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The potential of REDD+ for carbon sequestration in tropical forests: Supply curves for carbon storage for Kalimantan, Indonesia

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ABSTRACT

We study the potential of tropical multi-age multi-species forests for sequestering carbon in response to financial incentives from REDD+. Following existing carbon crediting schemes, the use of reduced impact logging techniques (RIL) allows a forest manager to apply for carbon credits whereas conventional logging (CL) does not. This paper is the first to develop a Hartman model with selective cutting in this setting that takes additionality of carbon sequestration explicitly into account. We apply the model using data for Kalimantan, Indonesia, for both private and government forest managers. The latter have a lower discount rate and are exempt from taxes. RIL leads to less damages on the residual stand than CL and has lower variable but higher fixed costs. We find that a system of carbon credits through REDD+ can increase carbon stored per hectare by 15.8% if the forest is privately managed and by 22% under government management if the carbon price equals the average 2015 price in the European Union's Emission Trading Scheme. Interestingly, awarding carbon credits to carbon stored in end-use wood products does not increase the amount of carbon stored, nor Land Expectation Value.

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1. Introduction

Forests play an important role in the carbon cycle and may be a low cost option to offset carbon emissions (Kindermann et al., 2008; Richards and Stokes, 2004; van Kooten and Sohngen, 2007). This has been acknowledged at the 16th Conference of the Parties (CoP 16) of the UNFCCC in Cancun in 2010, where the Parties recognized reduction of emissions from deforestation and forest degradation (REDD), including reduced emissions through conservation of forest carbon stocks combined with sustainable management of forests and the enhancement of forest carbon stocks (REDD+), as a means to offset carbon emissions.

The harvest of mature trees in managed tropical forests causes damage to the remaining stand. Through intensively planned and carefully controlled timber harvesting conducted by trained workers, reduced impact logging (RIL) decreases damages to the remaining stand (Zimmerman and Kormos, 2012). Therefore, ceteris paribus, the growing stock and the amount of carbon stored in the remaining forest stand are larger as compared to conventional logging (CL) (Pinard and Putz, 1996; Putz and Pinard, 1993; Putz et al., 2008). While previous literature has studied the effects of carbon storage and biodiversity constraints on optimal cutting cycles of managed tropical forests (Ingram and Buongiorno, 1996; Boscolo and Buongiorno, 1997; Boscolo and Vincent, 2003), the potential of REDD+ carbon payments on tropical forest carbon sequestration has not been studied systematically.

In this paper, we analyze the potential of REDD+ to induce carbon sequestration and we present supply curves for carbon storage in a tropical multi-age, multi-species forest; that is, for a range of prices of carbon credits we show the corresponding amount of carbon stored in aboveground biomass. We do so considering both private and public forest management; these differ in tax liability and the relevant discount rate. This paper is the first that develops a Hartman (1976) model for multi-age, multi-species forests and analyzes the tradeoffs between timber revenues and income from carbon credits for a tropical forest with additionality taken explicitly into account. Carbon credits are only granted under RIL while the amount of carbon stored under CL in the absence of carbon credits serves as a benchmark (see for example the Verified Carbon Standard, the largest voluntary greenhouse gas reduction program). Hence we take additionality explicitly into account. We also explicitly consider the case where no harvesting takes place. We use detailed data on the characteristics of a multi-age, multi-species forest in central Kalimantan, Indonesia, and solve the model for a range of carbon prices. Our data allow us to develop a detailed model in which the damage from harvesting to the residual stand depends on harvest intensity, forest density and logging technique, and differs across diameter classes (Macpherson et al., 2010). Furthermore we use detailed

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data on fixed and variable harvest costs from a forest company in East Kalimantan, according to which RIL has slightly lower variable costs than CL but higher fixed costs. Following the rules of existing voluntary schemes for forest carbon sequestration under REDD+ (Dangerfield et al., 2013), an additional novel element of our paper is the study of the effect of payments for carbon stored in end-use wood products such as building materials. As we will show, additionality plays a crucial role in determining whether receiving credits for carbon stored in end-use wood products is beneficial for land managers, while explicit modeling of the ‘no harvest’ case has important ramifications for the interpretation of supply curves for carbon storage. Our carbon supply curves can be used in simulation models for mitigation policies (see Bosetti et al., 2011; Rose and Sohngen, 2011; Sohngen and Mendelsohn, 2003).

The effects of carbon payments on timber harvesting regimes have been studied extensively for plantation forests. Van Kooten et al. (1995) analyze effects of carbon payments on the optimal management of boreal and coastal forest in Canada. Galinato and Uchida (2011) and Olschewski and Benitez (2010) study the effects of temporary and long term credits under the Clean Development Mechanism (CDM) in plantation forests in tropical countries while Köthke and Dieter (2010) and Tassone et al. (2004) study the effects of carbon crediting schemes on forest management for even-aged forests in Germany and Italy respectively. Boscolo et al. (1997) and Buongiorno et al. (2012) study carbon storage in un-even aged multi-species forests, but do not allow for optimizing behavior of forest managers. In addition, Buongiorno et al. (2012) study a forest in the northern hemisphere dominated by Norway spruce. The common finding is that an increasing carbon price leads to larger amounts of carbon stored in forests. However, none of these papers studies the incentives stemming from REDD+ where payments are received only for additional carbon stored as compared to a baseline, nor do they consider payments for carbon stored in end-use wood products. Furthermore, these papers typically use a discount rate that is too low for private forestry companies in Indonesia. These firms manage 96% of managed tropical forests in Indonesia (Hutan-Aceh, 2014). Therefore we study the case of a private forest manager with a 12% discount rate, and the case of a government forest manager (who does not have to pay taxes) with a 4% discount rate.

In the remainder of this paper we first describe the forest growth model and the economic optimization model. Next, in Section 3, we parameterize the model. We present our results in Section 4 and conclude in Section 5.

2. Model

2.1. Forest growth model

To describe the forest dynamics we use a matrix stand growth model. Such models are extensions of population growth models applied to forest stands (Buongiorno and Michie, 1980) and have been applied to tropical forest stands to study management strategies for maximizing economic returns (Boscolo and Buongiorno, 1997; Boscolo and Vincent, 2000; Ingram and Buongiorno, 1996; Tassone et al., 2004).

At time t a forest stand is represented by column vector $\mathbf{y}_t=[y_{ijt}]$, where y_{ijt} is the number of trees per ha of species (or species group) $i\in\{1,\dots,m\}$ and diameter class $j\in\{1,\dots,n\}$. The harvest is represented by vector $\mathbf{h}_t=[h_{ijt}]$. A tree living in species group i and diameter class j at time t will, at time $t+\theta$, either: (1) die, which happens with probability o_{ij}, (2) stay alive and move up from class j to class $j+1$, which happens with probability b_{ij}, or (3) stay alive in the same diameter class j, which happens with probability $a_{ij}=1-b_{ij}-o_{ij}$. Parameter θ represents the growth period in years.

We use I_{it} to denote the expected ingrowth, i.e. the number of trees entering the smallest size class of species group i during a growth period θ. The stand state at time $t+\theta$ is determined by the stand at time t, the harvest at time t, and the ingrowth during interval θ. Ignoring damages from harvesting for the moment, each species in the stand is represented by the following n equations:

$$y_{i1t+\theta}=I_{it}+a_{i1}(y_{i1t}-h_{i1t}) \tag{1}$$

$$y_{i2t+\theta}=b_{i1}(y_{i1t}-h_{i1t})+a_{i2}(y_{i2t}-h_{i2t})$$

$$\dots$$

$$y_{int+\theta}=b_{i\,n-1}(y_{i\,n-1\,t}-h_{i\,n-1\,t})+a_{in}(y_{int}-h_{int})$$

Ingrowth I_{it} is affected by the conditions of the stand (i.e. basal area and number of trees). The ingrowth function is a function of basal area B_{ij}, the initial stand and the harvest:

$$I_{it}=\beta_{0i}-\beta_{1i}\sum\nolimits_{j=1}^{n}B_{ij}\left(y_{ijt}-h_{ijt}\right)+\beta_{2i}\sum\nolimits_{j=1}^{n}\left(y_{ijt}-h_{ijt}\right), \tag{2}$$

$\beta_{0i},\beta_{1i},\beta_{2i}>0$. Substituting Eq. (2) into the first equation of (1) gives:

$$y_{i1t+\theta}=\beta_{0i}+e_{i1}(y_{i1t}-h_{i1t})+\cdots+e_{in}(y_{int}-h_{int}) \tag{3}$$

where:

$$e_{i1}=a_{i1}+\beta_{1i}B_{i1}+\beta_{2i} \tag{4}$$

$$e_{ij}=\beta_{1i}B_{ij}+\beta_{2i}\text{ for }j>1 \tag{5}$$

Ignoring damage for now, the stand after harvest is:

$$\mathbf{y}_{t+\theta}=\mathbf{G}(\mathbf{y}_t-\mathbf{h}_t)+\mathbf{c} \tag{6}$$

where

$$\mathbf{G}=\mathbf{A}+\mathbf{R} \tag{7}$$

and

$$\mathbf{A}=\begin{bmatrix}\mathbf{A}_1 & 0 & \dots & 0\\ 0 & \mathbf{A}_2 & \dots & 0\\ \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & \dots & \mathbf{A}_m\end{bmatrix};\ \mathbf{A}_i=\begin{bmatrix}a_{i1} & & & 0\\ b_{i2} & a_{i2} & & \\ & \ddots & \ddots & \\ 0 & & b_{in} & a_{in}\end{bmatrix} \tag{8}$$

$$\mathbf{R}=\begin{bmatrix}\mathbf{R}_{11} & \mathbf{R}_{12} & \dots & \mathbf{R}_{1m}\\ \mathbf{R}_{21} & \mathbf{R}_{22} & \dots & \mathbf{R}_{2m}\\ \vdots & \vdots & \ddots & \vdots\\ \mathbf{R}_{m1} & \mathbf{R}_{m2} & \dots & \mathbf{R}_{mm}\end{bmatrix};\ \mathbf{R}_{ik}=\begin{bmatrix}e_{i1} & e_{i2} & \dots & e_{in}\\ 0 & 0 & \dots & 0\\ \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & \dots & 0\end{bmatrix} \tag{9}$$

$$\mathbf{c}=\begin{bmatrix}\mathbf{c}_1\\ \mathbf{c}_2\\ \vdots\\ \mathbf{c}_m\end{bmatrix};\ \mathbf{c}_i=\begin{bmatrix}\beta_{i0}\\ 0\\ \vdots\\ 0\end{bmatrix} \tag{10}$$

Matrix $\mathbf{G}$ is the growth matrix. $\mathbf{A}$ is an $mn\times mn$ matrix consisting of species upgrowth matrices $\mathbf{A}_i$. It represents the probability of a tree to stay alive in the same diameter class j, move up the next diameter class $j+1$, or die. Ingrowth matrix $\mathbf{R}$ is an $mn\times mn$ matrix representing the effect of stand structure on the probability of a tree entering the smallest diameter class in one growth period. Vector $\mathbf{c}$ contains the ingrowth constants representing the number of trees exogenously entering the smallest diameter class for each species.

2.2. Maximizing Land Expectation Value: timber only

The unit of analysis in this study is one hectare of a forest stand. The economic harvesting decision involves three variables: (i) the type of harvesting practice, i.e. CL or RIL, (ii) the length of the cutting cycle in years, and (iii) the intensity of the harvest in trees per ha for each species group.

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