Deforestation and Forest Degradation

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Abstract

Reduction of carbon emissions from deforestation and forest degradation (REDD) has been identified as a cost effective element of the post-Kyoto strategy to achieve long-term climate objectives. The success of REDD depends primarily on the design and implementation of a financial mechanism that provides land-holders sufficient incentives to participate in a REDD scheme. This paper proposes relational contracting as a more appropriate framework for analyzing proposed REDD incentive regimes rather than that of complete contracting enforcement because relational contracting relies upon mutual self-enforcement in a repeated transaction framework, which better suits the stylized facts of REDD. We characterize the optimal REDD relational contract and provide the parameters under which self-enforcement is sustainable. The optimal payment scheme suggests that all payments should be made contingent on the carbon offsets delivered. Thus, the optimal contract does not observe any fixed ex ante payment. Self-enforcement is more difficult to sustain the higher the 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.

Key words: contracts, incomplete enforcement, carbon sequestration, climate change, institutions, development.
JEL Codes: D86, K12, L14, O12, Q54, Q56.

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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) as a major component to mitigate global climate change and meet the long-term climate objectives. However, previous initiatives such as the Kyoto Protocol contained few incentives for reforestation and none for forest conservation. Furthermore, developing countries were excluded from REDD initiatives primarily because of concerns about the effectiveness of monitoring and enforcement of carbon reductions in those countries.

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 strategy as they control an important share of the global forest. Moreover, deforestation and degradation 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 involve not only properly rewarding those who reduce emissions from deforestation and forest degradation (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 delegation, verification and 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 credit-constrained 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 encapsulates these factors and proposes a relational contracting approach as a new framework to examine the implementation of REDD contracts. Because 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 third party verifiability. 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 verifiability become 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. We assume that at the beginning of each period parties agree on an initial baseline of tonnes of carbon dioxide sequestered in the forest land controlled by the seller. The buyer offers a contract which includes a payment scheme that combines 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 period of time t. Because carbon sinks are difficult to verify 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 also provide the optimal contract structure when there is perfect contract enforceability.

When REDD contracts are perfectly enforceable, the buyer pays a fixed payment to the seller equivalent to the full cost of forest conservation including the cost of maintaining the forest and the opportunity cost of the land use. The payment can be made at the beginning or during period t and the seller maintains carbon stocks. This happens because a formal mechanism enforces the contract. The buyer receives the benefits of full conservation of carbon offsets and the seller gets profits equivalent to returns of the non-forest activities.

When REDD contracts are imperfectly enforceable, we assume that carbon sinks are not third-party verifiable but a the base price is perfectly enforced. The total payment under this regimen 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 the fixed payment. In the imperfect enforcement regime, the payment is structured such as the complete payment is made as a payment that is contingent on performance. As the fixed payment does not provide the seller incentives to perform, the optimal incentive provision in a REDD context is characterized with larger contingent payments and fixed payments closer to zero.

Furthermore, the model predicts that cooperation is negatively related to the total cost of forest conservation, e.g. the total payment to the seller, and positively related to the value of the carbon sinks form the contract. The higher the total cost of forest conservation is relative to net value of the carbon sinks 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 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.

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 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

Reducing emissions from deforestation and forest degradation (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 produces 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 cooperation agencies such as the Forest carbon Partnership Facility of the World Bank that seek to reach climate goals, while the sellers are those environmental service providers such as national or local organizations/governments. The signing of a large 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 small contracts, to 1) initiate costly land use, land-use change and forestry (LULUCF) projects and then 2) fulfill the contractual promise by not disturbing the carbon sink for many years even if, say, rising prices for forestry products or a costly family illness makes such an action individually desirable.

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.

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

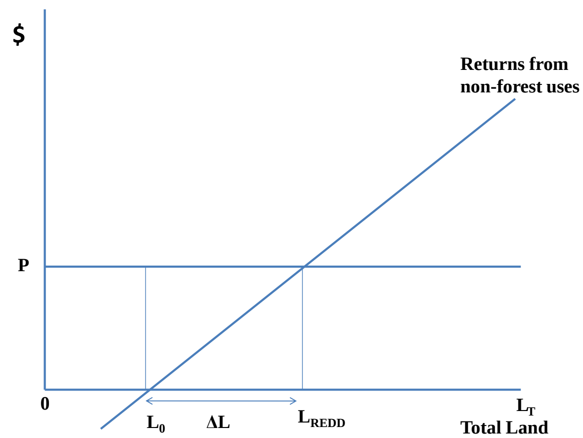

Figure 1: Land use choice with and without REDD payments

deforestation and forest degradation 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. The horizontal line on P represents a simplified payment for reducing carbon emissions from deforestation and forest degradation.

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 line that goes through P in the figure represents the maximum efficient REDD payment. 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 benefits of 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 and has to compensate for changes in the opportunity cost of forest conservation and the cost of conservation itself. In this context, the mechanism has to be cost efficient and achieve a given emission reduction at the minimum cost. This means that contracts should be implemented on land that has characteristics such as the one in the interval $[L_o, L_T]$.

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 or high costs of enforcement. Furthermore, effort and outcomes described in such contracts including important technical aspects from REDD are difficult to monitor and verify.

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 credit-constrained 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.

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 or an international agency such as the Forest Carbon Partnership Facility of the World Bank acting as an intermediary. 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, a local government or project developers and NGOs. The seller could be an individual landowner, farmer or local community or government who has the possibility of maintaining carbon stocks for specific periods of time.

The seller possesses forest land and is interested in adopting the land use and management practices that maximizes her economic returns. She has the option to conserve the forest and maintain the carbon stocks or she can change the land use to a non-forest activity such as agricultural and timber harvesting resulting in carbon emissions. The buyer is interested in 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. Because carbon stocks only have value if they stay for a long enough period of time, date t is the period of time that the buyer wants the seller to keep the current land use. For instance, if the buyer is interested in the provision of carbon stocks for five years then period t lasts five years.

The buyer is interested in the additionality and permanence of carbon offsets to comply with REDD objectives, thus he offers a seller a contract to achieve these objectives. Figure two shows the timing of actions and decisions. At the beginning of period t, the buyer and the seller agree on a initial baseline of tonnes of carbon stocked in the forest land owned by the seller. Once the initial carbon stock 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 deliver the quantity of tonnes of carbon initially agreed, q^*. Compensation consists of a fixed payment p_t and a contingent payment $b_t : Q \rightarrow \Re$, where Q is the observed tonnes of carbon. Carbon stocks are observable by both parties but they are not enforceable because carbon stocks are not verifiable by a neutral third-party either because a formal court does not have the technology and means for verifiability or because it is too costly to verify. Consequently, the desired tonnes of carbon, q^*, may differ from the delivered quantity, q_t. Let $q_t \in Q = [\underline{q}, \overline{q}]$ denote the set of tonnes of carbon delivered in period t, where $\overline{q}$ represents the tonnes of carbon dioxide sequestered at the beginning of the period given the initial land use. $\underline{q}$ represents the quantity of tonnes of carbon sequestered when the land use is completely changed to a non-forest activity.

The fixed payment, p_t, is paid independently of the final outcome and it is paid during

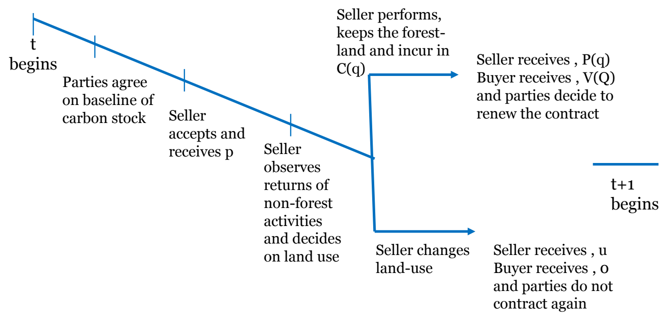

Figure 2: Timing line

the course of the trading period t. Because p_t is formally enforced, when it is paid becomes less important. However, having a fixed payment at the beginning of or during the period may more attractive for sellers who depend absolutely on the contract compensation as period t may last for long periods of time. 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 unverifiable 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 and her decision set is given by $d_t \in \{0, 1\}$. 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 deforestation and forest degradation, she performs under the contract and incurs a cost for forest protection. The cost includes aspects of maintaining the initial state of the forest land such as the seller's opportunity cost of time of taking care of the forest, the cost of materials for instance to build a fence around the property, or task difficulty which includes making sure other people do not exploit the forest. The cost is given by $c_t(q_t)$ where $c'(.) > 0$, $c''(.) \geq 0$, and $c(\underline{q}) = 0$. The seller's 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 sellers's carbon stock generates a direct benefit for the buyer, $V_t(q_t)$, where $V'(.) > 0$, $V''(.) \leq 0$, and $V(\underline{q}) = 0$. He also chooses whether or not to pay $b_t(q_t)$. The buyer's profits are given by $\pi_t = V_t(q_t) - P_t(q_t)$. Also, $V'(.) > c'(.)\ \forall\, q \in Q$, so it is socially efficient and Pareto optimal to maintain the forest land and trade $q = \overline{q}$, 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 receives the value of the non-forest activity $\overline{u}$ and the buyer receives $\overline{\pi}$ which is equivalent to the alternative source of carbon credits. These options are assumed to be less attractive than trading, but are desirable to the parties if there are insufficient incentives for the parties to trade. The sum of the fixed payoffs, $\overline{s} = \overline{u} + \overline{\pi}$, is the social value of the outside options. The net social surplus is given by $S(q_t) - \overline{s}$, where $S(q_t) - \overline{s} > 0\ \forall\, q \in (\underline{q}, \overline{q}]$, and $S(\overline{q}) > S(\underline{q}) \geq 0$. The net social surplus is the difference between the return to the relationship and the second-best market opportunity for both parties.

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 utility, given as

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

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 Optimal REDD Contract Under Perfect Enforceability

If carbon stocks were perfectly third-party verifiable and therefore contractible, the contract could explicitly include the quantity of tonnes of carbon and a single fixed 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 deforestation and forest degradation if and only if the benefits he obtained from the contract U^* are greater than the returns she obtains in other alternative land use activities. This situation is given by inequality 3:

$$U^* = P_t - c(q_t) \geq \overline{u}. \tag{3}$$

The left-hand side represents the seller's expected gains from the contract. She receives P_t in exchange of avoiding changing the land use and incurs in a cost for forest conservation. The right-hand side represents the expected returns of the seller if the contract is not signed and she chooses land-uses other than forest conservation following business-as-usual. The buyer maximization program is

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

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

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

Because $V'(.) > c'(.)\ \forall\ q \in Q$ 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 fixed payment to the seller equal to $P = \overline{u} + c(q)$ during date t, the seller maintains the carbon stocks, and each party gets profits:*

$$
\pi^* = \frac{V(\overline{q}) - c(\overline{q}) - \overline{u}}{1-\delta}, \text{ and} \tag{6}
$$

$$
U^* = \frac{\overline{u}}{1-\delta}. \tag{7}
$$

A formal mechanism enforces the optimal contract which implements full conservation of the forest land. The buyer obtains the net benefits of the carbon sink's storage in the forest. The seller receives a payment equivalent to the discounted value of the returns of the alternative land use including for instance agricultural and timber harvesting.

5 Relational Contracts and REDD

The nature of carbon stocks suggests that they are observable by the parties involved in a contract but not verifiable by a neutral third-party. In this case, 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 fixed payment credible as it is paid during the trading period. Because this payment does not include any additional incentives to the seller to continue to sequester the carbon, avoiding carbon emissions from reducing deforestation and forest degradation cannot occur in a static equilibrium. Consequently, trade does not occur and both parties receive their outside options.

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. There is no loss of assuming that deviation causes the parties to break-off trade forever because this outcome never happens in equilibrium (Levin, 2003). 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. In this setting, this assumption reflects the fact that it takes a long period of time to recuperate the forest land if the seller deviates via deforestation. Therefore the buyer will not be interested in trading with such a seller anymore as she does not have carbon sinks to offer. On the other hand, if the buyer deviates, the seller looses trust in the buyer and responds by changing the land use to a non-forest activity. Again, carbon sinks are 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, carbon sinks are destroyed and with them the social surplus. Therefore there is not 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. Last, because the buyer's behavior is perfectly observable, a stationary contract delivers the optimal surplus and the reduction of carbon emissions from deforestation and forest degradation.

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 deforestation and forest degradation and incurs the cost of forest conservation. The buyer pays the full payment $P_t(q_t) = p_t + b_t(q_t)$ and gets the benefits of the carbon stocks. If the seller breaches the contract, she does not incur in the cost of forest conservation and changes the land-use to a non-forest activity. Then, she receives p and the returns of the non-forest activity $\overline{u}$ and the buyer receives nothing. In this case, the parties break off trade forever. In the context of REDD, the contract described above can be explained as follows.

A buyer promises a seller to pay p_t at the beginning of the period plus a bonus, $b_t(q_t)$, conditioned on the seller's satisfactory carbon sequestration action. The seller can choose to shirk or conserve the forest by putting the necessary time (effort) and making sure the forest remains intact to deliver the same carbon stocks from the baseline. If she decides to provide the carbon stock, at the delivery date, since the tonnes are not verifiable by a third party, the buyer 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 he paid already, then trade continues overtime. If he decides to shirk then he can argue that the carbon sinks delivered are different from the baseline they agree on, and therefore pay $b_t(q_t) = 0$.

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 deforestation and forest degradation. The buyer pays p as a fixed 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_p^*, 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 tonnes of carbon 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

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

In addition, the buyer's offer has to meet the seller's individual rationality constraint, i.e., the offer has to provide a credible incentive to perform over the course of time. 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 instead of reneging. The seller's and the buyer's DICC are given by (9) and (10) respectively. A seller cooperates if and only if:

$$\frac{p + b(q) - c(q)}{1 - \delta} \geq p - c(\underline{q}) + \frac{\overline{u}}{1 - \delta} \tag{9}$$

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 forest conservation costs. 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 and to not incur in any cost for forest conservation but in this case the principal, after observing the carbon stocks delivered, will not pay the bonus. If the seller does so, she incurs in $c(\underline{q})$, receives the p and changes the land use to an alternative activity. Therefore, she collects the benefits from the alternative activity starting on period $t = 0$ and therefore, receives the present value of the returns from the non-forest activity for all periods.

Additionally, participation for the buyer in the long-term relationship is optimal if his DICC given by (10) 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 the carbon stocks delivered net of the payments he makes. If he deviates he gets the benefits of the carbon storage minus what he paid upfront. Then in all future periods, he guarantees himself the benefits of the alternative options for carbon credits.

$$\frac{V(q) - p - b(q)}{1-\delta} \geq V(q) - p + \frac{\delta}{1-\delta}\overline{\pi} \tag{10}$$

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

$$\begin{aligned} &\max_{p,b(q),q} \left(\frac{V(q) - p - b(q)}{1-\delta}\right) \\ &\text{subject to} \qquad p + b(q) = \overline{u} + c(q), \\ &\qquad \tfrac{p+b(q)-c(q)}{1-\delta} \geq p - c(\underline{q}) + \tfrac{\overline{u}}{1-\delta}, \\ &\qquad \tfrac{V(q)-p-b(q)}{1-\delta} \geq V(q) - p + \tfrac{\delta}{1-\delta}\overline{\pi}, \\ &\text{and} \qquad q \in [\underline{q}, \overline{q}]. \end{aligned} \tag{11}$$

The seller's IRC can be rearrange as

$$p \geq \overline{u} + c(q) - b(q) \tag{12}$$

and expression (9) can be restated as,

$$p \geq c(\underline{q}) + \frac{c(q) - c(\underline{q}) + \overline{u} - b(q)}{\delta} \tag{13}$$

which gives the lower bound on the fixed payment, p, for inducing long-term seller cooperation. The presence of the performance payment allows the buyer to offer a lower fixed payment. By substituting (12) in (13), the optimal distribution of the total compensation among the fixed 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),(8), (9), and (10), where (3) and (10) bind, and the compensation scheme is characterized by:*

$$b(q) \geq c(q) - c(\underline{q}) + \overline{u}\ , \tag{14}$$

$$p = c(\underline{q})\ , \text{ and} \tag{15}$$

$$p + b(q) = \overline{u} + c(q). \tag{16}$$

Equality (16) identifies the total compensation that the buyer offers the seller in the contract. Equality (16) gives the fixed payment that the seller receives during date t and equality (14) gives the size of the 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 cost of forest conservation, $c(\underline{q}) = 0$, the fixed payment included in the optimal REDD contract is equal to zero. That means that under the optimal relational contract the seller does not get pay anything upfront or during the time she is under the contract until the end of period. The contingent payment includes the complete payment to the seller. It includes the cost of providing optimal forest conservation and the opportunity cost of the alternative land use. This is intuitive because the seller knows the strategy of the buyer. If she deviates from the contract and changes the use of land, the buyer does not pay the performance payment and furthermore he does not do business 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 possible 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 cost for forest conservation and converting all land to agricultural or timber activities. Because an ex ante fixed 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 verifiability of carbon sinks. Moreover, because the contingent payments are limited by the future gains from the relationship and because the buyer's profit decreases when the fixed 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 5.1. *For imperfect enforcement regimes, all compensation is paid as a performance payment upon delivery of the carbon sinks, and the payment is weakly increasing on* *the returns of alternative activities and the full cost of forest conservation.*

The total compensation is weakly increasing in the returns of non-forest activities and the cost of forest conservation because the contingent payment is limited by the gains from the relationship. If the returns of other activities or the cost of conserving the land are too high, then the future gains from the relationship may not be enough to provide enough incentives to the parties to perform and self-enforce the contract. Furthermore, the payment in the contract represents the cost of forest conservation under a REDD contract.

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 (9) and (10) 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* $\underline{\delta} = \frac{c(q) - c(\underline{q}) + \overline{u}}{V(q) - c(\underline{q}) - \overline{\pi}}$.

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 $\underline{\delta}$ will cooperate in the REDD context.

Recalling again the assumption that $c(\underline{q}) = 0$, the parameter $\underline{\delta}$ can be rewritten as

$$\underline{\delta} = \frac{c(q) + \overline{u}}{V(q) - \overline{\pi}} \tag{17}$$

The term in the numerator includes the total payment the buyer has to make to the seller to avoid carbon emissions from deforestation and forest degradation. 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 value of the carbon sinks under contract for the buyer 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 it is too costly for the seller to conserve the forest or if the returns of the non-forest activity are too high. The latter implies a higher opportunity cost for the land use which also relates to the seller's cost of forest conservation. This happens because the land becomes more attractive to other parties who will try to get the returns of the non-forest activity. Therefore, it will be more costly for the seller to make sure the forest land is not deforested or degraded by other parties.

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 cost of forest conservation is relative to the difference of returns from the tonnes of carbon delivered under the contract and the alternative source of carbon credits, the smaller is the discount factor need to self-enforce the contract. In these situations, REDD contracts are more likely to achieve their objective.

6 Concussions 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 consideration, including the nature of carbon sinks regarding to verifiability and monitoring. 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 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 characterized 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 and the cost of forest conservation. The total payment includes a single fixed 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 fixed payment is set to zero and the contingent payment includes the total value of the compensation. As the fixed 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 fixed 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 carbon sinks 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. Such extensions include the presence of credit constrained sellers, 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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