Self-enforcing Contracts for Reducing Emissions from Deforestation and Forest Degradation *

Paula Cordero Salas[†]

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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 in developing contracts sufficient incentives to participate in a REDD 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 REDD implementation because relational contracting relies upon mutual private self-enforcement in a repeated transaction framework. The optimal REDD self-enforcing contract is characterized and the parameters for sustainable private enforcement are provided. The optimal payment scheme suggests that all payments should be made contingent on the carbon offsets delivered, i.e at the end of the contracting period. Thus, the optimal contract does not observe any ex ante payment. Private 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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[†]Economics, Finance, and Legal Studies Department, The University of Alabama. Tel.:+1 205-348-5633. Email address: pcordero@cba.ua.edu. Postal address: 361 Stadium Drive, 250 Alston Hall, Tuscaloosa, AL 35487-0224.

1 Introduction

Deforestation and forest degradation (DD) account for about twenty percent of greenhouse gas emissions (GHG) each year (Holloway and Giandomenico, 2009). Because DD is only marginally profitable, reducing emissions from deforestation and forest degradation (REDD) has been identified as a cost-effective strategy to mitigate global climate change while it can also lead to other benefits such as positive impacts in biodiversity and on economic development (Angelsen, 2008; Kindermann et al., 2008; Pagiola, Bishop, and Landell-Mills, 2002; Sohngen and Beach, 2008). Moreover, there is recognition that a successful REDD strategy must involve large-scale mitigation efforts from the global community including developing countries as they control an important share of the global forest. However, the success of REDD in a post-Kyoto protocol regime depends on the design and implementation of a financial mechanism that not only provide incentives to land-holders to manage forests in a sustainable manner according to climate goals (Agrawal, Nepstad, and Chhatre, 2011) but also consider technical issues such as the permanence of carbon offsets and the verification and enforcement of REDD contracts.

Enforcement represents one of the most important costs in implementing REDD contracts, and in fact developing countries were previously excluded from REDD initiatives because of concerns about the effectiveness of monitoring and enforcement of carbon reductions (Angelsen, 2008). However, landholders in those countries are of particular interest because they control areas with sensitive ecosystems and their efforts may yield greater marginal benefits. Nevertheless, enforcing contracts with smallholders in developing countries may be more costly due to slow court actions and the weak institutional framework (Cacho, Marshall, and Milne, 2003; Capoor and Ambrosi, 2008).

While contracts may be crucial in implementing REDD policies, little is known about how REDD contracts can be structured to maximize the likelihood of seller participation and performance, and to ensure permanence of carbon offsets, particularly for long-term contracts featuring sellers in environments where contracts may be difficult to monitor and enforce. 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 REDD implementation. 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 and ensure permanence. We find that if the social surplus generated by the REDD activity is sufficiently high, providers of carbon offsets perform under an optimal self-enforcing contract because it is structured in a way where contractual performance (forest conservation) is in their 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 can provide the service. We assume that at the beginning of each period parties agree on a baseline of tones of carbon dioxide sequestered in the forest land controlled by the seller. The buyer offers a contract which includes a two-part tariff, a base price and a contingent payment to induce the seller to avoid changing the land use and releasing the carbon to the atmosphere. We assume that the buyer's unique objective is achiving carbon sequestration and we do not consider any co-benefits of REDD.[1] The seller is not credit constrained and 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 contract. We derive the optimal contract under these circumstances and when contract enforcement is perfect.

If contract enforcement is perfect the buyer does not have to worry about given addi-

[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 (Forthcoming) for a version that includes a framework with other REDD co-benefits often included in REDD+ such as distributional issues.

tional incentives to the seller to perform because formal mechanism enforces the contract. Then, the optimal contract includes a single base payment. In contrast, we find that the optimal self-enforcing contract does not contain any ex ante payment, although, it also prescribes a single payment. As a base payment does not provide the seller incentives to perform, the optimal incentive provision in a REDD context is characterized with large contingent payments and base payments equal to zero. That is the full payment is made at the end of the contracting period. In addition, the model also predicts that self-enforcement is more difficult to sustain the higher the cost of forest conservation is, e.g. the costs of forest maintenance and the seller's opportunity cost, and lower the benefit of the contracted carbon offsets is. However, the contract structure achieves permanence of carbon offsets as long as the net surplus generated by the REDD contract is sufficiently high. Finally, the general form used in the model allow the payment to be adapted to changing external conditions such as changes in the market prices of timber competing for forest conservation as in the case of the Payments for Environmental Services (Engel, Pagiola, and Wunder, 2008; Pagiola and Platais, 2007).

There is limited extant research to guide the contract design of conservation payments to ensure permanence of carbon offsets and long-term participation and performance form landholders (Dutschke and Angelsen, 2008). Most research in conservation agreements has focused on risk management and considered payments that would change the decision for land-use in agricultural settings. For example Antle and Stoorvogel (2008) looks at per-ton carbon contracts that farmers need to receive such that they use carbon friendly practices. Benitez et al. (2006) use stochastic dominance rules to characterize conservation payments that are required to guarantee environmentally preferred land use. Other literature on conservation agreeement has documented case studies in the application of payments for environmental services (PES) and related policies. Examples of this are Asquith, Vargas, and Wunder (2008), Baylis et al. (2008) and Blackman and Woodward (2010). In contrast with this research, none of these papers look at optimal payment structure or sustainability of conservation contracts when enforcement is costly.

On the other hand, the bulk of contract theory has been developed for situations in which contracts are perfectly enforceable and involve only one-time interactions, however, there has been recently attempts to employ this set of theory to design carbon sequestration contracts. Examples os this are Gjertsen et al. (2010), Mason and Plantinga (2011) and MacKenzie, Ohndorf, and Palmer (2011). Gjertsen et al. (2010) model conservation agreements as dynamic relationships with renegotiation. In contrast, we assume that renegotiation is not possible if any party fail to fulfill the contract. The reason is that if either party deviates, carbon offsets are destroyed and with them the social surplus. Therefore there is not gain from renegotiation. Mason and Plantinga (2011) investigate the optimal contract structure when landholders have private information about their opportunity costs. They adapt a standard principal-agent model to the carbon offsets scheme in which contracts induce the agents to reveal their type truthfully while contracts are perfectly enforceable. MacKenzie, Ohndorf, and Palmer (2011) design carbon contracts in the context of projects that need up-front payments such as afforestation and reforestation and they assume that there exists some probability of contract enforcement. In contrast with Mason and Plantinga and MacKenzie, Ohndorf and Palmer, this paper proposes the use of self-enforcing (relational) contracts to overcome the multiple institutional frameworks in which REDD implementation is potentially embedded.

The power of relational contracts comes from the emergence of informal enforcement mechanisms that support incentives base on the parties' long-term relationship, characteristic desirable for the permanence of carbon offsets. The promise of future payoffs from the buyers of carbon credits can sustain landholders' performance today while the threat of termination and losing the stream of future payoffs can serve as incentives to maintain forest stocks and reduce degradation. In this paper a first step is taken to apply the relational contract framework to a REDD environment. The results contribute to debate 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 presents the relational contracts model in the context of REDD and the benchmark case of perfectly enforceable contracts. Section three derives the optimal relational contract and discusses the sustainability of self-enforcement under a REDD context. Finally, section four presents some conclusions and future extension of this work.

2 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 such as Conservation International. The seller could be an individual land-owner, 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.

The buyer is interested in the long-term permanence of carbon offsets to comply with REDD objectives, thus he offers a seller a contract to achieve this objective. Figure two shows the timing of actions and decisions. At the beginning of period t, the buyer and the seller agree on an 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 base 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 base payment, p_t, is paid independently of the final outcome and it is paid during the course of the trading period t. The contingent payment is considered as a *bonus* and it is used to reward complying with the forest baseline. Since the contingency payment depends

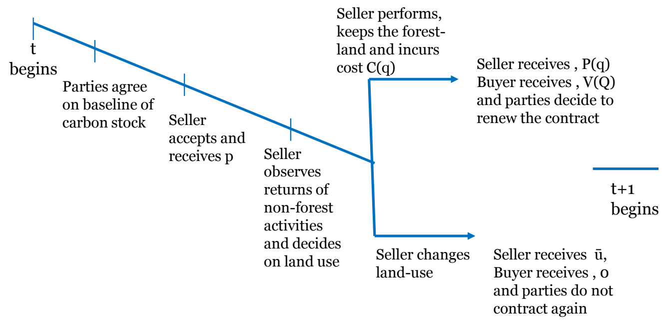

Figure 1: Timing line

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 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 $S(q_t) = V(q_t) - c(q_t)$. This assumption implies that the buyer contracts with sellers that keep additional forest relative to the business-as-usual scenario.

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 $S(\overline{q}) > S(\underline{q}) \geq 0$.

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 addition, the party's objective is to maximize the future discounted stream of payments, where the common discount factor is $\delta \in (0, 1]$. The objective of the seller is to maximize her present discounted utility, given as $\sum_{t=0}^{\infty} \delta^t \left\{d_t(P_t(q_t) - c(q_t)) + (1 - d_t)\overline{u}\right\}$ and the buyer's objective is to maximize his present discounted profit $\sum_{t=0}^{\infty} \delta^t \left\{d_t(V(q_t) - P(q_t)) + (1 - d_t)\overline{\pi}\right\}$, 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.

2.1 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 base payment in exchange of the carbon delivered. 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 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 the seller's individual rationality constraint (IRCs): $U^* = P_t - c(q_t) \geq \overline{u}$, where 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 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

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

Substituting the seller's participation constraint into the buyer's profit option, we obtain the following first order condition: $V'(q) = c'(q)$. 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 base payment to the seller equal to* $P = \overline{u} + c(\overline{q})$ *during date* t*, the seller maintains the carbon stocks, and each party gets profits:*

$$\pi^* = \frac{V(\overline{q}) - c(\overline{q}) - \overline{u}}{1-\delta}, \text{ and} \tag{2}$$

$$U^* = \frac{\overline{u}}{1-\delta}. \tag{3}$$

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.

3 Relational Contracts and REDD

The nature of carbon stocks suggests that they are observable by the contracting parties but may 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 base payment credible as it is enforced regardless of the final outcome. Because this payment does not include any additional incentives to the seller to continue to sequester the carbon, REDD 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 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 REDD surplus.

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 performs under REDD and the buyer pays the full payment $P_t(q_t) = p_t + b_t(q_t)$. 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.

For example, a party interested in carbon concentration, e.g. Conservation International (CI) or a government, promises a forest-land manager, i.e. a party that owns the right to use the land, to pay p_t at the beginning of the period plus a bonus, $b_t(q_t)$, conditioned on the forest-land manager's satisfactory carbon sequestration action. The forest-land manager 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, 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 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 $b_t(q_t) = 0$.

3.0.1 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_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, $b(q) = 0$. 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 individual rationality constraint (IRCb): $V(q) - p - b(q) \geq \overline{\pi}$.

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 over time instead of reneging. The seller's and the buyer's DICC are given by (4) and (5) respectively. A seller cooperates if and only if:

$$\frac{p + b(q) - c(q)}{1 - \delta} \geq p - c(\underline{q}) + \frac{\overline{u}}{1 - \delta} \tag{4}$$

The left hand side is the discounted payoff from the contract. 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 completely and to not incur any 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 $c(\underline{q})$, receives p and changes the land use to an alternative activity. Therefore, she collects the benefits from the alternative activity starting in 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 (5) 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.

$$(5) \qquad \frac{V(q)-p-b(q)}{1-\delta} \geq V(q)-p+\frac{\delta}{1-\delta}\overline{\pi}$$

A contract is self-enforceable if the parties find cooperation to be the optimal strategy. 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

$$(6) \qquad \begin{aligned} &\max_{p,b(q),q} \left(\frac{V(q)-p-b(q)}{1-\delta}\right) \\ &\text{subject to} \quad p+b(q)=\overline{u}+c(q), \\ &\tfrac{p+b(q)-c(q)}{1-\delta} \geq p-c(\underline{q})+\tfrac{\overline{u}}{1-\delta}, \\ &\tfrac{V(q)-p-b(q)}{1-\delta} \geq V(q)-p+\tfrac{\delta}{1-\delta}\overline{\pi}, \\ &\text{and} \quad q \in [\underline{q},\overline{q}]. \end{aligned}$$

As the buyer offers just enough incentives for the seller to participate, the IRCs can be rearrange as

$$(7) \qquad p = \overline{u}+c(q)-b(q)$$

and expression (4) can be restated as,

$$(8) \qquad p \geq c(\underline{q})+\frac{c(q)-c(\underline{q})+\overline{u}-b(q)}{\delta}$$

which gives the lower bound on the base payment, p, for inducing long-term seller cooperation. The presence of the performance payment allows the buyer to offer a lower base payment. By substituting (7) in (8), the optimal payment structure for REDD 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 IRCs, IRCb, (4), and (5), where IRCs and (5) bind, and the compensation scheme is characterized by:*

$$b^*(\overline{q}) \geq c(\overline{q}) - c(\underline{q}) + \overline{u}\ , \tag{9}$$

$$p^* = c(\underline{q})\ ,\ \textit{and} \tag{10}$$

$$P^*(\overline{q}) = \overline{u} + c(\overline{q}). \tag{11}$$

Equality (11) identifies the total compensation that the buyer offers the seller in the contract. Equality (10) gives the base payment that the seller receives during date t and equality (9) 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 base payment included in the optimal REDD contract is zero. That means that under the optimal relational contract the seller does not get paid anything upfront or during the time she is under the contract until the end of period. The contingent payment includes the cost of providing optimal forest conservation and the opportunity cost of the alternative land use. This is intuitive because the seller knows that 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 is 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 contingent 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 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 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 full cost of forest conservation under a REDD contract.

The payment structure in the relational contract is consistent with observed payment structures in some PES programs such as the Pimampiro program in Ecuador, the Payments for Environmental Services program (PSA) in Costa Rica and the Payments for Hydrological Environmental services program (PSAH) in Mexico among others (Wunder, Engel, and Pagiola, 2008). However, because the payment in the relational contract is based on the benefit and cost of providing carbon offsets in an specific location, the optimal relational contract calls for differentiated payments according to the value of carbon offsets provided by each seller.

3.0.2 Sustainability of Self-enforcing Contracts

Self-enforcing contracts are sustainable if parties find that 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. This is given by the discount factor derived from combining the dynamic constraints for both parties, equations (4) and (5).

Proposition 3. *Let* $\underline{\delta} > 0$*. Cooperation under the optimal REDD contract is achievable* $\forall\ \delta \in [\underline{\delta}, 1)$*, where* $\underline{\delta} = \frac{c(q)+\overline{u}}{V(q)-\overline{\pi}}$.

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. The term in the numerator includes the total payment the buyer has to make to the seller to avoid DD. The payment represents the full cost of forest conservation under a REDD contract. The denominator represents the value of the carbon sinks under contract for the buyer net of the value of 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. We end by summarizing these insights in Corollary 2.

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

4 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 consideration, including the verifiability and monitoring of carbon sinks. 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 (MacKenzie, Ohndorf, and Palmer, 2011). 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 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 and the cost of forest conservation. The total payment includes a single payment that can be made at any time during the trading period because it is formally enforced.

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 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 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 and objectives of REDD+. Such extensions include the presence of credit constrained sellers, distributional issues, moral hazard and adverse selection, as well as the existence of delegation and monitoring issues.

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