Overcoming tenurial constraints to carbon forestry projects in Africa

Working Paper No. 10

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Abstract

A common perception is that long-term environmental service provision, such as carbon sequestration through tree planting, cannot take place unless a landowner has secure and enforceable property rights to the land. This is especially viewed as a problem for Africa, where the dominance of customary law coupled with the inability of the state to develop and enforce legal institutions, policies and financing have thwarted efforts to introduce formal land titling.

However, in Africa, tree planting and other land investments can also improve land tenure security. Our analysis shows that landowners with customary land tenure can be efficient providers of long-term environmental services, such as carbon forestry, especially if tree planting helps secure their permanent claims to the land. Under customary tenure, where the farmer's tree planting can reduce the threat of eviction, the amount of land allocated to carbon forestry may be less than private ownership, but it is certainly more than if tenure security is completely absent. This finding has important implications for the participation in payment for ecosystem services (PES) schemes of many poor farmers with customary land tenure, especially in Africa. Not only is customary land tenure dominant throughout the region – only about 1% of the land is under formal title – but past efforts to convert rural farmland to private ownership have been largely unsuccessful. Instead, our results support the view that carbon forestry and other PES schemes should accommodate the traditional African customary tenure systems, and if designed successfully, can both promote carbon forestry and benefit the poor.

Keywords

Africa; carbon forestry; customary land tenure; property rights; tenure security.

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Contents

Acronyms

PES	Payment for ecosystem services
REDD	Reducing emissions from deforestation and forest degradation

1 Introduction

Using market-based payment systems to halt deforestation and protect or plant forests for carbon sequestration has recently received considerable attention. A good example is the current effort to establish a financial mechanism to reduce emissions from deforestation and forest degradation (REDD) in developing countries. The potential for REDD is promising, given that forest protection, reforestation and afforestation

are considered cost-effective methods of reducing carbon emissions (Adhikari 2009). On the forest-farm frontier, there may be tradeoffs between carbon forestry and improving the livelihoods of poor smallholders, but also potential synergies (Chhatre and Agrawal 2009).

However, tenure insecurity is often a major constraint in implementing payment for ecosystem services (PES) schemes for forests in developing countries (Adhikari 2009; Chhatre and Agrawal 2008, 2009; Wunder 2007, 2008). Many studies highlight how insecure land tenure can undermine the success of PES schemes, as participation in these programs often requires evidence of formal land title (Bailis 2006; Jindal et al. 2008; Unurh 2008; Wunder 2008; Zibinden and Lee 2005). For example, Unruh (2008) discusses how tenure insecurity limits the effectiveness of afforestation and reforestation carbon sequestration projects in Africa, and concludes that, without institutional and policy reform, "the prospects are quite dim".

While the literature on PES often recommends granting smallholders in developing countries formal statutory property rights to overcome tenure insecurity, in Africa the dominance of customary law coupled with the inability of the state to develop and enforce legal institutions, policies and financing have thwarted efforts to introduce formal land titling (Bruce et al. 1994; Easterly 2008; Unruh 2008). As a result, only about 1 percent of land in Africa is registered and titled formally (Easterly 2008). Properly enforced statutory property rights in Africa are limited to locations of intensive agriculture, fertile lands, mineral reach areas and areas closer to infrastructure. Wunder (2006) asks "Can and should these people receive PES?" and argues that the main concern for environmental service (ES) buyers should not be *de jure* land rights, but *de facto* land rights.

However, tenure security does not necessarily require the possession of statutory land titles (Roth et al.1989; Schlager and Ostrom 1992). For example, in parts of Africa where customary land allocation prevails, customary authorities regulate transfers of land, dictate land related investments and grant individuals with secure rights for grazing and cultivation, without any legal title definition (Besley 1995). Various authors note that in Sub-Saharan Africa tenure security is contingent on the continuous use of the land (Braselle et al. 2002; De Zeeuw, 1997; Sjaastad and Bromley 1997; Unruh 2008). Permanent land-related investments that show visible commitment to the long-term productivity of land, principally tree planting, are a well-recognized method of ensuring tenure security. For example, case studies from Niger and Kenya indicate that carbon finance transactions can result in overall increased land tenure security for landholders and communities participating in reforestation projects (de Aquino et al. 2011). Thus, in addition to the common perception that tenure security leads to land-related investment, the reverse can also occur: tree planting and other land investments can improve claims to the land (*endogenous* property right).

With these institutional factors in mind, this paper explores how participation in carbon forestry financed by PES schemes affects the land allocation decision of smallholders between crop production and tree planting. We model three scenarios for a representative smallholder: the land allocation decision under private ownership, under insecure tenure where the farmer faces an exogenous threat of eviction, and under customary tenure where the endogenous property right ensures that the smallholder's risk of eviction is reduced through converting and afforesting cropland. For each scenario, we also derive the imputed value of forested land and the corresponding optimal PES.

Using this framework, we demonstrate that, if the landholder is faced with an exogenous random threat of eviction, less land will be converted to carbon forestry compared to when the eviction threat is absent. Although tree planting under customary tenure is less than under private ownership, where the farmer's tree planting can reduce the threat of eviction, the amount of land allocated to carbon forestry is greater than under insecure tenure. The latter result accords with findings suggesting that the prospect of increased tenure security encourage African farmers with customary tenure to continue to commit resources beyond the point where marginal cost and benefits normally would converge (Sjaastad and Bromley 1997). The implication is that in the case of Sub-Saharan Africa land allocated for tree plantation under customary tenure may be less than under private ownership, but it is certainly more than if tenure security is completely absent.

The results of the model have far reaching policy implication in the design of carbon forestry PES schemes intended to reduce terrestrial emissions and enhance farmer livelihoods, especially under the conditions found in Africa and other developing regions where formal land titling is either not an option or ineffective in guaranteeing tenure security. Although much of the PES literature focuses on secure tenure as a requirement for participating in carbon forestry PES schemes, we find that the prospect of improving the security of tenure can also act as a potential incentive mechanism for tree plantation. This implies that, in situations where the production of environmental services requires a long-term commitment of land resources, a win-win PES scheme can be designed for poor farmers with only customary land tenure. As African agriculture is dominated by customary land holdings, working with the existing *de jure* land right system is not necessarily an impediment to carbon forestry PES schemes; to the contrary, a properly designed scheme with appropriate incentives can both increase carbon forestry on customary land and improve the livelihoods of millions of African farmers.

The rest of the paper is organized as follows. In section 2 we develop a theoretical model of competing land uses between crop production and carbon sequestration tree plantation under private ownership. In section 3 we extend the basic model to take into account the effect of exogenous risk of eviction in the smallholder's land allocation decision. In section 4 we develop a third version of the model to take into account land allocation under customary tenure, the most plausible scenario in Sub-Saharan Africa. In section 5, we calculate the optimal PES under each type of land tenure regime. In the concluding section 6, we discuss the major policy implication for carbon forestry in Africa based on our findings.

2 Smallholder land allocation under private property

The provision of environmental services, for example carbon sequestration, is affected by the landholder's use of agricultural land. In this section, we model the land allocation decision of a smallholder with an initial fixed amount of land, represented by $L(0) = L_0$, allocated to crop production. The smallholder may also have some initial land devoted to a carbon sequestration tree plantation, $F(0)=F_0 \geq 0$. The main land use decision is whether the farmer is willing to convert existing cropland to carbon forestry. In the following version of the problem, we assume that the smallholder has secure and properly enforced private property rights to all the land.

At any time t, let $L(t)$ denote the amount of land allocated to crop production, and $F(t)$ the amount of land allocated to tree plantation. We assume that the farmer converts the land from one use to the other gradually over time. If $c(t)$ is the amount of land converted in each period from crop production to carbon forestry, then

$$L(t)=L(0)-\int_0^t c(s)\,ds, \qquad \dot{L}(t)=-c(t) \qquad (1)$$

Similarly,

$$F(t)=F(0)+\int_0^t c(s)\,ds, \qquad \dot{F}(t)=c(t) \qquad (2)$$

Equations (1) and (2) indicate that $F(t)=F(0)+L(0)-L(t)$ implying that the amount of afforested land is correspondingly increasing (decreasing) by a unit for each unit increase (decrease) in agricultural land. It is also assumed that no clearing of trees for crop production occurs, i.e., $c(t)\geq 0$.

Note that if the smallholder does not receive compensation for the carbon forestry tree planting, then the farmer would ignore this benefit in the private land use decision-making. The result is a social welfare loss due to the underproduction of the externality generating activity, carbon forestry, by the smallholder. This is likely to be one of the factors contributing to the observed reduction in some ecosystem services provided by agricultural lands (Kroeger and Casey 2007). PES schemes for carbon afforestation, like other market mechanisms, are intended to induce farmers to incorporate the economic value of tree planting and thus attain a social optimum (Pattanayak et al. 2010; Pagiola and Platais 2007).

Crop production

For simplicity, we assume a single crop is produced and hence further complications arising from crop rotation and multiple crop production is suppressed. In producing this single crop, in addition to land, in each period the smallholder employs a vector of conventional variable inputs $z(t)$ at a total cost $W(z(t)),\ W' > 0,\ W'' < 0$. The crop production function is then

$$q(t) = f\left(L(t), z(t)\right),\ f_L > 0,\ f_{LL} \le 0,\ f_z > 0,\ f_{zz} \le 0,\ f_{Lz} = f_{zL} \ge 0, \tag{3}$$

where $q(t)$ is output at time t. Equation (3) indicates crop production is a concave function of both conventional inputs and land. This latter relationship is due to the assumption that land quality is heterogeneous, and the most productive land is used for crop production first. Note that the relationship $F(t) = F(0) + L(0) - L(t)$ allows the crop production function (3) to be rewritten as $q(t) = f\left(F(t), z(t)\right),\ f_F < 0,\ f_{FF} \ge 0$. A continuous conversion of agricultural land to tree plantation reduces output at increasing rate.

If P is the price of the crop and r is the farmer's private discount rate, then the present value of stream of profit from crop production received by the private land holder is

$$\pi = \int_0^T \left(Pf\left(L(t), z(t)\right) - W\left(z(t)\right)\right) e^{-rt} dt. \tag{4}$$

Tree plantation for carbon sequestration

A landholder with a clearly defined and defendable private property right has the option to participate in local or international PES carbon forestry schemes. A farmer would enter contracts to adopt tree plantation for a specified period. According to Wunder (2008), a PES scheme of this sort can be economically viable if and only if the payment for the environmental service, such as carbon sequestration, should cover the forgone income plus transaction costs of afforestation.

Payments made to farmers participating in a tree plantation PES scheme can be indexed to output where the payment is based on the amount of carbon sequestered. However, the most widely used approach is area-based indexation in which the contract between the ES buyer and the farmer stipulates the size of land for carbon forestry (Wunder 2007). For example, the Nhambita Community Carbon Project (Mozambique) deposits US$40.50 per hectare (ha) of land brought under carbon sequestration (Jindal et al. 2008). We therefore assume that the farmer receives a payment based on the area of land devoted to tree plantation, where $B(F(t))$, $B' > 0$ and $B'' \leq 0$ is the periodic payment received by the farmer. Let $C(c(t))$ be the total cost of converting $c(t)$ units of land from cropland into tree plantation, and that $C' > 0$, $C'' > 0$ and $C(0) = C'(0) = 0$. It follows that the present value of net return from tree plantation under the PES scheme is

$$M = \int_0^T \left[B(F(t)) - C(c(t)) \right] e^{-rt} dt + e^{-rT} R(F(T)). \tag{5}$$

The last term, $e^{-rT} R(F(T))$, in (5) is the salvage value representing the revenue from clear cut harvesting of the standing trees at the end of the PES contract at time T. For example, The Forests Absorbing Carbon dioxide Emissions Forestation Programme (PROFAFOR) of the highland region of Ecuador applies the area based PES scheme and the contract allows at the end of the 15 to 20 year cycle a minimum of 70% of the revenue from the sale of harvested trees is received by landowners (Wunder 2007). Note that, as it is assumed that the smallholder continues farming beyond T, there is no corresponding salvage value associated with cropland.

Maximizing aggregate returns

The objective of the smallholder is to choose the optimal land allocation to maximize the aggregate present value return from all land uses, i.e., $V = \pi + M$, by choosing the optimal variable inputs $z(t)$ and the rate of land conversion $c(t)$

$$\underset{z,c}{Max}\, V = \int_0^T \left[Pf\left(F(t), z(t)\right) - W\left(z(t)\right) + B\left(F(t)\right) - C\left(c(t)\right)\right] e^{-rt} dt + e^{-rT} R\left(F(T)\right) \quad (6)$$

subject to (2) and the non-negativity constraints imposed on the control variables $z(t) \geq 0$ and $c(t) \geq 0$. However, ignoring the time argument, the current value Hamiltonian of the problem is

$$H = Pf(F, z) - W(z) + B(F) - C(c) + \mu c \quad (7)$$

where $\mu(t)$ is the co-state variable that represents the shadow, or imputed, value of afforested land.

The first-order conditions of the problem are

$$Pf_z - W' \leq 0, \;\; z(t) \geq 0, \;\; z(t)\left[Pf_z - W'\right] = 0 \quad (8)$$

$$\mu - C' \leq 0, \;\; c(t) \geq 0, \;\; c(t)\left[\mu - C'\right] = 0 \quad (9)$$

$$\dot{\mu} = r\mu + Pf_L - B'. \quad (10)$$

Condition (8) indicates that, if conventional inputs are employed, i.e. $z(t) > 0$, then the value marginal product of an additional input equals the marginal cost of using the input. Condition (9) determines whether or not the smallholder will convert any cropland to carbon forestry. For $c(t) > 0$ requires that the farmer converts crop land into afforested land until the marginal cost of conversion equals the shadow value of converted land. However, if $\mu < C'$, then it is not worthwhile for the farmer to convert cropland to carbon forestry, and $c(t) = 0$.

Condition (10) describes the dynamics of the shadow value of afforested land, and it indicates that in making the optimal land allocation decision there are capital gains to consider. It also suggests, along the optimal path, the marginal profit from the converted land, $\dot{\mu} + B'$, must equal the foregone returns if the farmer leaves the land for the original crop production use $r\mu + Pf_L$.

The corresponding transversality condition is

$$\mu(T) = R'(F(T)), \tag{11}$$

which indicates that, at the end of the planning horizon T, the marginal benefit of an increase in $F(T)$ through its contribution to tree harvest value at the end of the PES contract is equal to the marginal cost of such increase represented by $\mu(T)$.

Combining (9) and (10), and rearranging, yields

$$\frac{\dot{\mu}}{\mu} + \frac{B'}{C'} = r + \frac{Pf_L}{C'}, \tag{12}$$

which specifies that along the optimal path of conversion the internal rate of return, i.e. the increase in the value of the afforested land plus relative marginal return from carbon forestry, is equal to the opportunity cost of conversion, i.e. the discount rate plus the forgone relative marginal returns from crop production.[1]

As discussed previously, if farmers do not receive compensation for the production of trees characterized by positive externalities, their private decision-making would lead to underproduction of carbon forestry. Thus it is reasonable to assume that, at the beginning of the PES scheme at time 0, $F_0 < F(T)$ where $F(T)$ is the standing stock of trees at the end of the PES contract at time T. This implies that $\mu(0)$, a measure of the initial desirability of land for carbon forestry relative to crop production, is positive. Given (9), and provided that $\mu = C'$ so that cropland conversion is justified, it follows that initially c is large during the PES scheme. However, over time as more land is converted for carbon forestry, μ and c will fall. As the transversality condition (11) requires the shadow value of land for tree plantation

[1] Condition (12) is a standard result in economic models of competing land uses; e.g., see Amacher et al. (2009); Barbier (2008) and Hartwick et al. (2001).

use to be positive at the end of the PES contract, then there will also be a positive stock of afforested land at time T.

3 Smallholder land allocation under exogenous tenure insecurity

We now extend the basic model to take into account the effect of exogenous tenure insecurity on the farmer's optimal land allocation between crop production and carbon forestry. A concern in the literature is the lack of common definition of tenure insecurity. Roth et al., (1989) offer a workable definition as "the land owner's perception of the probability of losing land within some future time period.'' Alternatively, one can associate tenure insecurity with the perceived probability of losing specific rights in land such as the right to cultivate the land, graze, fallow, and transfer through sell, rent or inheritance.

We therefore view tenure insecurity as the smallholder's perceived probability of the risk of eviction. Let τ be the time at which eviction occurs, and assume it is a continuous random variable specified as the cumulative distribution function $G(t)=\Pr(\tau<t)$. The corresponding probability density function is $G'(t)=g(t)$. A related concept is the survival function, which refers to the probability that farmer survives eviction up to time t, or $S(t)=1-G(t)=\Pr(\tau\geq t)$. Finally, in our model the hazard rate function, denoted by $h(t)$, is the conditional probability of eviction at time t, given that the smallholder has not been evicted up to that time. Formally, these probabilities are related, as

$$h(t)=\frac{g(t)}{S(t)}=-\frac{\dot{S}}{S}=-\frac{d\ln S(t)}{dt} \text{ and thus } S(t)=\exp\left\{-\int_0^t h(v)\,dv\right\}.$$

This last expression enables us to introduce a new state variable

$$y(t)=-\ln S(t)=\int_0^t h(v)\,dv,\quad \dot{y}=-\frac{\dot{S}}{S}=h(t),\quad y(0)=0. \qquad (13)$$

In this version of our model, we assume that tenure security is purely exogenous to the farmer; that is, no actions by the smallholder can affect the probability of eviction. Thus we have a constant hazard rate function i.e., $h(t)=\bar{\theta}$, and the survival function is

$$S(t)=\exp\left\{-\int_0^t h(v)\,dv\right\}=e^{-\bar{\theta}t}.$$

If there is neither a penalty nor compensation at the time of eviction, the problem of the farmer is simply to maximize the expected present value of the aggregate returns earned from all land uses until time τ. Note also that if the smallholder has not been evicted by the end of the PES contract at time T, a return $R(F(T))$ is earned by clear cutting the remaining stand of trees. Thus the farmer chooses $z(t)$ and $c(t)$ to maximize the expected present value of aggregate returns from competing land uses

$$\underset{z,c}{Max}\,J=\int_0^T\left[Pf(F(t),z(t))-W(z(t))+B(F(t))-C(c(t))\right]e^{-rt-y(t)}dt+e^{-rT-y(T)}R(F(T)) \quad (14)$$

subject to (2), (13) and the non-negativity constraints imposed on the control variables $z(t)\geq 0$ and $c(t)\geq 0$. Note that now there is an additional premium in the discount rate due to the additional state variable $y(t)$. Consequently, following Reed and Heras (1992), we employ the conditional current value Hamiltonian (the current value Hamiltonian divided by $e^{-y(t)}$)

$$\tilde{H}=Pf(F,z)-W(z)+B(F)-C(c)+\tilde{\mu}_1 c+\tilde{\mu}_2 h \quad (15)$$

where $\tilde{\mu}_1$ and $\tilde{\mu}_2$ are the conditional current shadow values of afforested land and $y(t)$, respectively.[2]

[2] Following the proof by Reed and Heras (1992), with the assumption of no penalty or reward at the time of eviction from the land, $\tilde{\mu}_2=-W(t)$ where $W(t)$ is the aggregate value of all the land at time t provided that the farmer is not evicted at time t.

The first-order conditions are

$$Pf_z - W' \leq 0,\ z(t) \geq 0,\ z(t)\left[Pf_z - W'\right] = 0 \tag{16}$$

$$\tilde{\mu}_1 - C' \leq 0,\ c(t) \geq 0,\ c(t)\left[\tilde{\mu}_1 - C'\right] = 0 \tag{17}$$

$$\dot{\tilde{\mu}}_1 = (r + y)\tilde{\mu}_1 + Pf_L - B' \tag{18}$$

$$\dot{\tilde{\mu}}_2 = (r + y)\tilde{\mu}_2 + Pf(F, z) - W(z) + B(F) - C(c). \tag{19}$$

And the transversality conditions that specify the value of the co-state variables at time T are

$$\tilde{\mu}_1(T) = R'(F(T)) \text{ and } \tilde{\mu}_2(T) = -R(F(T)). \tag{20}$$

Combining (17) and (18) and rearranging yields

$$\frac{\dot{\tilde{\mu}}_1}{\tilde{\mu}_1} + \frac{B'}{C'} = r + \bar{\theta} + \frac{Pf_L}{C'} \tag{21}$$

Along the optimal path of conversion, the internal rate of return from converting and afforesting land must equal to the opportunity cost of converting cropland. Note that, compared to condition (12) for the private property right case, now we have an additional term $\bar{\theta}$ that increases the effective discount rate. The result is an increase in the opportunity cost of tree planting, due to the risk of eviction. The implication is that less land will be converted to carbon forestry compared to the case when the eviction threat is absent.

In sum, if the risk of eviction from land is independent of the action of the farmer, then its presence acts to increase the effective discount rate, $r + \bar{\theta}$, and less land will be allocated to tree plantation.

4 Smallholder land allocation under customary land tenure

When land rights are predominantly informal and customary, farmers engage in permanent investments that show visible commitments to the long-term productivity and continued use of the land, thereby improving tenure security. Among such investments, tree planting is a well-recognized method of ensuring tenure security (Unruh 2008; Braselle et al. 2002; De Zeeuw, 1997; Sjaastad and Bromley 1997; de Aquino et al. 2011). Thus, in addition to the common perception that tenure security leads to land-related investment, the reverse can also occur; i.e., property rights can be *endogenous*. For example, Braselle et al., (2002) find that in Burkina Faso farmers undertake tree planting and other land-related investments primarily to improve tenure security rather than as a response to secure tenure. Likewise, Deininger (2003) shows that in Ethiopia insecure tenure encourages planting of trees. In Niger and Kenya, carbon financing of reforestation has improved the land tenure security of participating landownders and communities (de Aquino et al. 2011).

In this section, we therefore model the risk of eviction as an endogeneous variable. For a smallholder with customary land tenure, we assume that the hazard rate is inversely related to the amount of land committed to carbon forestry, i.e. $h(t)=\theta(F(t)),\ \theta'<0$. It follows that the state equation (13) is now

$$\dot{y}=h(t)=\theta(F(t)),\quad y(0)=0. \tag{22}$$

The farmer's problem is the same as before, which is to maximize (14) subject to (2), (22) and the non-negativity constraints imposed on the control variables $z(t)\geq 0$ and $c(t)\geq 0$. The corresponding conditional current value Hamiltonian is

$$\tilde{H}=Pf(F,z)-W(z)+B(F)-C(c)+\rho_1 c+\rho_2\theta(F) \tag{23}$$

where ρ_1 and ρ_2 are the conditional current shadow values of afforested land and $y(t)$, respectively.

The first order conditions for maximization are

$$Pf_z - W' \leq 0,\ z(t) \geq 0,\ z(t)\left[Pf_z - W'\right] = 0 \tag{24}$$

$$\rho_1 - C' \leq 0,\ c(t) \geq 0,\ c(t)\left[\rho_1 - C'\right] = 0 \tag{25}$$

$$\dot{\rho}_1 = (r + y)\rho_1 + Pf_L - B' - \rho_2\theta' \tag{26}$$

$$\dot{\rho}_2 = (r + y)\rho_2 + Pf(F, z) - W(z) + B(F) - C(c). \tag{27}$$

And the transversality conditions that specify the value of the co-state variables at time T are

$$\rho_1(T) = R'(F(T)) \text{ and } \rho_2(T) = -R(F(T)). \tag{28}$$

As before, from condition (25) and (26) one obtains

$$\frac{\dot{\rho}_1}{\rho_1} + \frac{B' + \rho_2\theta'}{C'} = r + \theta(F) + \frac{Pf_L}{C'} \tag{29}$$

Along the optimal path of conversion the internal rate of return now includes the impact of afforestation in decreasing the relative risk of eviction, $\rho_2\theta'/C' > 0$.[3] As before is equal to the opportunity cost of conversion, i.e. the effective discount rate $r + \theta$ plus the forgone relative returns to crop production. The implication is that, in the presence of endogeneous tenure security, the internal rate of return from tree plantation is higher, and as a result, more land will be converted to carbon forestry compared to when tenure security is exogenous.

Condition (29) is also analogous to the optimal land allocation rule (12) derived under the assumption of private ownership, except now we have two addition terms: $\theta(F) > 0$ on the right hand side and $\rho_2\theta'/C' > 0$ on the left hand side. The additional term $\theta(F) > 0$ increases the effective discount rate, thereby decreasing the land allocated to tree plantation as the risk of eviction means that any returns may not be realized in the future. The effect of

[3] As discussed in the previous note, by definition $\rho_2 = -W(t) < 0$, where $W(t)$ is the aggregate value of all the land at time t provided that the farmer is not evicted at time t.

$\rho_2\theta'/C' > 0$ is to increase the net marginal benefit from carbon forestry by reducing the risk of eviction, as an increase in the stock of trees improves the smallholder's tenure security. However, given that $\rho_1(t) = e^{\gamma(t)}\mu(t)$, the optimal land allocated to carbon sequestration tree plantation at the end of the PES contract at time T is less under customary tenure than in a private ownership regime.[4] $\theta(F) > \rho_2\theta'/C'$ $\theta(F) < \rho_2\theta'/C'$

5 The optimal payment for carbon forestry

In the previous sections, we argued that the purpose of a PES scheme is to maintain and expand the flow of positive externalities by internalizing benefits. In the absence of such compensation, in the case of carbon forestry this implies less than optimal land allocated to tree plantation. Wunder (2008) emphasize that a PES scheme can be economically viable and will be accepted by the ecological service provider if and only if the payment for the environmental service is at least as large as the opportunity cost plus any transaction cost. In our analysis, we assume that there are no transaction costs associated with the PES scheme, in order to focus our attention on the opportunity costs to the farmer of allocating existing cropland to tree planting for carbon forestry.

It is relatively straightforward to calculate the optimal payment for carbon forestry each of the land tenure regimes that we have analyzed. For example, in the case of private property, rearranging equations (9) and (10) yields

$$\mu(t) = \frac{B' + \dot{\mu}}{r} - \frac{Pf_L}{r} \leq C'. \tag{30}$$

The shadow value of afforested land is the difference between the capitalized marginal benefits of carbon forestry on that land, $(B' + \dot{\mu})/r$ and the capitalized marginal returns from foregone crop production on that land, Pf_L/r. Moreover, for the smallholder to convert

[4] For example, the first transversality condition in (28) can be rewritten as $\rho_1(T) = e^{\gamma(T)}\mu(T) = R'(F(T))$. Compared to (11), it is clear that $R'(F(T))$ must be larger, which in turn requires $F(T)$ to be smaller, assuming the normal property that $R'' < 0$.

cropland to carbon forestry, i.e. $c(t) > 0$, this difference must equal the marginal cost to the smallholder of converting cropland to carbon forestry, C'. Thus the smallholder must receive a payment in each period equal to $\left(B' + \dot{\mu}\right)/r$ in order to engage in the carbon forestry scheme. If not, then the smallholder will not be compensated for the opportunity cost of converting cropland to carbon forestry, Pf_L/r, and no afforestation will take place. That is, $\mu < C'$, and $c(t) = 0$.

Note that, as discussed previously, both $\mu(t)$ and $c(t)$ should be large initially and decline as more cropland is converted to carbon forestry during the PES scheme. In addition, as $F(t)$ increases over time, B' will fall. It follows that the optimal payment to the farmer should initially be large and decline over the life of the PES contract.

Similarly, for the case of exogenous tenure insecurity, from equations (17) and (18)

$$\tilde{\mu}_1 = \frac{B' + \dot{\tilde{\mu}}_1}{r+\theta} - \frac{Pf_L}{r+\theta} \le C'. \tag{31}$$

The optimal carbon forestry payment is again the capitalized marginal benefits of carbon forestry on afforested land, $\left(B' + \dot{\tilde{\mu}}_1\right)/\left(r+\theta\right)$. However, this payment must now take into account the higher effective discount rate due to the threat of eviction. The result may be that the payment is lower than in the case of private property, but this outcome is unclear. The change in the conditional shadow value, $\dot{\tilde{\mu}}_1$ may be different than for $\dot{\mu}$. However, as in the private property case, the optimal carbon forestry payment should be large initially but then fall as the PES contract proceeds.

For customary land tenure, from (25) and (26)

$$\rho_1 = \frac{B' + \dot{\rho}_1 + \rho_2\theta'}{r + \theta(F)} - \frac{Pf_L}{r + \theta(F)} \leq C' .$$

(32)

The carbon forestry payment now must include the benefit of afforestation through reducing the risk of eviction, $\rho_2\theta'$. In addition, as more land is converted to carbon forestry, and $F(t)$ increases, the effective discount rate $r + \theta$ will decline. Thus the carbon forestry payment for a smallholder under customary land tenure is likely to be larger than for a farmer facing an exogenous threat of eviction. However, once again, the optimal payment to the smallholder with customary tenure should be large initially and decline over the life of the PES contract.

6 Discussion

Wunder (2006 and 2008) defines genuine PES schemes as those that satisfy the following five criterions; (1) *voluntary* transaction where (2) a *well-defined* ES (or corresponding land use) is (3) being 'bought' by a (minimum one) ES *buyer* (4) from a (minimum one) ES *provider* (5) if and only if ES provision is secured (*conditionality*). This implies that PES schemes involve voluntary, negotiated, explicit contracts between environmental service (ES) providers and ES buyers. The conditionality criterion suggests that these contracts need to clearly specify that PES are contingent to ES provision on continuous basis which in turn require secure property right in the part of the ES provider.

However, imposing tenure security, commonly associated with possession of land title, as a requirement for farmer's participation in carbon sequestration projects tends to exclude many poor farmers (Swallow and Meinzen-Dick 2009; Jindal et al 2008; Unruh, 2008; Wunder, 2006). For example in Costa Rica, when landowners who lacked formal title were excluded from the PES program, many of the poor were prevented from participating as they were more likely to lack titles than better-off farmers (Pagiola 2002). The problem is even worse for poor farmers in Sub-Saharan Africa where customary tenure without clear titles prevails. Properly enforced statutory property rights in Africa are limited to locations of intensive agriculture, fertile lands, mineral reach areas and areas closer to infrastructure (Unruh 2008).

As a result, only about 1 percent of land in Africa is registered and titled formally (Easterly 2008). Consequently, despite the belief that tree-based carbon sequestration is ideal for Sub-Saharan Africa, such PES arrangements are currently scarce in the continent (Jindal et al. 2008; Unruh 2008). For example, out of the 23 carbon sequestration projects approved under the Kyoto protocol's Clean Development Mechanism only two were in Africa (Jindal et al. 2008).

There is a growing skepticism about the common association of tenure security with the possession of statutory land titles (Roth et al.1989; Schlager and Ostrom 1992). For example, in parts of Africa where customary land allocation prevails, the customary authority, such as a tribal chief, grants individuals with secure rights for grazing and cultivation, without any legal title definition, registration, or government enforcement. Customary authorities may also regulate transfers of land and dictate land related investments (Besley 1995). On the other hand, high levels of tenure insecurity may exist even with statutory title. This might happen when there is a lack of institutions with both legal backing and social legitimacy that are accessible by and accountable to the holders of property rights. Mindful of this fact, Pagiola (1999) asserts that lack of title should not automatically be equated with tenure insecurity. Generally, in identifying PES participants, a formal land title may not be necessary as long as tenure is secure (Pagiola et al. 2005). Similarly, Wunder (2006) argues that the main concern for environmental service (ES) buyers should not be *de jure* land rights, but *de facto* land rights.

In Africa, the dominance of customary law coupled with the inability of the state to develop and enforce legal institutions, policies and financing have thwarted efforts to introduce formal land titling to ensure secure property right (Bruce et al. 1994; Easterly 2008; Unruh 2008). For instance, although the land tenure reforms in Niger during the 1980s and 1990s allowed customary rights to be register as statutory rights, ambiguity about what rights to register and insufficient administrative preparedness led many farmers to opt out of formalizing their customary land tenure (Benjaminsen et al. 2008). Even when the capacity to introduce formal land titling exists, community-based systems of land rights may better meet the needs of farmers with customary tenure (Toulmin 2008; Fitzpatrick 2005).

Communal land titling may also be a cost-effective way of ensuring tenure security, provided that community members have clear rights over their plots (Roth et al.1989; Schlager and

Ostrom 1992). As a consequence, in recent years there has been a resurgence of formal recognition of customary land rights. In Mozambique, although land belongs to the state, communities are allowed to manage land rights according to customary practices (Kanji et al. 2007). Similarly, the government of Ghana recognizes the role of customary tribal leaders and community decisions in allocating land, and in South Africa, the titling of communal land occurs through communal property associations (CPAs) (Cousins 2002). In Namaqualand, South Africa, local communities were allowed to vote between land privatization, CPA ownership or municipal ownership. Although one communal area opted out of the vote, four communities chose CPA ownership and one voted for municipal ownership (Benjaminsen et al. 2008)

Under customary land rights, tenure security is contingent upon continued use of the land and eviction is likely when land is scarce and when land is abandoned for extended time. However, in Sub-Saharan Africa, where land is the mainstay of households and has been becoming scarce overtime mainly due to population pressure, there is little incentive to abandon land and thus security is ensured (Sjaastad and Bromley 1997). In fact, a common method of securing land tenure is through permanent investment. Farmers invest in trees, buildings and other fixed structures to show to the customary authorities and other members of the community their commitment to the long-term productivity of the land and this usually insures continued use of the land and thus tenure security is implied.

This has led various authors to conclude that accommodating the characteristics of African tenure systems is the way forward to promote successful tree-based carbon sequestration projects that can reduce terrestrial emission and benefit the poor (Jindal et al. 2008; Unruh 2008). Already, some schemes in Africa are accommodating local tenure arrangements. For example, the Nhambita Community Carbon Project in Mozambique involves land held under customary tenure (Jindal et al. 2008).

The results of our analysis confirm that informal property right systems may, under certain conditions, help rather than hinder tree planting for carbon sequestration. A farmer with customary land tenure enjoys additional benefit from carbon forestry in the form of reduced risk of eviction due to tree planting enhancing claims to the land. Although our results indicate that the optimal land allocated to carbon sequestration tree plantation under customary tenure might not be as much as compared to the private ownership regime, the additional benefit of reducing tenure insecurity can significantly influence how households manage their land. As Sjaastad and Bromley (1997, p 557) note, any "conclusive statement about which regime provides the higher investment incentive cannot be given", because in Sub-Saharan Africa the "prospect of increased tenure security will lead a farmer with indigenous tenure to continue to commit resources … beyond the point where marginal cost and benefits normally would converge."

Because carbon forestry entails a long term commitment, secure property rights over land resources are clearly relevant for carbon sequestration PES schemes. However, there is an important distinction between secure tenure being required as a condition for participating in carbon sequestration tree plantation PES scheme as opposed to secure tenure also being a potential incentive mechanism for tree planting. In situations where the production of environmental services requires long-term commitment of land resources, for example carbon forestry, a win-win PES scheme can be designed for farmers with customary land tenure that reduces poverty, tenure insecurity and environmental degradation.

Our analysis also indicates that, in the presence of exogenous random eviction threat, less land will be converted to carbon forestry compared to when land is under private property or customary tenure. Smallholders with land tenure that is insecure, transitory, or weakly enforced cannot be efficient providers of carbon forestry, mainly for two reasons. First, a smallholder facing exogenous eviction threats discounts the future heavily, and thus is less willing to participate in a carbon forestry program that requires a long term contract. Second, because insecure tenure implies that others might occupy a smallholder's land or harvest the resources, a PES scheme may actually threaten land claims by the poor (Jindal et al. 2008). For instance, in Bualeba Reserve in Uganda a carbon sequestration project actually led to increased eviction of local people from their rights for farming, grazing, fishing, and timber collection.

Although PES schemes are conceptualized and undertaken as a mechanism to improve the efficiency of natural resource management, many proponents have argued that PES can also have positive impacts on poverty (Landell-Mills and Porras 2002; Pagiola 2002). Our analysis provides some support for this view. As we have noted, the most widely used approach in designing PES payment is the area-based indexation scheme, in which the contract is based on the amount of land aside for carbon forestry. In such a scheme, the opportunity cost of the land is an important factor determining farmer participation. A carbon forestry PES scheme may be less attractive to landowners with high-productivity land as their opportunity cost (forgone crop production) is much higher, while farmers with less productive land (usually the poor) in crop production are more likely to participate in the scheme. As far as this economic relationship is concerned, the PES scheme seems pro-poor. Evidence from Latin America supports this effect. For example, Wunder (2008) maintains that voluntary user-financed PES programs in Bolivia (Los Negros) and Ecuador (Pimampiro and PROFAFOR) benefited poor farmers. As we have also shown, poor farmers with customary land tenure may receive an additional incentive for participation, if tree planting enhances their tenure security. However, our results do not include any analysis of the transaction costs faced by the poor in carbon forestry schemes, as they have the effect of excluding poor smallholders and may be significant in developing countries with poor institutions (Bromley 2008; Wunder 2007; Swallow and Meinzen-Dick 2009).

7 Conclusion

A common perception is that long-term environmental service provision, such as carbon sequestration through tree planting, cannot take place unless a landowner has secure and enforced private property rights to the land. Our analysis explores the conditions under which PES carbon forestry can be targeted to smallholders without statutory land titles but with well-functioning customary land rights. We show that landowners with customary land tenure can be efficient providers of long-term environmental services, such as carbon forestry, especially if tree planting helps secure their permanent claims to the land. Empirical evidence from Niger and Kenya indicate that these effects might be significant (de Aquino et al. 2011).

This conclusion has important implications for the participation in PES schemes of many poor farmers with customary land tenure, especially in Africa. Not only is customary land tenure dominant throughout the region, but past efforts to convert rural farmland to private ownership have been largely unsuccessful. Mindful of this reality, a number of African governments have begun introducing formal recognition of customary land rights (Toulmin 2008; Kanji et al. 2007). Thus, the results of our analysis support the view that carbon forestry and other PES schemes should accommodate the traditional African customary tenure systems, and if designed successfully, can both promote tree-based carbon sequestration and benefit the poor (Jindal et al. 2008; Unruh 2008).

However, our results show that tenure security, especially if it involves a threat of eviction from the land, is still a problem for PES schemes. Under customary land rights, tenure security is contingent upon continued use of the land and eviction is likely when land is scarce and when land is abandoned for extended time. This is not the same situation as when smallholders have land tenure that is insecure, transitory, or weakly enforced. The latter case does inhibit both farmers' participation in carbon forestry schemes and the amount of cropland they devote to tree planting. Unfortunately, the problem of insecure tenure remains prevalent throughout much of the developing world.

Finally, all poor smallholders face significant transaction costs to participating in long-term PES schemes, such as for carbon forestry, especially in developing countries with poor institutions (Bromley 2008; Wunder 2005; Swallow and Meinzen-Dick 2009). Although the analysis of such transaction costs was not the focus of our paper, the actual design of carbon forestry PES schemes need to consider them seriously in order to be effective in encouraging the participation of poor farmers.

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