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Life's a breach! Ensuring 'permanence' in forest carbon sinks under incomplete contract enforcement

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Abstract

As carbon sinks, forests play a critical role in helping to mitigate the growing threat from anthropogenic climate change. Forest carbon offsets transacted between GHG emitters in industrialised countries and sellers in developing countries have emerged as a useful climate policy tool. A model is developed that investigates the role of incentives in forestry carbon sequestration contracts. It considers the optimal design of contracts to ensure landowner participation and hence, permanence in forest carbon sinks in a context of uncertain opportunity costs and incomplete contract enforcement. The optimal contract is driven by the quality of the institutional framework in which the contract is executed, in particular, as it relates to contract enforcement. Stronger institutional frameworks tend to distort the seller's effort upwards away from the full enforcement outcome. This also leads to greater amounts of carbon sequestered and higher conditional payments made to the seller. Further, where institutions are strong, there is a case for indexing the payment to the carbon market price if permanence is to be ensured. That is, as the carbon price increases, the payment could be raised and vice versa.

JEL codes: K12; Q15

Keywords: forest carbon offsets; permanence; contract design; incomplete enforcement

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1 Introduction

Anthropogenic warming of the earth's climate system as a result of greenhouse gas (GHG) emissions is a growing threat to people, economies and the environment (Stern, 2007). To help mitigate climate change, activities in land use and forestry through afforestation and reforestation (AR), forest management and avoided deforestation, have an important role to play in future climate change policy (Eliasch, 2008). In particular, carbon dioxide emissions from tropical deforestation account for up to a fifth of annual global GHG emissions (see Baumert et al., 2005).[1] Due to a variety of risks and uncertainties, one of the most pertinent issues in the efficacy of using forestry carbon as a mitigation strategy is that of 'permanence' (Eliasch, 2008; Dutschke and Angelsen, 2008; Palmer and Engel, 2009).[2] That is, for forestry carbon to be successful, projects must ensure the permanence of carbon offsets throughout the duration of the contract. This must be resolved if forestry carbon is to be adopted on a wider scale than it is at present, e.g. in a post-2012 international climate regime (UNFCCC, 2007).

An important question is how optimal carbon sequestration contracts could be created to ensure permanence in a variety of institutional frameworks and how this might differ from standard contracts (e.g. environmental service contracts). In this paper, we show how optimal contracts are designed under different institutional frameworks for contract enforcement, e.g. legal systems and enforcement mechanisms. Such frameworks in least-developed countries tend to be weaker relative to industrialised and some emerging economies. We find that, to ensure permanence in a context of weak contract enforcement and uncertain opportunity costs, the optimal, self-enforcing contract is strongly dependent on the quality of institutional framework in a given place.

We develop a forestry carbon contract in the form of an AR scheme. Project-based AR transactions occur when a buyer such as a government or firm from an advanced economy, e.g. from an Annex I country under the Kyoto Protocol's Clean Development Mechanism, invests in a carbon sequestration scheme in a developing or emerging economy, and receives emissions credits in return. Carbon sellers originate in countries characterised by wide variation in the

[1] Inclusion of GHG emissions from forest degradation expands this definition to REDD: 'Reducing Emissions from Deforestation and Degradation'.

[2] Forestry carbon is particularly vulnerable to natural risks (e.g. pests and diseases, climate change), anthropogenic risks (e.g. encroachment, land management), political risks (e.g. weak property rights, non-enforcement), economic and financial risks (e.g. exchange rate fluctuations, changing opportunity costs), and institutional risks (Watson et al., 2000).

quality and robustness of institutional frameworks necessary for contract enforcement. Under Kyoto, the predominant contractual arrangement that has evolved is a simple purchase contract known as the Emission Reduction Purchase Agreement (ERPA).[3] These contracts in addition to those made in the small but rapidly growing voluntary carbon markets rarely provide upfront investments to potential sellers (Capoor and Ambrosi, 2007; 2008; Jindal et al., 2008). The extent and number of AR schemes have, however, been limited by this lack of upfront financing, alongside constraints on demand formalised under Kyoto and the latter's stringent regulatory regime (UNEP, 2004).

Without upfront financing, AR projects in developing countries struggle to get implemented. Poorer landowners and farmers typically lack collateral necessary for third-party financing. Given insecure property rights in many developing countries, even land cannot be used as collateral (see, for example, Feder and Feeny, 1991). Furthermore, poor governance and incomplete enforcement in these countries implies that carbon buyers may be reluctant to make upfront investments in forestry projects. Incomplete contract enforcement in turn suggests that it might be very difficult to ensure the maintenance or permanence of forest carbon sinks over the duration of the contract should there be a risk of opportunistic contract breach. Opportunistic contract breach might occur, for example, when the seller's opportunity costs are uncertain and rise after contracting leading to a reversal of the forest carbon sink.

Ensuring the permanence of newly-created forest carbon sinks has mainly been investigated using risk management, pricing and accounting approaches. The former include specialised carbon-pooling vehicles, and reinsurance approaches (see Bayon et al., 2007, for a review), while the latter is more concerned with institutional design (e.g. Dutschke, 2002; Kim et al., 2008). Risk management and liability in forestry carbon contracts have also been considered at the aggregate, i.e. national, in addition to the individual level (Eliasch, 2008). However, relatively little research has been undertaken on how contracts between buyers and sellers could be efficiently designed to ensure permanence (Dutschke and Angelsen, 2008). The second important issue is that the possibility of contract breach depends on the uncertain and changing opportunity cost. Benitez et al. (2006) considered changing opportunity costs by applying stochastic dominance rules to identify the payments needed to prevent land-use changes that reduces biodiversity in developing countries. One important implication of their analysis was

[3] A transaction that transfers carbon credits between two parties under the Kyoto Protocol.

that alongside incorporating risk-hedging strategies and insurance possibilities for small farmers, conservation payments to a farmer could be made dependent on the agricultural revenue generated by his farm. The effectiveness of this approach, however, rests upon the ability of the buyer to observe the farmer's opportunity costs.[4]

In this paper, we create a new framework in order to model forest carbon contract incentives in the context of price volatility in agricultural commodities' markets. Our framework allows for a variety of institutional frameworks for contract enforcement. Potential changes in the seller's opportunity costs are anticipated at the time of contracting but only realise after the contract is already signed. We take into account that these changes are not necessarily observable to the buyer. Given the potential for landowners' opportunity costs to change and incomplete contract enforcement, we consider the design of optimal carbon contracts to ensure landowner participation and hence, permanence in the provision of forestry carbon benefits over the duration of the contract.[5] We develop a simple, static contract between the principal, a carbon buyer such as a government, firm or NGO looking to offset GHG emissions originating in an advanced economy and the agent, a seller in a less-developed economy. In our setting, the seller can be characterised as a landowner, local community or government, which has limited liability with respect to the contract. The consideration of a static contract enables us to analyse the impact of the buyer's demand for permanence on incentives contained within the contract and hence, on the seller's land use behaviour with respect to the contract.

The buyer and seller contract ex ante on an upfront payment along with a payment made conditional on carbon delivery. We model the upfront payment as a productive transfer, one that is not only productive in carbon sequestration but also productive in the seller's outside option. Permanence, incomplete contract enforcement and limited liability are modelled as constraints restricting the buyer's optimisation programme. We find a driving force in the optimal contract is the institutional framework in which the contract is executed. We show that a contract that ensures permanence under incomplete enforcement is likely to lead to a distortion in the level of contracted effort made by the seller. In particular, stronger and more

[4] There is a considerable body of research on contracting in agriculture and in the provision of environmental services, which tend to focus on the role of information asymmetries in outcomes (e.g. Bourgeon et al., 1995; Wu and Babcock, 1995;1996; Moxey et al., 1999; Ozanne et al., 2001; Feng, 2007).

[5] We assume a policy goal of carbon retention in biomass over several decades. During this time, technological changes may reduce the costs of alternative mitigation options thus enabling substitution from forestry carbon sinks to these other options (Chomitz et al., 2006). CDM guidelines propose that Land Use, land Use Change and Forestry (LULUCF) projects have a duration of between 20 and 60 years (Harris et al., 2009).

robust institutional frameworks tend to distort the seller's effort upwards away from the full-enforcement outcome. Ensuring permanence in the contract thus implies more effort needs to be expended by the carbon provider or seller, although this also leads to greater amounts of carbon sequestered and higher conditional payments made to the seller. Furthermore, in a context of relatively strong institutions, we find an increase in conditional payments as the value of the marginal offset increases. This suggests potential for indexing conditional payments to carbon prices in order ensure permanence. That is, as the carbon price increases, the conditional payment could be raised. Where institutions are relatively weak, on the other hand, less effort is required but less carbon is sequestered and with lower payments made to sellers. Moreover, indexing is less likely to be effective. With the provision of upfront payments, permanence can still be ensured even in a context of incomplete contract enforcement.

Our contribution is threefold. Firstly, ensuring permanence within a carbon sequestration contract has allowed us to create a unique contract framework that guarantees contract enforceability and provides for an upfront payment that is both productive, in terms of carbon sequestration, and with respect to the opportunity cost of the seller. Incomplete contract enforcement is not considered in other frameworks such as the one developed by Benitez et al. (2006). Second, the optimal contract shows the menu of contract options that help to ensure permanence. Given the potential cost-effectiveness of forest-based carbon sequestration as a climate change mitigation strategy (Chomitz et al., 2006; Lubowski et al., 2006; Stern, 2006; Eliasch, 2008, Palmer and Engel, 2009), ensuring permanence would be important to realise forestry carbon benefits over a time-scale of decades. Third, other than carbon sequestration, our model has potential applications to other environmental contracts whether considered conceptually or in practice. Permanence is an issue that applies more widely to the preservation of environmental services over time, and is not just a problem for carbon sinks per se (see, for example, Swart, 2003; McCauly, 2006; Engel et al., 2008).

The remainder of the paper is structured as follows. Section 2 introduces the model and formally describes the constraints on the seller. Section 3 discusses the principal's optimal choice of contract while section 4 investigates the impacts of the carbon market price on the optimal contract. Section 5 discusses the model results, and some policy implications and ideas for future research are presented in section 6.

2 The model

To focus on the problem of permanence within forestry projects we consider a purchase contract between a project developer and a buyer of emission offsets. Both, buyer and seller are assumed to be risk neutral.[6] The buyer may be a firm attempting to comply with its obligations to reduce its GHG emissions within an emissions trading market, a national government complying with Kyoto Protocol requirements or even a non-governmental organisation that voluntarily but cost-effectively attempts to reduce the GHG emissions from its activities via payments for carbon offsets. The seller could represent a farmer or landowner, a local community or government, or even a national government who has the ability to provide for the sequestration of q tonnes of carbon dioxide through investment in forestry, such as a tree planting programme or a forest rehabilitation scheme.[7]

In exchange for q tonnes of carbon the buyer offers a two-tiered payment scheme consisting of an upfront investment α and a per-unit price β, which is paid conditional on delivery. The contract is hence assumed to be linear, which corresponds to the standard setup of Emission Reduction Purchase Agreements (ERPA) under Kyoto.[8] The upfront investment α is either a direct transfer of capital or production inputs, e.g. seeds, land, or cash that could be used by the seller to invest in the scheme. It can be interpreted as a true upfront investment, i.e. α is assumed to have an positive influence on the amount of carbon produced, but is in itself not utility relevant to the seller.[9] The conditional payment β is paid to the seller on delivery of the carbon offsets.[10]

The amount of carbon offsets q produced by the seller is a function of the (productive) upfront payment α, and the seller's effort e, which is assumed to be observable and hence contractible. The function $q(\alpha, e)$ is assumed to be concave or linear in both of its arguments.

Assuming effort $e \geq 0$ is not costless to the seller, the seller's corresponding cost func-

[6]The presence of the limited liability constraint confers an element of risk aversion on the seller (see 2.1).

[7]Tree planting could involve either reforesting a previously forested area or afforesting an area with no previous forest cover. Note that afforestation and reforestation projects are currently the only forestry projects eligible within the Kyoto Protocol's Clean Development Mechanism.

[8]See, for example, Capoor and Ambrosi (2008).

[9]Depending on the nature of the initial investment, some proportion of it may be recoverable to the seller after the expiry of the project. A 'recoverability' parameter could easily be incorporated into the model to account for this.

[10]Note that while we assume β to be a pecuniary transfer in our framework, some forestry carbon schemes in developing countries may also involve the transfer of non-pecuniary benefits on condition of offset delivery, for example, fuelwood and fruits (see Smith and Scherr, 2003).

tion $C(e)$ is assumed to be convex, continuous and differentiable in e, with $C'(e), C''(e) \geq 0$. The costs from e can be considered sunk and therefore non-recoverable. In case of contract performance the value of the contract to the seller is thus given by:

$$\beta q(\alpha, e) - C(e) \tag{1}$$

However, the seller's performance of the contract is not guaranteed. Sudden increases in commodity or rental prices that could be obtained as the next best alternative to forestry investment imply rising opportunity costs, which might create an incentive for the seller to breach the contract. At the moment of contracting, the level of future opportunity costs are uncertain. This is a plausible assumption. For example, if the opportunity costs are driven by volatile commodities' or rental prices, the seller can reasonably be expected to be unsure of the precise value of his outside option. We further assume that the change in opportunity costs is not necessarily observable to the buyer. Hence, should opportunity costs increase then the seller's commitment to adhere to the contract instead of switching land use is questionable. To take this uncertainty into account, future opportunity costs are modelled as a random variable $\tilde{z}$, which will be realized after the contract has been signed and the seller has incurred costs $C(e)$. For simplicity, we allow for two possible states of opportunity costs where $\tilde{z} \in \{\underline{z}, \overline{z}\} \subset \mathbb{N}^0$, with $\underline{z} < \overline{z} > z_0$. At the time of contracting the probability of a low level of opportunity cost $\underline{z}$ is π, while the probability for the occurrence of $\overline{z}$ is $(1-\pi)$. It is assumed that these probabilities are publicly known.

Contrary to standard contractual setups, we further assume that the value of opportunity cost is positively dependent on the upfront investment α. Hence, $z = z(\alpha)$ with $z'(\alpha) \geq 0$. This assumption reflects the fact that investing in a larger upfront payment could indirectly benefit the seller through boosting the value of his opportunity cost. Capital inputs, for example, could be used for the production of goods and services other than carbon sequestration via forestry. This is most obvious if the upfront payment is used by the seller to acquire additional territory for AR projects which would potentially be of use for other agricultural purposes as well. Note that the conditional payment β is not indexed with respect to the opportunity costs in order to reflect their potential unobservability to the buyer.

If the high opportunity cost level $\overline{z}$ is realized, the seller has a potential incentive to breach the contract. In case of breach it is assumed that the seller reverses the carbon sink, for example, through cutting down the forest in order to switch his land use to the more attractive alternative. In this case the buyer will try to enforce the contract through a court order. However, it can be reasonably assumed that the judicial system is not perfect, such that enforcement of the contract is not guaranteed. Many developing countries where forestry carbon offsets are located tend to be plagued by corruption, poor governance, weakly defined property rights, e.g. over land and natural resources, and incomplete enforcement of rules, laws and regulations. We take this into account by assuming that the probability of contract enforcement, denoted γ is lower than 1. In the case where the contract is enforced by a court, the buyer receives contract damages θ which are stipulated in the contract. With probability $(1-\gamma)$ the contract is not enforced. In this case the buyer is not awarded any damages and loses the initial investment α.

Given the above-depicted setup, the condition for the seller's participation in the agreement can be derived. Under the assumption:

$$\underline{z}(\alpha) - \gamma\theta < \beta q(\alpha, e), \tag{2}$$

the seller would participate in the contract if:

$$\pi\beta q(\alpha, e) + (1-\pi)(\gamma(\overline{z}(\alpha) - \theta) + (1-\gamma)\overline{z}(\alpha)) - C'(e) \geq \pi \cdot \underline{z}(0) + (1-\pi)\overline{z}(0) \tag{3}$$

The left-hand side of this constraint represents the seller's expected gains from the contract, including the possibility of contract breach in case the high level of opportunity costs is realized. The latter occurs with probability $(1-\pi)$. In this case the seller will gain $\overline{z}(\alpha)$, but risks being obliged to pay damages θ should the contract be enforced by a court. Enforcement occurs with probability γ. The right-hand side of the constraint represents the ex ante expected utility of the seller if the contract is not signed. In this case the opportunity costs will change with the same probability, but as the buyer does not provide any investment the argument of the opportunity cost function is set to zero. Constraint (3) hence ensures participation of the seller as his expected gains from the contract are at least as high as without the agreement.

The buyer's payoff from the contract is the net value of carbon sequestered given the payment made to the seller in terms of upfront investment α, and the per-unit price, β. Formally, the buyer's payoff when the contract is performed is equal to

$$V(q(\alpha, e)) - \alpha - \beta q(\alpha, e) \tag{4}$$

As the buyer, similar to the seller, is assumed to be risk neutral this payoff corresponds, up to a linear transformation, to the buyer's utility. In the following, we assume that $V(q) = vq$. Hence, the buyer's value per ton of carbon or certificate is constant. This is due to the fact that the opportunity costs to paying the contract price are not the buyer's own marginal abatement costs, but the market prices for identical certificates. For example, in the context of the Kyoto regime, a buyer whose marginal abatement costs are lower than the contract price would abate and sell the acquired CDM certificates on the market. In contrast, if the buyer's marginal abatement costs exceed the contract price he would use the contracted certificates for fulfilling his reduction target instead of buying certificates on the market. Hence, in all cases the buyer's valuation of the contracted certificates will be equal to the market price for similar certificates on the secondary CDM market.[11] For the sake of simplicity, this market price for tradable emission rights is further assumed to remain constant, or as being at least perfectly foreseeable.

Under assumption (2), the buyer's objective function is hence:

$$-\alpha + \pi(v - \beta) \cdot q(\alpha, e) + (1 - \pi) \cdot \gamma\theta \tag{5}$$

Timing and possible pay-offs of the model are summarized in Figure 1. Here, it can be seen that at $t = 0$, the buyer, as the principal, offers a contract in which the two-tiered payment scheme represented by α and β, the amount of carbon q, contract damages θ, and the seller's level of effort e, are all observed and contractible. Should the seller agree to this contract, he then immediately receives the upfront payment, α, at $t = 1$. At $t = 2$, the seller then implements the scheme and hence, incurs a production cost, i.e. of scheme implementation, C. Once implemented and with carbon sequestration activities underway, the seller's opportunity

[11] Note that this assumption is realistic, as within the Kyoto system certificates from the different mechanisms are completely fungible.

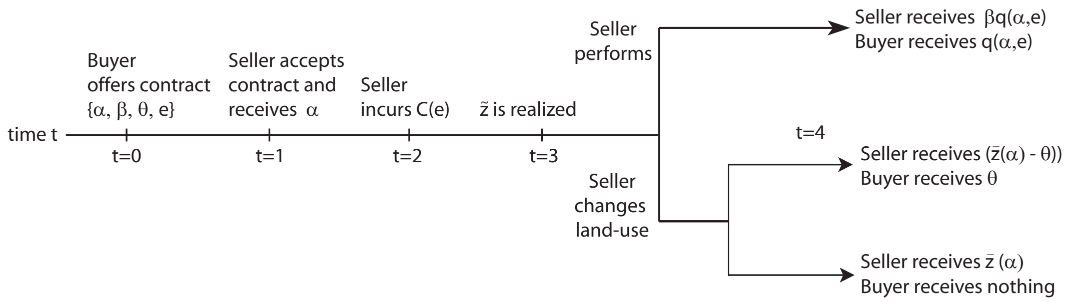

Figure 1: Timing and outcomes of the contract

cost, $\widetilde{z}$, is realised at $t = 3$. The seller then makes one out of two possible choices: he can either fulfill the contract or not. If he chooses to breach the contract, for example, through timber harvesting, then he faces the possibility of contract enforcement, at $t = 4$.

2.1 Permanence, enforceability and liability constraints

Similar to standard complete contract frameworks, we solve for the optimal linear contract by maximizing the buyer's expected utility subject to several constraints. The most important constraint is based on the assumption that the buyer is interested in the permanence of the contracted carbon absorption through the forestry scheme. This reflects the current attribution of liability within the international climate policy regime. Within the context of Kyoto, liability for replacing invalidated certificates is implicitly attributed to the buyer, as invalidated certificates need to be replaced within the National Registry of the buyer country.[12] As the buyer country will necessarily subrogate to the project investor, we can reasonably assume that the latter is always interested in permanence. Given the assumption of a buyer interested in the permanence of the carbon sink over the time of contract validity, the following *permanence constraint* needs to hold:

$$(1 - \pi)\beta q(\alpha, e) \geq (1 - \pi)(\overline{z}(\alpha) - \gamma\theta) \quad (6)$$

which can be reduced to

$$\beta q(\alpha, e) - z(\alpha) + \gamma\theta \geq 0 \quad (7)$$

[12]See UNFCCC (2005), Decision 5, Annex, paragraph 55.

Intuitively, the constraint (6) can be interpreted as follows. Should the seller's (upper-level) opportunity cost $\overline{z}$ realise then the seller's expected utility under a potential non-breach situation needs to be equal to or larger than the expected utility in case of contract breach. The latter also includes the expected costs (to the seller) from the possibility of contract enforcement. Hence, (7) ensures that the seller always finds it optimal to comply with the contract and prefers to take the agreed rent rather than cashing in on his outside option. Note that a similar constraint can be constructed for the lower level opportunity costs $\underline{z}$, which will always hold if (7) is fulfilled. This constraint resembles an 'enforcement proofness' constraint, established by Laffont and Martimort (2002). More importantly, within the current setup the constraint acts to ensure permanence in the contracted carbon gains for the duration of the contract between the buyer and seller.

The fact that the buyer might depend on legal courts for enforcement entails an additional restriction to the contract, one that is generally neglected in economic contract theory. In principle, within all modern legal systems contracts that are deemed to be exploitative are not only non-enforceable but will also be rescinded when brought before a court.[13] Within our framework, a contract would be deemed exploitative if the seller's pay-off from the contract is lower than his expected reservation utility. Given these considerations, the buyer must take into account the following *enforceability constraint*:

$$\beta q(\alpha, e) - C(e) - \pi\underline{z}(0) - (1-\pi)\cdot\overline{z}(0) \geq 0 \tag{8}$$

It is easy to see that with (7) condition (2) must hold with inequality. Furthermore, the seller's participation constraint (3) always holds with inequality if (7) and (8) are fulfilled. Hence, an enforceable contract proposed by a buyer interested in permanence implies that the buyer always receives a positive ex-ante rent. This is an important difference to the standard case usually considered in the theory of complete contracts where full enforcement of feasible agreements is assumed a priori.

In our setting, an upfront payment is required due to the fact that the seller's access to the

[13] The design of contracts to provide for possible uncertain contingencies and remedies for breach is considered in some depth in the law and economics literature (for example, see Shavell, 1980; 1984). Apart from an obvious dysfunction of the court system, the case of where no damages are paid by the seller could also occur where the various costs of seeking damages are large enough to render doing so impractical. In our setting, there may also be ethical reasons for courts to rescind potentially exploitative contracts between poor-country sellers and rich-country buyers.

credit market is assumed to be restricted. This is due to the reasonable assumption that the seller has only very limited assets and hence, a lack of collateral. In turn, this suggests that the level of contract damages potentially payable by the seller is restricted as well. To reflect this, the following altered *limited liability constraint* must hold:

$$l + \delta\alpha \geq \theta \tag{9}$$

This constraint places a limit on the feasible transfers between the buyer and the seller. It states that the damages payable by the seller need to be smaller or equal to his own net asset holding l, plus a multiple of the upfront payment, $\delta\alpha$. The δ is a scaling factor for contract damages, and can be either larger than, equal to, or lower than 1. For example, when $\delta = 1$ and $l = 0$, equation (9) requires that stipulated contract damages θ should not exceed the seller's upfront investment. In legal terms this level is typically referred to as 'restitution damages'. We hence extend the standard concept of a limited liability constaint to reflect also limitations to contract damages which are set by the host country's contract law and jurisprudence. Evidently, if $l = 0$ the damages payable $\delta\alpha$ cannot be larger than the seller's gains from contract breach, i.e. $z(\alpha)$. We return to δ and its role in the optimal contract in the following section.[14] A final non-negativity constraint is introduced on effort of the seller, e:

$$e \geq 0 \tag{10}$$

3 The principal's optimal choice of contract

Having established the restrictions the buyer has to take into account when proposing a contract, we can now proceed to derive the optimal contract. In order to obtain the buyer's optimal contract, the following Programme (P) is solved:

[14]Note that limited liability could also be interpreted as an indirect expression of risk-aversion on the part of the seller, as her downside risk from breach is limited. Further on this interpretation of limited liability, see for example Horvath and Woywode (2005).

$$\max_{\alpha,\beta,e}(5), \quad \text{subject to } (7), (8), (9) \text{ and } (10)$$

The corresponding Lagrangian for Program (P) is:

$$\begin{aligned}
\mathcal{L}(\alpha,\beta,e) \quad = \quad & -\alpha + \pi(v(q(\alpha,e) - \beta q(\alpha,e)) + (1-\pi)\gamma\theta \\
& +\phi\,[e] \\
& +\mu\,[\beta q(\alpha,e) - \overline{z}(\alpha) + \gamma\theta] \\
& +\lambda\,[\beta q(\alpha,e) - C(e) - \pi\underline{z}(0) - (1-\pi)\overline{z}(0)] \\
& +\psi\,[l + \delta\alpha - \theta]
\end{aligned}$$

where ϕ, μ, λ, and ψ are the Lagrange multipliers for the effort, permanence, enforceability, and limited liability constraints respectively. Solving this, we obtain the following first order conditions:

$$\frac{\partial \mathcal{L}}{\partial \alpha} = -1 + (v-\beta)\pi q_\alpha + \lambda\beta q_\alpha + \mu\left(\beta q_\alpha - z'(\alpha)\right) + \psi\delta = 0 \qquad (11)$$

$$\frac{\partial \mathcal{L}}{\partial e} = (v-\beta)\pi q_e + \lambda\left(\beta q_e - C'(e)\right) + \mu\beta q_e + \phi = 0 \qquad (12)$$

$$\frac{\partial \mathcal{L}}{\partial \beta} = -\pi + \lambda + \mu = 0 \qquad (13)$$

$$\frac{\partial \mathcal{L}}{\partial \theta} = (1-\pi)\gamma + \mu\gamma - \psi = 0 \qquad (14)$$

From (11) and (14) we obtain:

$$\lambda = \frac{1 - \gamma\delta - \pi v q_\alpha + \pi z'}{-\gamma\delta + z'} \qquad (15)$$

where λ is positive if $z'(\alpha)$ is large enough. Substitution of λ in (13) yields:

$$\mu = \frac{-1 + (1-\pi)\gamma\delta + \pi v q_\alpha}{-\gamma\delta + z'} \qquad (16)$$

If $\mu > 0$ and $\lambda > 0$ it follows directly from (14) that $\psi > 0$. Note that there exist parameter combinations for which each constraint is either slack or binding, which entails different possible constrained optima. A sufficient condition for the permanence constraint to hold with equality is that $\overline{z}'(\alpha)$ is large enough and that the expected marginal gross gain from the contract $\pi v q_a$ is larger than or close enough to the marginal costs in α, i.e. 1. This is a realistic case and will be assumed throughout the paper. The enforceability constraint will bind if the difference in marginal gains in α between the buyer (in case of contract performance, i.e. vq_α) and for the seller (in case of breach, i.e. $\overline{z}'(\alpha)$) is slightly smaller than zero. Such a case might, for example, arise if the seller's outside option is driven by rising timber prices, rendering the premature harvest of the forest almost as profitable as preserving it as a carbon sink.[15] Finally, if λ is positive then the non-negativity constraint $e \geq 0$ might become binding as well. This will, however, only be the case for relatively high values of $C'(e)$.

In the following, we consider the case where the permanence and enforceability constraints are binding while the contracted effort level is strictly larger than zero. We thus assume that the corresponding above-depicted conditions hold accordingly. In this case, the optimal contract is defined by (7), (8), and (9), each holding with equality. Note that this system can only be solved explicitly for α if a functional form for $\overline{z}(\alpha)$ is specified. We assume that the upper-level of opportunity costs increases linearly with the ex-ante upfront payment:

$$\overline{z}(\alpha) = n + m\alpha \tag{17}$$

where $n, m \geq 0$ are exogenous parameters. From (17), the upper-level opportunity cost is increasing in the upfront initial transfer. Note that with a linear functional form the concavity of program (P) is ensured.

Using (8), (7), and (9) where each holds with equality, we can derive the second-best optimal levels of α and β. The optimal contract is given by the following Proposition:

Proposition 1 *The optimal contract, given by the 3-tuple $(\alpha^{**}, \beta^{**}, \theta^{**})$, is:*

$$\begin{aligned}
\alpha^{**} &= \frac{C(e) + \gamma l - \pi n}{m - \gamma\delta} \\
\beta^{**} &= \frac{C(e) + (1-\pi)n}{q(\alpha^{**}, e)} \\
\theta^{**} &= \frac{lm + C(e)\delta - \pi n\delta}{m - \gamma\delta}
\end{aligned}$$

[15] Note that even if $\overline{z}'$ becomes larger than the carbon certificate price on the market, v, contract breach might not be efficient from a welfare perspective, as the latter might well lie below the actual social costs of carbon.

From Proposition 1, first note that for any given cost level $C(e_0)$ both the optimal upfront payment α^{**} and the optimal penalty θ^{**} are explicitly determined. The optimal conditional payment β^{**} is, however, ambiguous due to the generalised production function for carbon sequestration, $q(\alpha^{**}, e)$. As expected, the seller's production costs $C(e)$ plays an important role in determining all aspects of the optimal contract. Given an increase in costs, the buyer would increase the ex-ante payment and the penalty for contract breach. Moreover, both the ex ante payment and penalty are increasing in the seller's collateral, l. Throughout we assume that $m - \gamma\delta > 0$, which can be interpreted as the seller's marginal net benefit of cheating should he decide to breach the contract, i.e. under contract enforcement, when $\alpha > 0$. It can easily be seen that both the optimal upfront payment and the penalty for breach are decreasing in the seller's marginal net benefit of cheating.

One key term is δ, the scaling factor for contract damages in case of contract breach. As δ increases the seller's marginal benefit from contract breach declines. This is quite intuitive as the deterrence from breaching will necessarily increase if contract damages are allowed to be set to higher levels.

Given we now have derived explicit functions for the optimal contract, we now turn to the seller's optimal level of effort.

3.1 The second-best optimal effort level

As is clear from Proposition 1, the effort level chosen by the seller e^{**} will determine at what level the 3-tuple contract is set. Therefore, in order to provide a complete characterisation of the optimal second-best contract, it is necessary to determine the seller's second-best effort level. To solve for the optimal contracted effort made by the seller e^{**} we substitute the 3-tuple $(\alpha^{**}, \beta^{**}, \theta^{**})$ derived in Proposition 1 into the buyer's objective function (5) and consider the buyer's decision problem given the following (unconstrained) optimisation problem (P'):

$$\max_e \left[\pi(v(q(\alpha^{**}(C(e)), e) - \alpha^{**}(C(e)) - \beta^{**}(C(e)) \cdot q(\alpha^{**}(C(e)), e)) + (1-\pi)\gamma \cdot \theta^{**}(C(e))\right]$$

Differentiating with respect to e provides the following first order condition:

$$\pi v q_e(\alpha(e^{**}), e^{**}) = C'(e^{**}) \cdot \frac{1 + \pi m - \gamma\delta}{m - \gamma\delta} \Longleftrightarrow \frac{C'(e^{**})}{q_e(\alpha(e^{**}), e^{**})} = \pi v \cdot \frac{m - \gamma\delta}{1 + \pi m - \gamma\delta} \tag{18}$$

which implicitly defines the second-best level of effort, e^{**}. Note that as we assume the permanence constraint and the enforceability constraint to be binding, both the enumerator as well as the denominator on the right hand side of (18) are strictly positive.

In order to gain further insights on the optimal level of effort, we make the following assumption:

Assumption 1 $\frac{q_e((\alpha(e^{**}),e^{**}))}{q_{ee}((\alpha(e^{**}),e^{**}))} > \frac{C'(e^{**})}{C''(e^{**})}$

Note that this assumption is quite plausible and can for example be proven to hold when $q_e(\alpha, e^{**})$ is specified as a Cobb-Douglas function. Assumption 1 is particularly useful for a further discussion of the contracted effort level. Under this assumption and from the quotient rule it is straightforward that $\frac{C'(e^{**})}{q_e(\alpha(C(e)),e^{**})}$ is convex in e^{**}. We use this insight for a comparison of the second best effort level to the level of effort that is chosen under full enforcement, denoted by FE.

3.2 Comparing effort under complete and incomplete enforcement

Under the strong assumption that the contract will be fully enforced, the seller would never choose the outside option because a court would always force him to specifically perform the contract. Yet, it is quite evident that full enforcement is only feasible if the contract fulfills the enforceability constraint, subject to which the buyer would still have to optimize. Consequently, the chosen effort level e_{FE} would be implicitly defined by the following first order condition:

$$v q_e(\alpha, e_{FE}) = C'(e_{FE}) \Leftrightarrow \frac{v q_e(\alpha, e_{FE})}{C'(e_{FE})} = 1 \tag{19}$$

Comparison with the second best effort levels reveals that:

$$\frac{C'(e^{**})}{q_e(\alpha, e^{**})} \gtreqless \frac{C'(e_{FE})}{q_e(\alpha, e_{FE})} \Longleftrightarrow \pi v \cdot \frac{m - \gamma\delta}{1 + \pi m - \gamma\delta} \gtreqless v \tag{20}$$

which yields

Proposition 2 *Given Assumption 1, then* $e^{**} \gtreqless e_{FE}$ *if* $(1-\pi)\gamma\delta \gtreqless 1$

Proposition 2 implies that a contract that ensures permanence under incomplete enforcement is likely to lead to a distortion in the level of contracted effort made by the seller. In other words, the provision of permanence distorts the contract when enforcement is incomplete.[16] The direction of distortion is dependent on the institutional framework determining the enforceability of the contract in case of breach, i.e. the probability of enforcement γ, and the scaling factor of contract damages, δ. In a full-enforcement setup, the seller's effort level will be chosen under complete deterrence from opportunistic breach.[17] This result is counter-intuitive as one would expect that with increasing quality in, for example, the rule of law, our results should converge towards the full enforcement level of effort. Instead, an improvement in enforceability of the contract distorts the seller's effort away from the full enforcement level. Yet, it is to be kept in mind that both the enforceability and the permanence constraints are

[16]The case where enforcement would no longer be an issue is one where we could disregard the enforceability constraint. This, the most efficient case, could be characterised by a buyer and a seller integrated into a single firm, denoted IR. Here, the possibility of higher outside opportunity costs would be taken into account. In this case, the chosen effort level, e_{IR}, would be implicitly defined by the first order condition:

$$\pi v q_e(\alpha, e_{IR}) = C'(e_{IR}) \Leftrightarrow \frac{v q_e(\alpha, e_{IR})}{C'(e_{IR})} = \frac{1}{\pi}$$

comparing the second-best effort level and the effort under an integrated relationship, we find
:

$$e^{**} > (<)\ e_{IR} \Longleftrightarrow (1-\pi)m > (<) 1$$

Hence, if this condition holds e is distorted upwards (downwards) with respect to the IR-level. Here, effort is larger than the level chosen in the integrated relationship when the marginal expected gross benefit from the outside option $\overline{z}(\alpha)$ is larger than 1. Consequently, efficiency requires that e^* will be chosen at the first-best level if the sum of the costs in α for both contract participants correspond exactly to the expected marginal gross gain from the outside option in α. If, ceteris paribus, the incentives to breach the contract become larger, i.e. the right hand side of the permanence constraint is raised through an increase in m, the buyer will increase the contracted effort level in order to raise the value of the conditional payment through an increase in q. If, instead, the incentives to breach decrease, the contracted effort can fall below the level e_{IR}.

[17]In the full enforcement case, there is no need for the buyer to be concerned about ensuring permanence in carbon sequestration. The seller always performs the contract regardless of the potential value of his outside option.

assumed to be binding. As a consequence, the expected marginal contract damages $\gamma\delta$ are assumed to be always significantly lower than m, i.e. the level which would guarantee an 'a priori' deterrence from breach. Taking these restrictions into account, the intuition for proposition 2 is as follows. Given a stronger (yet not perfect) institutional framework, i.e. larger $\gamma\delta$, the buyer has sufficient confidence in the contract and would be willing to increase the upfront payment α to the seller. The productive upfront payment increases the opportunity costs. Inspection of the permanence constraint (7) shows that should these become too large then the buyer would need to contract for a higher level of effort (to produce q tons of carbon) in order to ensure permanence. From Proposition 2, weaker institutional frameworks, i.e. smaller $\gamma\delta$, on the other hand, would result in the contracted effort being lower than the full-enforcement level. In turn, however, the amount of carbon sequestered, along with the upfront payment are also lower.

4 Changes in the carbon market price

In Section 3 the Principal's optimal contract structure was derived to show how a contract could be designed to ensure permanence. However, it is important to understand how this optimal contract might adjust given changes in exogenous factors. In particular, the buyer may be motivated to purchase carbon offsets at least partially on the basis of the international equilibrium permit price, v. Recall from Section 2 that this can be interpreted as the buyer's marginal benefit of not reducing own emissions, i.e. by offsetting.

To begin the analysis, first note that from (18) and invoking Assumption 1 that $\frac{de^{**}}{dv} > 0$. Therefore changes in the carbon market price can be observed by changes in second-best optimal effort. From Proposition 1, the optimal upfront payment α^{**} is unambiguously increasing in an increase in the carbon market price (and thus an increase in the seller's effort). We now investigate how the optimal contracted per-unit price β^{**} changes.

Differentiating β^{**} in Proposition (1) with respect to e^{**} yields:

$$\frac{d\beta^{**}}{de^{**}} = \frac{(C'(e) \cdot q(\alpha, e)) - (C(e) + (1 - \pi) \cdot n) \cdot q_e(\alpha, e^{**})}{q(\alpha, e)^2} \tag{21}$$

To determine the sign of this derivative, we can ignore the denominator which is always positive. Rearranging yields:

$$\frac{d\beta^{**}}{de^{**}} \gtreqless 0 \Leftrightarrow \frac{C'(e)}{C(e) + (1-\pi) \cdot n} \gtreqless \frac{q_e(\alpha, e^{**})}{q(\alpha(e), e)} \tag{22}$$

From this condition a first conclusion can be drawn with respect to the relationship between certificate price v and the conditional payment β. If the expected value of the seller's alternative to signing the contract $(1-\pi)n$ is large enough then the optimal contract requires an increasing β but only if v becomes larger. To see this, note that from (18) and Assumption 1 it follows that an increase in in v leads to an unambiguous increase in e^{**}. If the seller's expected outside option $(1-\pi)n$ is large, the resulting change in seller's costs e^{**} would render the contract unenforceable in the sense that (8) would be violated if the conditional payment β is not increased as well. Further conclusions can be drawn when taking into account the value of β^{**} and substituting (18) into (22), which yields $\frac{d\beta^{**}}{de^{**}} \gtreqless 0$ if and only if:

$$\pi \cdot \frac{m - \gamma\delta}{1 + \pi m - \gamma\delta} \gtreqless \frac{\beta^{**}}{v} \tag{23}$$

Note that under the given assumptions, the right hand side of this inequality is always smaller than one. Therefore, simplifying (23), results in a sufficient condition for $\frac{d\beta^{**}}{de^{**}} > 0$:

$$(1-\pi)\gamma\delta > 1 \tag{24}$$

Comparison of (24) with Proposition 2, and invoking Assumption 1, results in the following proposition

Proposition 3 *For strong institutional frameworks ($(1-\pi)\gamma\delta > 1$), β^{**} will be increasing in v.*

Under a specific set of institutional conditions, namely where there is a strong rule of law and functioning legal system, i.e. large $\gamma\delta$, by definition leads to upward shifts in both e^{**} and e_{FE}. We also know from Proposition 2 that α, q and $\overline{z}$ will all increase. Proposition 3 states that, given these conditions, β^{**} is increasing in v. The intuition is as follows. As

e^{**} increases, the change in the marginal production of carbon, q_e, will be smaller than any change in the seller's marginal costs, $C'(e)$ due to the convexity of the latter. Inspection of the permanence constraint (7) and enforceability constraint (8) shows that for these to hold, the conditional payment to the seller β must increase with increasing v. Our result implies that where institutions are strong, the buyer could potentially index the optimal contract to changes in the carbon market price in order to ensure permanence. Thus, as the carbon price increases, the conditional payment could be raised and vice versa. However, our result would not apply where institutions are particularly weak, which suggests that indexing might not work for offset contracts negotiated in many parts of the developing world.

5 Discussion

In this paper, a model is developed to investigate the role of incentives in forestry carbon contracts in order to deal with two types of risk. First, we consider the quality of governance and the enforcement of property rights in a given country; and second, changing opportunity costs due to unpredictable changes in, for example, commodities' prices such as palm oil and coffee. The management of these types of risk may play an important role in ensuring permanence in new carbon sinks, created as a consequence of contract implementation, e.g. by buyers and sellers participating in the Kyoto Protocol's CDM. Permanence has been and continues to be an important topic for discussion at the international level with regards to forestry offsets and the role of forests in climate change (UNFCCC, 2007). While strategies to manage permanence have been discussed at higher aggregate levels, e.g. at the national level (see Eliasch, 2008), or an aggregate level concerning a number of farmers or landowners, this paper contributes to the debate by considering incentives at the level of the contract in ensuring permanence in forestry carbon sinks.

Current regulatory restrictions in the compliance markets aside, better permanence management at the contractual level may encourage more carbon buyers not only to purchase forestry offsets but also in the kinds of countries where these risks are more prevalent. For example, in the context of the CDM, offset projects are implemented in non-Annex I countries, many of which have large and economically-important agricultural sectors, widespread poverty and weak systems of contract enforcement. The two types of risk of interest, institutional and economic, are modelled explicitly within the constraints on the buyer's optimisation programme, alongside one that limits the possible transfers between buyer and seller. Given that liability for non-permanent offsets in current compliance schemes are attributed to the buyer, the observable reluctance to provide upfront finance to poor country sellers is understandable. Note that the buyer risks the loss of his investment if the seller decides to switch land use. Thus, the buyer is by necessity interested in ensuring permanence than would otherwise be the case. In our model this is reflected in the permanence constraint. This ensures that the carbon sink persists even if enforcement is limited and the seller's opportunity costs increase.

First, our model is solved for the optimal upfront and conditional payments (α, β), along with the optimal penalty to be paid by the seller in case of contract breach (θ). These results hold if the upfront investment has a large influence on the seller's opportunity costs and if the value of the certificates to the buyer, i.e. their market price, is high enough. As expected, the optimal upfront payment increases with the quality of contract enforcement and the amount of collateral the seller can bring into the contract. The value of the conditional payment is mainly determined by the enforceability requirements to the contract, i.e. as determined by the enforceability constraint, as well as the number of certificates achievable under the optimal second-best effort and the initial investment made. Under the given assumptions, contract damages will always be chosen at their maximum level.

Second, our model emphasises the importance of provision of some positive level of upfront payment in order to provide incentives to the seller to sequester carbon. This is contrary to the message in the general payments for environmental services (PES) literature, which suggests that to be effective payments should only be made on condition of delivery of the service being contracted (e.g. see Engel et al., 2008). Yet at least in the discussion on forestry carbon policy, there are calls, e.g. by Dutschke and Angelsen (2008) and Jindal et al. (2008) among others, for increasing the scope of upfront transfers made to landowners or farmers in addition to carbon payments conditional on carbon sequestration. Implemented as a tool for risk sharing between buyers and sellers, upfront payments tend to exist only in contracts of the kind established by development-orientated institutions such as the World Bank's BioCarbon Fund, and not in the commercial contracts that have evolved under the CDM. The far smaller voluntary markets have witnessed wide experimentation in payment types and schedules. For example, in Mozambique, a tree planting carbon project that was launched in 2003 provided free seeds and some training to farmers enrolling in the scheme (Palmer and Silber, 2009). In another example, the International Small Group Tree Planting Programme (TIST) in Tanzania makes upfront cash payments to farmers (Scurrah-Ehrhart, 2006). Larger upfront investments could potentially enable the seller to acquire additional territory for afforestation or reforestation, which could lead to a scaling-up of AR activities. This is quite important in the context of current global climate policy objectives. The fact that such a scale-up would increase the incentive for opportunistic contract breach due to a higher value in opportunity costs is taken into account in our model framework.

Third, we show that the optimal effort level is distorted away from the full enforcement case when permanence is considered by the buyer. Since we would expect effort to converge on the full-enforcement level with increasing quality in contract enforcement institutions, this result seems counterintuitive. Given a higher-quality institutional framework, i.e. larger $\gamma\delta$, the buyer is willing to increase the upfront payment to the seller. This, however, also increases the seller's opportunity cost. Should it become too large then the buyer would need to contract for a higher level of effort (to produce q) in order to ensure permanence. The trade-off is clear. In exchange for guaranteed permanence in carbon sequestered, the seller would have to expend more effort in producing carbon in a country with better institutions than in one with lower quality institutions. But, on the other hand less carbon would be produced in the institutionally-constrained place and the upfront payment to the seller would also be lower compared with the situation where institutions might be in better shape.

Therefore, to optimise the amount of carbon sequestered our results imply the need for buyers to target potential sellers in countries with relatively good levels of governance, and where institutions function relatively well. In our framework this is modelled as situations where a higher probability of contract enforcement γ might be expected.[18] The World Bank's 'Doing Business' project attempts to measure the quality of business regulations and their enforcement across 181 economies. One measure, 'enforcing contracts' ranks, for example, the important forest nations of Brazil and Indonesia at 100th and 140th, respectively.[19] These are the kinds of countries that up to now have struggled to attract sequestration projects due at

[18]Note, however, that there may also be possibilities for improving the probability of contract enforcement via policy measures that improve governance, for example by securing property rights and tenure for sellers.

[19]See: http://www.doingbusiness.org/economyrankings/?direction=Asc&sort=10.

least in part to a lack of investors willing to provide upfront investments. Tanzania is ranked at 33, which implies that contracts could be designed with a higher allocation of α than would be the case, for example with Brazil, Indonesia or Mozambique (ranked 124). Furthermore, higher upfront investments could be expected in countries where contract law allows for higher levels of damages, i.e. a higher scaling factor δ.[20]

Fourth, we investigated how the optimal contract might change with changes in carbon prices. Again, where institutions are strong we would expect to increase the conditional payment as the value of the marginal offset increases. This implies that the buyer could potentially index the conditional payment to carbon prices in order to ensure permanence. Note this result does not hold where institutions are relatively weak, i.e. indexing is less likely to be effective. Thus, while price indexing could be implemented in countries such as Tanzania, it should perhaps not be considered in places like Indonesia where enforcement institutions are particularly weak. Also note that this result is contrary to the approach suggested by Benitez et al. (2006) who advocated price indexing of payments but to the seller's opportunity costs. Moreover, in the specific case of forestry carbon offset contracts, Dutschke and Angelsen (2008) recommend that the risk of a change in commodity prices ex post to contracting could potentially be shared between the carbon buyer and seller by including an indexing clause to commodities' markets in the contract. This would foresee additional payments during the times when the prices of, for example, coffee or palm oil move outside a predetermined price corridor. Yet, it is unlikely that the buyer is capable of (fully) observing actual changes in the seller's opportunity costs. If this is the case and given that we explicitly model for changes in opportunity costs via the permanence constraint, our results suggest that an indexing clause to the international carbon price might be preferred by a potential buyer than one indexed to the seller's opportunity cost. More explicit modelling of indexing through the dynamic extension of our simple contracting problem to two periods would enable an analysis of the optimal contract to manage ex post commodity price swings. This represents an interesting area for future research.

[20] In contrast to civil law the 'penalty doctrine' in case law, for example, does not allow for levels of damages that are deemed 'punitive' by the courts. Note, however, that penalty fees have rarely been agreed in forestry carbon contracts implemented in developing countries. Project implementers in come cases might rely on informal group sanctioning to ensure compliance (Matin Qaim, pers. comm.).

6 Conclusion

In this paper, we develop a framework that models forest carbon contract incentives in the context of price volatility in agricultural commodities' markets and incomplete contract enforcement. Given the potential for landowners' opportunity costs to change, we consider the design of optimal carbon contracts to ensure landowner participation and hence, permanence in the provision of forestry carbon benefits over the duration of the contract. The buyer and seller contract ex ante on an upfront payment along with a payment made conditional on carbon delivery. We model the upfront payment as a productive transfer, one that is not only productive in carbon sequestration but also productive in the seller's outside option. With the provision of upfront payments, permanence can still be ensured even in a context of incomplete contract enforcement. The optimal contract is driven by the quality of the institutional framework in which the contract is executed, in particular as it relates to contract enforcement. We show that a contract that ensures permanence under incomplete enforcement is likely to lead to a distortion in the level of contracted effort made by the seller. Stronger institutional frameworks tend to distort the seller's effort upwards with respect to the full-enforcement outcome. This also leads to greater amounts of carbon sequestered and higher payments made to the seller. Further, where institutions are strong, there is a case for indexing the contract price to the carbon market price if permanence is to be ensured. That is, as the carbon price increases, the ex-post payment could be raised and vice versa.

The present model considers the implementation of activities to create new biomass, such as forest maintenance or reforestation, that lead to the production of carbon credits that are purchased ex-ante to project implementation, and where the seller's effort is known and contractible. This raises two issues. First, regardless of market to which payments to sellers might be indexed, the purchase of forestry carbon contracts at market prices ex ante to project implementation (see EcoSecurities, 2008) implies that indexing would be problematic. At best, it could involve a more efficient allocation of rents in the carbon price, i.e. between upfront and conditional payments made to the seller. Second, our model could potentially be extended from one in which forests are utilized as carbon sinks to one that also considers them as a source of GHG. In an extension to forest conservation and avoided deforestation (or Reducing Emissions from Deforestation and Degradation, REDD), we might expect the seller's effort to be private information. Subject to moral hazard, the contract would need to be structured so as to provide for a robust signal of the seller's effort in ensuring permanence of the natural carbon sink. Upfront financing would also be an important component of contracts for REDD similar to the kind of contract discussed in this paper (see Dutschke and Angelsen, 2008).

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