

Finnish Forest and Energy Policy Model

FinFEP

An overview

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Aim

- To build a model for policy analysis
- Use the model in questions related to forest and energy industries as well as to forest owners decision-making
 - Renewable energy policies
 - Climate policies
 - Carbon sequestration
 - Structural change in forest industries

What we need

- Applicability for several policy instruments
- Intertemporal optimization of the use of forest resources (including thinning management)
- Description of forest and energy industries and their markets
- Model for technological change
- Modeling of optimal investments on new production capacity

Basic structure

- Partial equilibrium
- Several agents (mainly a plant level approach)
- Multiple markets:
 - Endogenous supply of wood
 - Endogenous demand of intermediate goods
 - Exogenous demand of final goods
- Model formulated as a mixed complementarity problem (MCP)

MCP (1): Definition

- Defined through a function and a box

$$f : \Omega \rightarrow \mathbb{R}^n \quad B = [l, u]$$

- MCP: find vector $\mathbf{x} \in B$
s.t. $(\mathbf{x} - l)' f_+(\mathbf{x}) = 0$
 $(u - \mathbf{x})' f_-(\mathbf{x}) = 0$

where

$$f_{+i}(\mathbf{x}) = \max\{0, f_i(\mathbf{x})\}$$
$$f_{-i}(\mathbf{x}) = -\min\{0, f_i(\mathbf{x})\}$$

- Every function has a complementary variable

MCP (2): In action

- First order conditions (maximization)

$$f(\mathbf{x}) = -\pi_i(\mathbf{x}) \quad x_i \in [l_i, u_i]$$

- Inequality constraints

$$g_j(\mathbf{x}) \geq 0 \quad \lambda_j \geq 0$$

- Equality constraints

$$g_j(\mathbf{x}) = 0 \quad \lambda_j \in \square$$

Forest industry (1): Basics

- Industry uses:
 - Wood: Logs, pulpwood, logging residue, bark, sawdust, chips etc.
 - Energy: Both power and heat
- Industry generates:
 - Wooden by-products: Bark, sawdust, chips
 - Energy: Both power and heat
 - Final goods: Pulp, paper or sawn goods
- Integrates have various ways to utilize wood

Forest industry (2): Profits

- Wood processing: Nested Leontieff and perfect substitute production functions
- Separation of costs of pre-optimized endogenous and other inputs

$$\begin{aligned}
 \max_{\{y, Z, X, V, I\}} \pi(y, Z, X, V, I) = & \\
 \sum_{m \in FP} \left(p_m - \sum_{i \in I_m} p_i a_i^m \right) y_m + \sum_{i \in R} \left\{ (z_i^S - z_i^B) p_i - c_i^{trans}(z_i^B) \right\} & \\
 + \sum_{i \in IM \cup E} \left\{ (p_i - c_i^S) x_i^S - (p_i + c_i^B) x_i^B - \sum_{j \in R_i} \alpha_j^i z_j^i \sum_{k \in I_i} p_k a_{kj}^i \right\} & \\
 - \sum_{s \in BT} \left\{ c_s(v_s) + \sum_{f \in F_s} p^{ec} \varepsilon_f v_{fs} \right\} - \sum_{i \in FP \cap IM \cap BT} c_i^I(I_i) &
 \end{aligned}$$

Forest industry (3): Constraints

Raw material and by-products

$$z_{w\tau}^B + \sum_{i \in IM \cup FP} \sum_{w' \in WT} \gamma_{ww'}^i z_{w'\tau}^i - z_{w\tau}^S - \sum_{i \in IM} z_{w\tau}^i - (\rho_w^E)^{-1} \sum_{i \in BT} v_{w\tau}^i \geq 0$$

Intermediate goods

$$x_{i\tau}^B + \sum_{w \in WT} \alpha_{w\tau}^i z_{w\tau}^i - \sum_{m \in M} a_i^m y_{m\tau}^m - x_{i\tau}^S \geq 0$$

Energy

$$x_{el,\tau}^B + \sum_{s \in BT} \eta_{el}^s \sum_{f \in F_s} v_{f\tau}^s - x_{el,\tau}^S - \sum_{m \in FP} a_{el}^m y_{m\tau}^m - \sum_{i \in IM} \sum_{j \in R} a_{el,j} \alpha_j^i z_{j\tau}^i \geq 0$$

$$x_{heat,\tau}^B + \sum_{s \in BT} \eta_{heat}^s \sum_{f \in F_s} v_{f\tau}^s + \sum_{j \in R} \sum_{i \in A} \gamma_{heat,ij} \alpha_j^i z_{j\tau}^i - x_{heat,\tau}^S - \sum_{m \in FP} a_{heat}^m y_{m\tau}^m - \sum_{i \in IM} \sum_{j \in R} a_{heat,j} \alpha_j^i z_{j\tau}^i \geq 0$$

Capacity constraints

$$K_m + I_m - y_{m\tau} \geq 0$$

$$K_i + I_i - \sum_{j \in R} \alpha_j^i z_{j\tau}^i \geq 0$$

$$K_s + I_s - \sum_{f \in F_s} v_{fs\tau} \geq 0$$

Energy sector (1)

- We focus on power markets and district heating
- Key points in Finland
 - Combined Heat and Power production (CHP)
 - Renewable energy from forest biomass
 - Co-firing of biomass with fossil fuels
 - Export/import - NordPool

Energy sector (2): Co-firing

- Plant-level presentation is contained in industry problem
- Linear energy transformation

$$\sum_{s \in BT} \eta_{el}^s \sum_{f \in F_s} v_{f\tau}^s - x_{el,\tau}^s \geq 0$$

$$\sum_{s \in BT} \eta_{heat}^s \sum_{f \in F_s} v_{f\tau}^s - x_{heat,\tau}^s \geq 0$$

- Convex co-firing costs term
- Convex transportation costs term

$$C_{\tau}(\mathbf{v}_{\tau}) = \sum_{f \in F} \left(w_f + \frac{2}{3} t_f v_{f\tau}^{1/2} + \varepsilon_f \right) v_{f\tau} + \left(\frac{\sum_{f' \in F_{bio}} v_{f'\tau}}{\sum_{f \in F} v_{f\tau}} - \sigma_{bio} \right)^2 c^{co} \sum_{f \in F} v_{f\tau}$$

Energy sector (3): Other power plants

- Plants of lesser interest are aggregated
- Aggregation is done via efficiency coefficients

$$\Pi_{\tau}^{AGG}(\mathbf{v}_{\tau}) = \sum_{i \in Y} p_{i\tau}^{eff}(\mathbf{v}_{\tau}) \int_0^{\sum_{f \in F} v_{f\tau}} \eta_i(x) dx - C_{\tau}(\mathbf{v}_{\tau})$$

- Merit order assumption \leftrightarrow decreasing η
- Uniform distribution of eff. coef. \leftrightarrow linear FOC
- Technical restrictions in CHP

- Output generated $q_i(v) = \int_0^v \eta_i(x) dx$

Energy sector (4): CHP & district heating

- Previous equations allow for CHP
- Industrial CHP is easy: demand for heat is based on industrial process
- District heating is more difficult:
 - Producer is typically a monopoly
 - Price of district heat is strictly regulated
 - Demand and production are highly local
- Solution this far:
 - Specification for regional district heat demand which has a price ceiling; Producers are price takers

Timber supply: Two-Step method

- Representative forest owners
- Amenity valuation
- Age-structured forests
- Infinite time horizon

- Allowed management actions
 - Thinning
 - Final harvests

- Timber supply in two-step
 1. Stand-level optimization
 2. Aggregation

Step One: Stand-level optimization I

- Dynamics of the stand

- Transient thinning &

- Growth

$$\tilde{n}_a = (1 - |\theta_a|)n_a$$

$$\tilde{v}_a = (1 + \sigma_a \theta_a)v_a$$

$$n'_1 = \bar{n}_1$$

$$v'_1 = \bar{v}_1$$

$$\sigma'_1 = \bar{\sigma}_1$$

$$n'_{a+1} = s(\tilde{n}_a, \tilde{v}_a)\tilde{n}_a$$

$$v'_{a+1} = G(\tilde{n}_a, \tilde{v}_a)\tilde{v}_a$$

$$\sigma'_{a+1} = f(\sigma_a, \theta_a)\sigma_a$$

- Discrete time, continuous state problem:

Maximize present value of

harvest profits and amenity flows

thin: $\left\{ (P_t(v_t) - c_t) \left(1 - (1 - \theta_t^T) \sigma_t \right) v_t n_t x_t \mid \theta_t^T \mid + A_t - F_\theta I(\mid \theta_t^T \mid > 0) \right\}$

clearcut: $\left\{ (P_T(v_T) v_T n_T - F_\gamma) x_T \right\}$

Step One: Stand-level optimization II

- Backward induction
- Discrete state approximation

- Constant price: Faustmann-Hartman
 - Given rotation length, optimize management
 - Find optimal rotation length (maximum LEV)

- Variable price: Bellman equation
 - Iterative procedure
 - Rotation length is a random variable

Step Two: Aggregation

- Aggregate stand-level:
 - Decision rules
 - Harvest simulations
- Use generated data to estimate
 - Thinning function $\theta_a(\mathbf{p}, \mathbf{z}^\theta)$
 - Clear-cut function $\gamma_a(\mathbf{p}, \mathbf{z}^\gamma)$

- Dynamics of age-class distribution

$$x'_1 = \sum_{a \in A} \gamma_a x_a$$

$$x'_{a+1} = (1 - \gamma_a) x_a$$

- Harvests

$$H_{it}(\mathbf{p}_t) = \sum_s \sum_a \left[\left((1 - (1 - \theta_{isa}(\mathbf{p}_t, \mathbf{z}_t^\theta)) \sigma_{isat}) n_{isat} v_{isat} x_{isat} \mid \theta_{isa}(\mathbf{p}_t, \mathbf{z}_t^\theta) \mid + n_{isat} v_{isat} x_{isat} \gamma_{isa}(\mathbf{p}_t, \mathbf{z}_t^\gamma) \right) \right]$$

Investments

- Size of an unit
 - Production capacity of new plants
 - Capacity increases of old plants
- Number of new plants
- Optimal timing
- Aggregate investment costs that represent economy level limitation of resources

Technological change

- Technologies that we model are under development
- Partial equilibrium and national scope
- Exogenous:
 - Market entry of a technology
 - Time dependency of costs (partly)
- Endogenous (learning by doing):
 - Operation costs
 - Investment costs (partly)

Current work

- Forest owner's problem:
 - Optimization procedure
 - Estimation methods

- Industries' problem:
 - Investments
 - Technological change
 - Exogenous demand of final goods

Kiitos!

APPENDIX

Policies

- RES-E policy instruments:

1) Feed-in tariff (FIT)

- Co-firing power plant

$$p_{el,\tau t}^{eff}(\mathbf{v}) = p_{el,\tau t} + \frac{\sum_{f' \in F_{bio}} v_{f'\tau t}}{\sum_{f \in F} v_{f\tau t}} \max\{0, p_{fit,t} - p_{el,\tau t}\}$$

- Wind power plant

$$p_{el,\tau t}^{eff}(\mathbf{v}) = p_{el,\tau t} + \max\{0, p_{fit,t} - p_{el,\tau t}\}$$

2) Renewables subsidy (s)

- Co-firing power plant

$$p_{el,\tau t}^{eff}(\mathbf{v}) = p_{el,\tau t} + \frac{\sum_{f' \in F_{bio}} v_{f'\tau t}}{\sum_{f \in F} v_{f\tau t}} s_t$$

- Wind power plant

$$p_{el,\tau t}^{eff}(\mathbf{v}) = p_{el,\tau t} + s_t$$

Co-firing power plants

- Co-firing costs:
 - Technically optimal biomass ratio σ_{bio}
 - FBC: positive; PF: zero
 - Assumed to be quadratic around technical optimum
- Substitutability of fuels varies with biomass ratio

$$C^{co} \left(\frac{v_{bio,\tau t}}{\sum_{f \in F} v_{f\tau t}} - \sigma_{bio} \right)^2 \sum_{f \in F} v_{f\tau t}$$

Efficiency aggregation

- Efficiency function: $\eta_i(X)$
 - Represents efficiency coefficients of the aggregate
 - Locus approximated by a differentiable function
 - Merit order assumption: decreasing in X

- Investments:
 - Specific technology (constant efficiency)