Forest Carbon Sequestration under uncertainty

When Not in the Best of Worlds

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Introduction

Background and Question

- Climate change
- Forest carbon sequestration, a low cost abatement strategy
- Uncertainties concerning sequestration potential
- How does uncertainty affect forest carbon sequestration?
- Our contribution

Model

- Integrated assessment model: DICE2007 (Nordhaus)
- Economic growth model with a climate damage function
- Maximizes the present value of the social welfare function
- Two control variables: investment and carbon control rate (the transition from carbon to non-carbon energy)

- FOR-DICE (Eriksson 2015) with global forest biomass, bioenergy harvest, avoided deforestation
- Extended to include afforestation, climate feedback on forest
- Three types of forest sequestration control variables: avoided deforestation, afforestation, bioenergy harvest

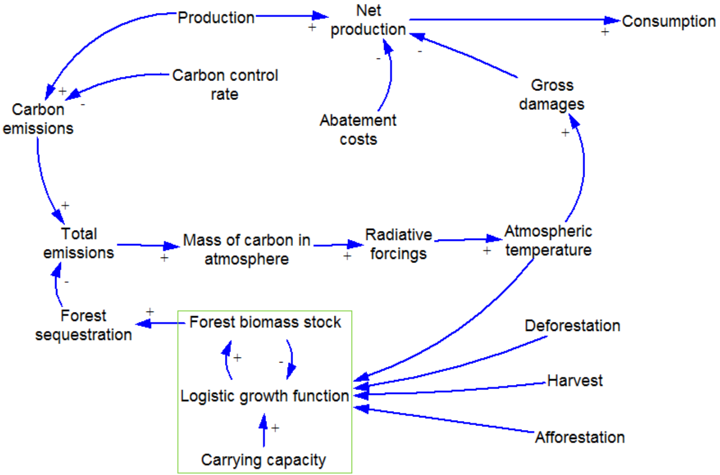
Uncertainty

How uncertainty is modeled will affect the robustness of the results and policy implications

- Truly stochastic
  Decision in each period made prior to realization
- Averaging multiple runs
  All uncertainty resolved before optimization
- Contingent state
  Uncertainty as multiple states of the world, partly resolved before optimization
  Random parameters drawn from distributions in advance

The Model

The Big Picture



Forest Dynamics (tropical, boreal, temperate)

Logistic growth for stocks of biomass

$$F_{n,t+1} = F_{n,t} + \psi_{n,t} F_{n,t} \left[1 - \frac{F_{n,t}}{F_{n,t}^{MAX}} \right] - H_{n,t} - D_{n,t} - B_{n,t}, \quad (1)$$

n is type of forest, $F_{n,t}$ is stock of forest biomass, $\psi_{n,t}$ is growth rate, $H_{n,t}$ is total harvest. $D_{n,t}$ is loss from deforestation, $B_{n,t}$ is loss from climate change

Carrying capacity

$$F_{n,t+1}^{MAX} = F_{n,t}^{MAX} - \frac{F_{n,t}^{MAX}}{F_{n,t}} D_{n,t} + A_{n,t} + G_{n,t}. \quad (2)$$

$\frac{F_{n,t}^{MAX}}{F_{n,t}}$ is a rescaling factor, $A_{n,t}$ is afforestation increase, $G_{n,t}$ is climate induced change

Climate feedback on forest

An increased global mean temperature affects forest

Intrinsic growth rate

Degree	Tropical	Boreal	Temperate
2	-6.8%	9.3%	-5.1%
3	-21%	-26%	-16%

Geographical distribution (affects carrying capacity in model)

Degree	Tropical	Boreal	Temperate
2	-1.6%	2.9%	-
3	-5.0%	9.0%	-

Forest Control Variables

- Avoided deforestation (tropical)

  Opportunity cost - rental payment to prevent conversion of forest land

  Marginal cost function derived from Kinderman et al (2008)

  cost

- Afforestation (tropical, temperate)

  Opportunity cost + plantation cost

  Marginal cost function estimated from GAEZ v3 crop production/hectare

  cost

- Bioenery harvest (tropical, temperate, boreal)

  Bioenergy harvest contributes to energy by a nested Cobb-Douglas function calibrated with data from IEA and FAO

  No extraction cost

Energy

Total energy used in production = fossil energy (FO_t) + forest bioenergy ($HB_{n,t}$) + non-carbon energy (μ_t)

Carbon emissions:

$$\Pi_t = Y_t \sigma_t (1 - \mu_t) \tag{3}$$

Y_t is gross production, σ_t is ratio of uncontrolled emission to output, μ_t is carbon control rate (mitigation)

Carbon energy required:

$$\Xi_t = \Pi_t \xi \tag{4}$$

ξ_t is enery emission parameter

Carbon energy sources:

$$\Xi_t = \varsigma HB_{tro,t}^{\beta_{tro}} HB_{bor,t}^{\beta_{bor}} HB_{tem,t}^{\beta_{tem}} FO_t^{1-(\beta_{tro}+\beta_{bor}+\beta_{tem})} \tag{5}$$

Emissions

Total carbon emissions = emission from energy (E_t) - forest sequestration (EF_t)

Emission from energy:

$$E_t = FO_t + \sum_n HB_{n,t}\theta_n \tag{6}$$

FO_t is fossil energy, $HB_{n,t}$ is bionergy harvest, θ_n is conversion factor

Carbon sequestration:

$$EF_{n,t} = (F_{n,t} - F_{n,t-1})\theta_n \tag{7}$$

$F_{n,t}$ is stock of forest biomass

Output

Final output:

$$Q_t = \frac{1}{(1+\pi_1 \Delta T_t^{\pi_2})}(1-\Lambda_t)Y_t - CD_t - \sum_n CA_{n,t} \tag{8}$$

ΔT_t is temperature increase, Λ_t is carbon control cost, CD_t is cost of avoiding deforestation, $CA_{n,t}$ is cost of afforestation

Per capita consumption:

$$c_t = \frac{Q_t - I_t}{L_t} \tag{9}$$

Utility function:

$$U_t(\cdot) = L_t \left(\frac{c_t^{1-\alpha}}{1-\alpha} \right) \tag{10}$$

L_t is population/labor, α is elasticity of the marginal utility of consumption

Uncertainty

Contingent state optimization:

$$W = \max_{I_t, \mu_t, RD_{n,t}, HA_{n,t}, HB_{n,t}} \frac{1}{S} \sum_{s=1}^{S} \sum_{t=1}^{T} (1+\rho)^{-t} U_{s,t}(\cdot) \qquad (11)$$

s is state index, I_t is investment, μ_t is carbon control rate, $RD_{n,t}$ is reduction of deforestation, $HA_{n,t}$ is afforestation, $HB_{n,t}$ is harvest bioenergy, ρ is pure rate of time preference

Uncertainty parameters

	tropical	boreal	temperate
Initial intrinsic growth	N(0.199, 0.04)	N(0.373, 0.04)	N(0.113, 0.04)
Climate feedback on intrinsic growth	N(-0.04, 0.02)	N(-0.03, 0.015)	N(-0.79, 0.027)
Climate feedback on forest cover change	N(-20,10)	N(0.2)	N(20,10)

Preliminary Results

Recognizing uncertainty

Comparing without and with forest control. Metric: carbon price

No uncertainty

Carbon price	2015	2035	2055	2075
Carbon control	41.6	81.2	137.8	215.7
All controls	41.5	81.0	137.6	216.0

$\Longrightarrow$ small difference between with or without forest control

Forest uncertainty

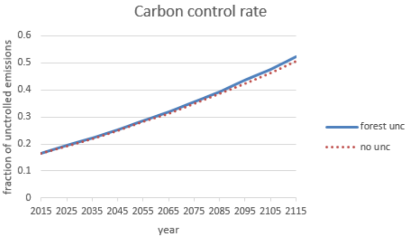
Carbon price	2015	2035	2055	2075
Carbon control	62.5	153.9	355.2	736.3
All controls	41.5	81.1	138.0	217.0

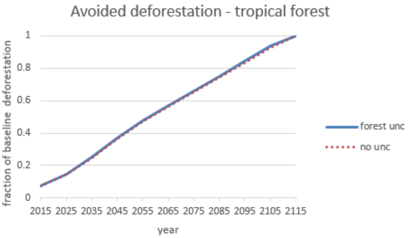
$\Longrightarrow$ large difference between with or without forest control

Carbon control is not enough when forest uncertainty is introduced.

Rebalancing of controls 1

Comparing with and without uncertainty when using all controls.
Metric: carbon control rate and avoided deforestation

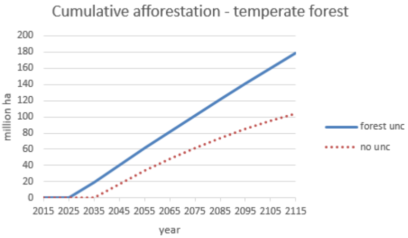


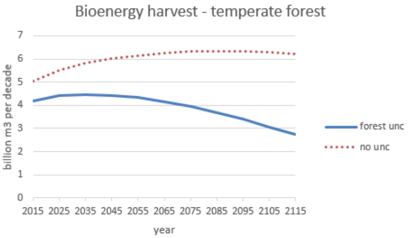


$\Longrightarrow$ A small difference

Rebalancing of controls 2

Comparing with and without uncertainty when using all controls. Metric: optimal cumulative afforestation and optimal bioenergy harvest.





$\Longrightarrow$ A big difference

Forest uncertainty makes a rebalancing of controls neccessary.

More insights

- Better to reduce bioenergy (short-term) harvest than to increase afforestation (long-term)
- The forest type with the least uncertainty regarding growth rate is preferred when rebalancing
- The balance between forest and carbon control is clearly affected by uncertainty
- Ignoring uncertainty will give a biased estimate of costs and hence the wrong carbon price.

Thank you

Thank you!

Deforestation Marginal Cost

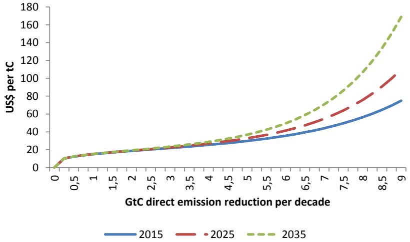


Figure : Cost of avoiding emissions from deforestation

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Afforestation Marginal Cost

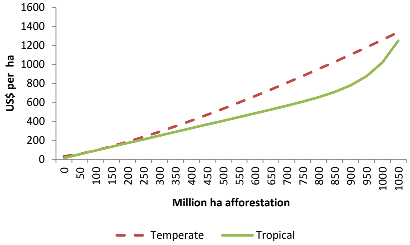

Figure : Cost of afforestation

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