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Forests, land use and climate change:

Deriving optimal carbon policies for biomass utilization

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IEA Task 38 Workshop on Forests

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In this presentation…

- We present a model which includes:
  - The allocation of land to competing uses
  - The allocation of biomass to competing uses
  - Carbon storage in biomass, soils and products

- We use it to derive an efficient (tax) policy for regulating of biomass emissions

What its based on

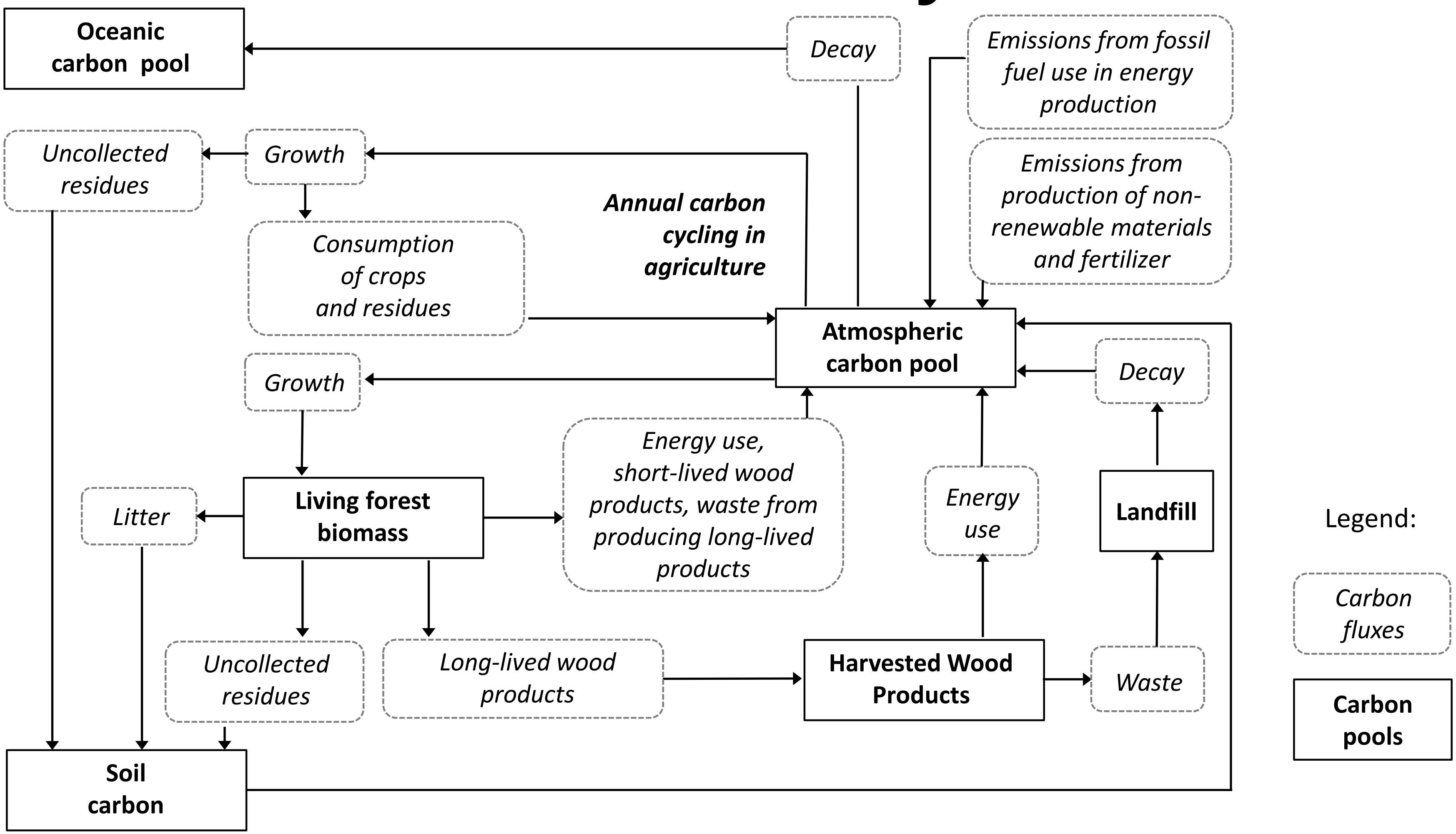
- Lintunen, J. and Uusivuori, J. 2014. On the economics of Forest Carbon: Renewable and Carbon Neutral But Not Emission Free. Fondazione Eni Enrico Mattei Working Paper Series. 13.2014.
- Rautiainen, A. Lintunen, J. and Uusivuori, J. (Work in Progress)

Earlier Research (e.g.)

- Stand-level analysis:
  - van Kooten ym. 1995, Hoen & Solberg 1994
- National-level analysis:
  - Tahvonen 1995
- Substitution vs. Carbon storage:
  - Marland ja Schlamadinger 1997
- Bioenergy emissions:
  - Fargione ym. 2008, Searchinger ym. 2009 ja Repo ym. 2011

I
Model properties

The carbon cycle



EOM for atmospheric C

$$S_{t+1}^{ATM} = (1-\delta^{ATM})S_t^{ATM}$$

$$+\varepsilon^f f_t + \varepsilon^z z_t + \varepsilon^v \sum_{i=1}^{N} v_{it} x_{i1t}$$

$$-\varepsilon^w G_t^W + \varepsilon^w [w_t^P + (1-\alpha) w_t^L + w_t^E + w_t^{RES} + w_t^{HWP}]$$

$$-\sum_{i=1}^{N} \left(\varepsilon_i^c G_{it}^C + \varepsilon_i^r G_{it}^R\right) + \sum_{i=1}^{N} \left(\varepsilon_i^c a_{it}^F + \varepsilon_i^c a_{it}^E + \varepsilon_i^r a_{it}^{RES}\right)$$

$$+\sum_{i=1}^{N+1} \sum_{a=1}^{A_i} \sum_{j=1}^{J_i} \delta_{ij}^S S_{iajt}^S + \delta^{LF} S_t^{LF}$$

EOM for atmospheric C

$$S_{t+1}^{ATM} = (1-\delta^{ATM})S_t^{ATM}$$

Atmospheric C in period *t+1*

$$+\varepsilon^f f_t + \varepsilon^z z_t + \varepsilon^v \sum_{i=1}^{N} v_{it} x_{i1t}$$

Atmospheric C in period *t* minus decay into oceans

$$-\varepsilon^w G_t^W + \varepsilon^w [w_t^P + (1-\alpha) w_t^L + w_t^E + w_t^{RES} + w_t^{HWP}]$$

$$-\sum_{i=1}^{N} (\varepsilon_i^c G_{it}^C + \varepsilon_i^r G_{it}^R) + \sum_{i=1}^{N} (\varepsilon_i^c a_{it}^F + \varepsilon_i^c a_{it}^E + \varepsilon_i^r a_{it}^{RES})$$

$$+\sum_{i=1}^{N+1} \sum_{a=1}^{A_i} \sum_{j=1}^{J_i} \delta_{ij}^S S_{iajt}^S + \delta^{LF} S_t^{LF}$$

EOM for atmospheric C

$$S_{t+1}^{ATM} = (1-\delta^{ATM})S_t^{ATM}$$

$$+\varepsilon^f f_t + \varepsilon^z z_t + \varepsilon^v \sum_{i=1}^{N} v_{it} x_{i1t}$$

Fossil fuel emissions

Material emissions *(from non-renewables)*

Fertilizer emissions *(from agriculture)*

$$-\varepsilon^w G_t^W + \varepsilon^w [w_t^P + (1-\alpha) w_t^L + w_t^E + w_t^{RES} + w_t^{HWP}]$$

$$-\sum_{i=1}^{N} \left(\varepsilon_i^c G_{it}^C + \varepsilon_i^r G_{it}^R\right) + \sum_{i=1}^{N} \left(\varepsilon_i^c a_{it}^F + \varepsilon_i^c a_{it}^E + \varepsilon_i^r a_{it}^{RES}\right)$$

$$+\sum_{i=1}^{N+1} \sum_{a=1}^{A_i} \sum_{j=1}^{J_i} \delta_{ij}^S S_{iajt}^S + \delta^{LF} S_t^{LF}$$

EOM for atmospheric C

$$S_{t+1}^{ATM} = (1-\delta^{ATM})S_t^{ATM}$$

Forest growth

Emissions from wood use

$$+\varepsilon^f f_t + \varepsilon^z z_t + \varepsilon^v \sum_{i=1}^{N} v_{it} x_{i1t}$$

$$-\varepsilon^w G_t^W + \varepsilon^w [w_t^P + (1-\alpha) w_t^L + w_t^E + w_t^{RES} + w_t^{HWP}]$$

PULP, LOGS, ENERGY WOOD, RESIDUES, HWP

$$-\sum_{i=1}^{N} (\varepsilon_i^c G_{it}^C + \varepsilon_i^r G_{it}^R) + \sum_{i=1}^{N} (\varepsilon_i^c a_{it}^F + \varepsilon_i^c a_{it}^E + \varepsilon_i^r a_{it}^{RES})$$

$$+\sum_{i=1}^{N+1} \sum_{a=1}^{A_i} \sum_{j=1}^{J_i} \delta_{ij}^S S_{iajt}^S + \delta^{LF} S_t^{LF}$$

EOM for atmospheric C

Growth in agriculture

Emissions crop and residue use

$$S_{t+1}^{ATM} = (1-\delta^{ATM})S_t^{ATM}$$

$$+\varepsilon^f f_t + \varepsilon^z z_t + \varepsilon^v \sum_{i=1}^{N} v_{it} x_{i1t}$$

$$-\varepsilon^w G_t^W + \varepsilon^w [w_t^P + (1-\alpha) w_t^L + w_t^E + w_t^{RES} + w_t^{HWP}]$$

$$-\sum_{i=1}^{N} (\varepsilon_i^c G_{it}^C + \varepsilon_i^r G_{it}^R) + \sum_{i=1}^{N} (\varepsilon_i^c a_{it}^F + \varepsilon_i^c a_{it}^E + \varepsilon_i^r a_{it}^{RES})$$

FOOD AND ENERGY CROPS, RESIDUES

$$+\sum_{i=1}^{N+1} \sum_{a=1}^{A_i} \sum_{j=1}^{J_i} \delta_{ij}^S S_{iajt}^S + \delta^{LF} S_t^{LF}$$

EOM for atmospheric C

$$S_{t+1}^{ATM} = (1-\delta^{ATM})S_t^{ATM}$$

$$+\varepsilon^f f_t + \varepsilon^z z_t + \varepsilon^v \sum_{i=1}^{N} v_{it} x_{i1t}$$

$$-\varepsilon^w G_t^W + \varepsilon^w [w_t^P + (1-\alpha) w_t^L + w_t^E + w_t^{RES} + w_t^{HWP}]$$

$$-\sum_{i=1}^{N} (\varepsilon_i^c G_{it}^C + \varepsilon_i^r G_{it}^R) + \sum_{i=1}^{N} (\varepsilon_i^c a_{it}^F + \varepsilon_i^c a_{it}^E + \varepsilon_i^r a_{it}^{RES})$$

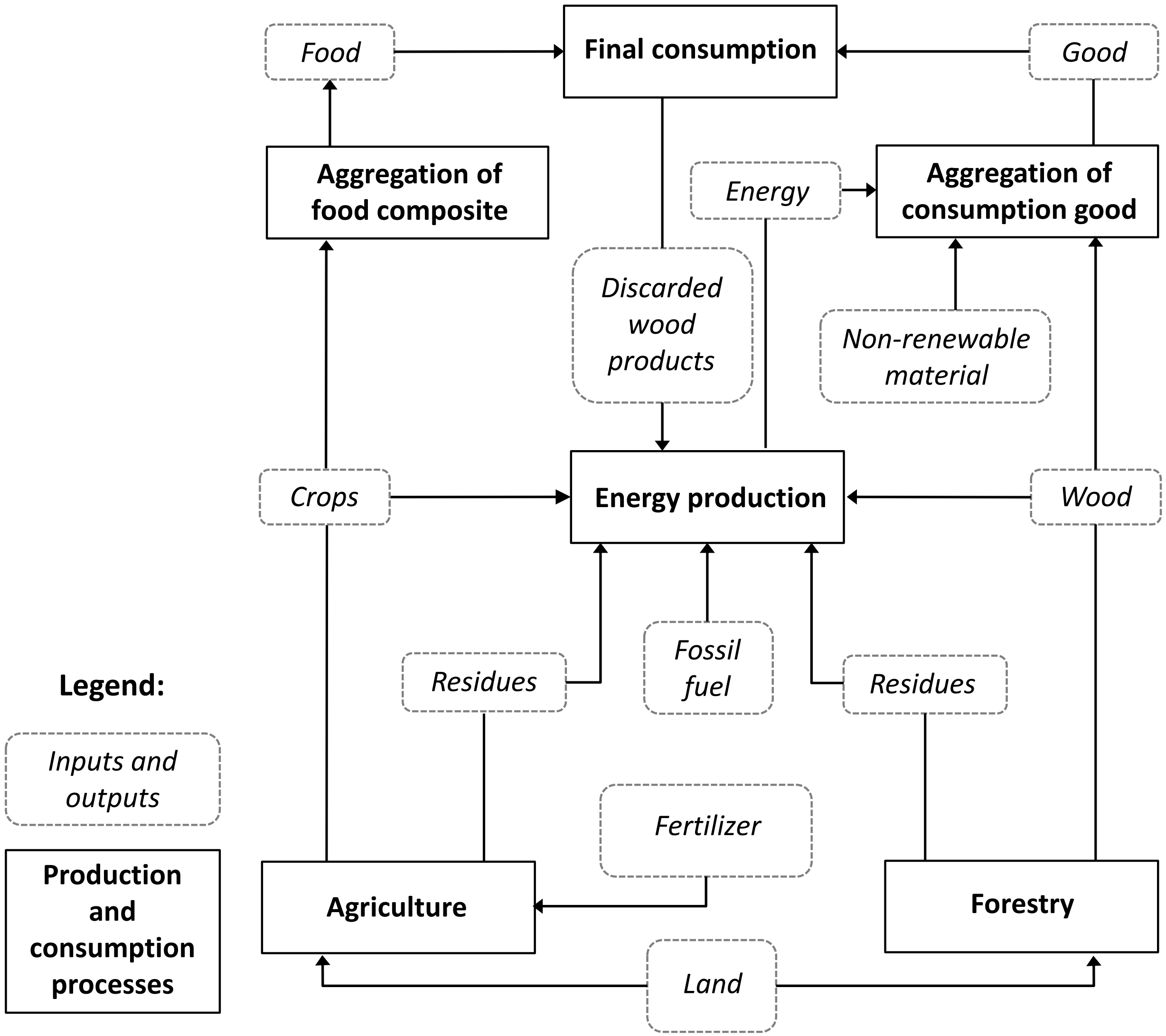
$$+\sum_{i=1}^{N+1} \sum_{a=1}^{A_i} \sum_{j=1}^{J_i} \delta_{ij}^S S_{iajt}^S + \delta^{LF} S_t^{LF}$$

Soil carbon emissions by

- *Land use class*
- *Age class*
- *Decay class*

Landfill emissions *(discarded HWP)*

The Economy


Food
Final consumption
Good
Aggregation of food composite
Energy
Aggregation of consumption good
Discarded wood products
Non-renewable material
Crops
Energy production
Wood
Legend:
Residues
Fossil fuel
Residues
Inputs and outputs
Fertilizer
Production and consumption processes
Agriculture
Forestry
Land

Objective function

Periodic Social Welfare

$$\max_{\{\mathbf{d}_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t [u_F(y_t^F) + u_C(y_t^C) - D(S_t^{ATM}) - C_t],$$

Utility from food

Utility from good

Disutility from atmospheric C

Total costs

Contains substitution between energy, non-renewable and renewable materials

Simplified form! Could be made more complex.

Contains:
Cost of fossil fuels,
Nonrenewable materials,
Agriculture,
Forestry,
Land use conversions
HWP collection
Landfilling

Capture the substitution between food and other consumption

$$\mathbf{d}_t = \left\{ \begin{matrix} z_t, f_t, v_{it}, \mathbf{a}_\mathrm{t}^\mathbf{F}, \mathbf{a}_\mathrm{t}^\mathbf{E}, \mathbf{a}_\mathrm{t}^\mathbf{RES}, w_t^L, w_t^P, w_t^E, w_t^{FRES}, w_t^{CRES}, w_t^{HWP}, \boldsymbol{\theta}_\mathrm{t}, x_{N+1,0,t}, \mathbf{x}_\mathrm{t+1}, \mathbf{s}_\mathrm{jkt}, \\ \mathbf{S}_\mathrm{t}^\mathrm{AR}, S_t^{FT}, S_t^{CT}, \mathbf{S}_\mathrm{iaj,t+1}^\mathrm{S}, S_{t+1}^{ATM}, S_{t+1}^{HWP}, S_{t+1}^{LF} \end{matrix} \right\}$$

Objective function

Periodic Social Welfare

$$\max_{\{\mathbf{d}_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t [u_F(y_t^F) + u_C(y_t^C) - D(S_t^{ATM}) - C_t],$$

Summed over infinite time horizon

Discounted

$$\mathbf{d}_t = \begin{Bmatrix} z_t, f_t, v_{it}, \mathbf{a}_t^{\mathbf{F}}, \mathbf{a}_t^{\mathbf{E}}, \mathbf{a}_t^{\mathbf{RES}}, w_t^L, w_t^P, w_t^E, w_t^{FRES}, w_t^{CRES}, w_t^{HWP}, \boldsymbol{\theta}_t, x_{N+1,0,t}, \mathbf{x}_{t+1}, \mathbf{s}_{jkt}, \\ \mathbf{S}_t^{AR}, S_t^{FT}, S_t^{CT}, \mathbf{S}_{iaj,t+1}^{S}, S_{t+1}^{ATM}, S_{t+1}^{HWP}, S_{t+1}^{LF} \end{Bmatrix}$$

Objective function

Vector of choice variables

$$\max_{\{\mathbf{d}_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t [u_F(y_t^F) + u_C(y_t^C) - D(S_t^{ATM}) - C_t],$$

Non-ren. materials
Fossil fuels
Fertilizer

Food crops
Energy crops
Residues

Harvests (logs, pulp, energy)
Harvesting residues (coarse, fine)
Collected discarded HWP

Clear-cuts
(By age class / as total area)

Land allocation
Land conversions

$$\mathbf{d}_t = \left\{ \begin{array}{c} z_t, f_t, v_{it}, \mathbf{a}_t^{\mathrm{F}}, \mathbf{a}_t^{\mathrm{E}}, \mathbf{a}_t^{\mathrm{RES}}, w_t^L, w_t^P, w_t^E, w_t^{FRES}, w_t^{CRES}, w_t^{HWP}, \boldsymbol{\theta}_t, x_{N+1,0,t}, \mathbf{x}_{t+1}, \mathbf{s}_{jkt}, \\ \mathbf{S}_t^{\mathrm{AR}}, S_t^{FT}, S_t^{CT}, \mathbf{S}_{\mathrm{iaj,t+1}}^{\mathrm{S}}, S_{t+1}^{ATM}, S_{t+1}^{HWP}, S_{t+1}^{LF} \end{array} \right\}$$

C stocks (Soils, Atmosphere, HWP, Landfills)

What we can derive from this:

- Optimality conditions:
  – Optimal land allocation and conversions
  – Optimal harvesting rule for forests
  – **Optimal biomass allocation conditions**
    - …which include the valuation of the carbon impacts

→ Our focus in this presentation

II
Policy recommendations

Social Cost of Carbon (SCC)

- First, we derive SCC_t for each period
  - It is the discounted damage from emitting a unit of C into the atmosphere (in period *t*), summed over the infinite time horizon.
  - It can be interpreted as ”the periodic carbon price”.
- Then, we show how the social cost of burning or using different varieties of biomass can be expressed relative to SCC
  - We obtain optimal taxes on biomass use

Social Cost of Carbon

- Assuming time-invariant decay:

$$SCC_t = \lambda_t^{S^{ATM}} = \sum_{i=1}^{\infty} \underbrace{\beta^i}_{\text{Discounting}} \underbrace{(1-\delta^{ATM})^{i-1}}_{\text{Decay}} \underbrace{D'(S_{t+i}^{ATM})}_{\text{Damage}}$$

Decay

Damage

Discounting

METLA

Social Cost of Carbon

- Assuming time-invariant decay:

$$SCC_t = \lambda_t^{S^{ATM}} = \sum_{i=1}^{\infty} \beta^i (1 - \delta^{ATM})^{i-1} D'(S_{t+i}^{ATM})$$

Time-invariant decay

- Assuming time-variant decay:

$$SCC_t = \sum_{i=1}^{\infty} \beta^i \mu_{t+i} D'(S_{t+i}^{ATM})$$

where

$$\mu_{t+i} = \begin{cases} 1 & when\ i = 1 \\ \prod_{j_t=1}^{i-1} \left(1 - \delta_{j_t}^{ATM}\right) & when\ i \geq 2 \end{cases}$$

Time-variant decay

Social Cost of Carbon

- Assuming time-invariant decay:

$$SCC_t = \lambda_t^{S^{ATM}} = \sum_{i=1}^{\infty} \beta^i (1-\delta^{ATM})^{i-1} D'(S_{t+i}^{ATM})$$

- Assuming time-variant decay:

$$SCC_t = \sum_{i=1}^{\infty} \beta^i \mu_{t+i} D'(S_{t+i}^{ATM})$$

where

$$\mu_{t+i} = \begin{cases} 1 & when\ i = 1 \\ \prod_{j_t=1}^{i-1} \left(1-\delta_{j_t}^{ATM}\right) & when\ i \geq 2 \end{cases}$$

How does SCC compare with GWP?

	Global Warming Potential*	Social Cost of Carbon
Time horizon	**Finite** (Fixed to e.g. 20 or 100 years)	**Infinite**
Damage indicated by	**Warming effect**, i.e. the time-integrated radiative forcing caused by an instantaneous release of CO_2	**Damage function** indicating the disutility caused by atmospheric CO_2 and its warming effect
Time preference indicated by	**Time horizon** Short time horizon → short-term impacts emphasized Long horizon → long-term impacts emphasized	**Discount rate** A high discount rate → short-term impacts emphasized A low discount rate → long-term impacts emphasized

** The treatment of CO_2 in the calculation of GWP for other GHGs*

Deriving optimal taxes Background: Temporary C stocks

- The C stocks
  - Soils
  - Products
  - Landfills
- Carbon is released gradually
  - The carbon releases are harmful
    - They are valued at the current SCC when they occur
    - The social costs are discounted to present value…
    - …and summed over the infinite time horizon.

Deriving optimal taxes: Assumptions

- Assumptions:
  - Fluxes are accounted as they occur
    - or at least treated ”as if”
    - As noted on the previous slide: Emissions of from temporary stocks are valued at the current SCC (when the occur), discounted to present value and summed over the infinite time horizon
  - The regulations directly target the actions that cause the emissions
    - Optimal tax on a given action =

      \+ The Social cost of C releases due to the taken given action

      \- The Social cost C release without taking the given action (i.e. the opportunity cost)

Optimal taxes on actions

Fossil fuel burning	$SCC_t^{ATM}\varepsilon^f$
Burning logs	$\left(SCC_t^{ATM} - SCC_t^{DOM_C}\right)\varepsilon^w$
Logs as raw material	$\left\{\left[(1-\alpha)SCC_t^{ATM} + \alpha SCC_t^{HWP}\right] - SCC_t^{DOM_C}\right\}\varepsilon^w$
Energy wood	$\left(SCC_t^{ATM} - SCC_t^{DOM_C}\right)\varepsilon^w$
Residues	$\left(SCC_t^{ATM} - SCC_t^{DOM_k}\right)\varepsilon^w$ $\quad k = F \text{ or } C$
Burning HWP	$(SCC_t^{ATM} - SCC_t^{LF})\varepsilon^w$
Burning food/energy crop	$\left(SCC_t^{ATM} - SCC_t^{DOM_i}\right)\varepsilon_i^c$
Burning residues	$\left(SCC_t^{ATM} - SCC_t^{DOM_i}\right)\varepsilon_i^r$

Effective emission factors

- Example: *Residues*

$$\left(SCC_t^{ATM} - SCC_t^{DOM_i}\right)\varepsilon^w = \left(1 - \frac{SCC_t^{DOM_i}}{SCC_t^{ATM}}\right)\varepsilon^w \times SCC_t^{ATM}$$

Effective Emission Factor (EEF)

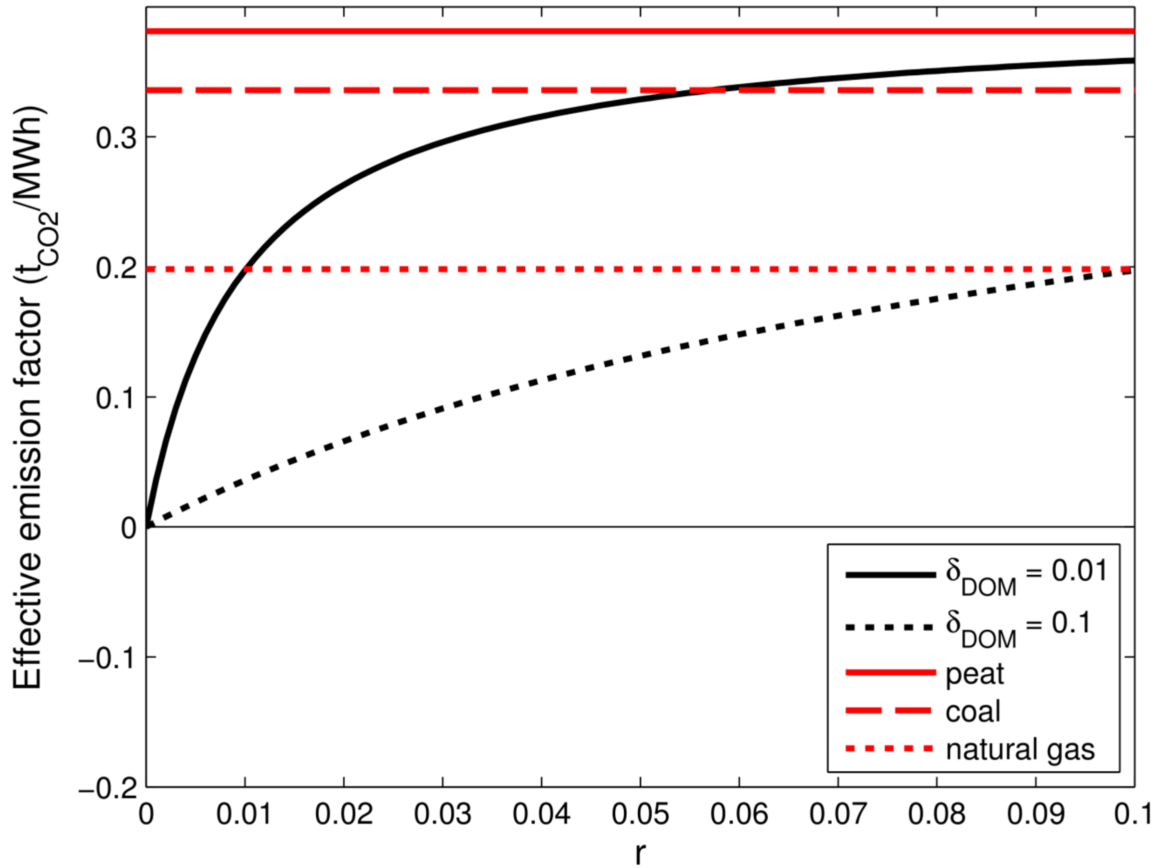
”Carbon price”

Emissions from harvest residues

EEF:

$$\left(1 - \frac{SCC_t^{DOM_i}}{SCC_t^{ATM}}\right)\varepsilon^w$$

Time-invariant SCC



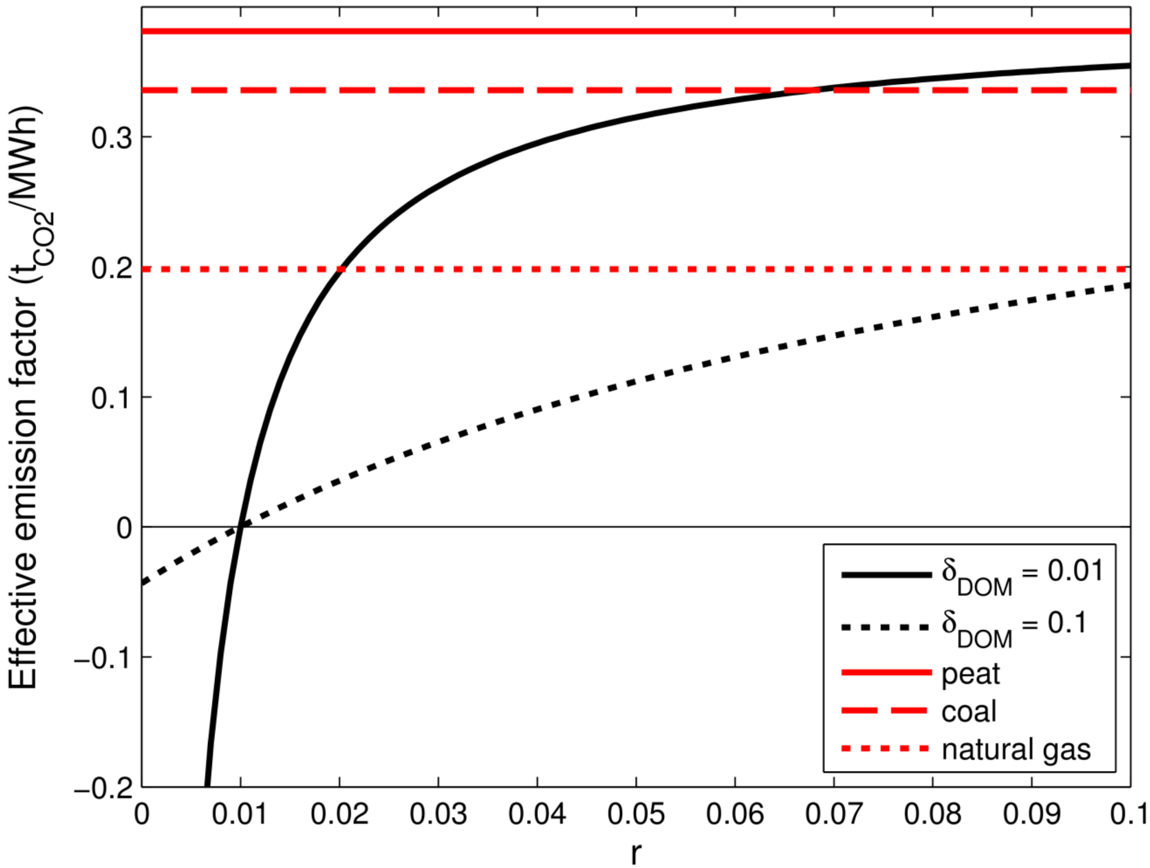
”Long horizon” ”Short horizon”

Emissions from harvest residues

EEF:

$$\left(1 - \frac{SCC_t^{DOM_i}}{SCC_t^{ATM}}\right)\varepsilon^w$$

SCC increases 1% per period



”Long horizon” ”Short horizon”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osaaminen
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Kiitos