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
- The model includes four different sectors; energy production, the pulp- and paper industry, the sawmilling and board industries and forest owners behavior
- 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) using PATH solver in GAMS modeling system

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

$$\max_{\{\mathbf{y},Z,X,V,\mathbf{I}\}} \pi\left(\mathbf{y},Z,X,V,\mathbf{I}\right)=$$

$$\sum_{m\in FP}\left(p_m-\sum_{i\in I_m}p_i a_i^m\right)y_m+\sum_{i\in R}\left\{\left(z_i^S-z_i^B\right)p_i-c_i^{trans}\left(z_i^B\right)\right\}$$

$$+\sum_{i\in IM\bigcup E}\left\{\left(p_i-c_i^S\right)x_i^S-\left(p_i+c_i^B\right)x_i^B-\sum_{j\in R_i}\alpha_j^i z_j^i\sum_{k\in I_i}p_k a_{kj}^i\right\}$$

$$-\sum_{s\in BT}\left\{c_s(\mathbf{v}_s)+\sum_{f\in F_s}p^{ec}\varepsilon_f v_{fs}\right\}-\sum_{i\in FP\bigcap IM\bigcap BT}c_i^I(I_i)$$

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

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

Energy

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

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

Capacity constraints

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

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

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

Transport costs (1)

- An amount of wood *x* needs to be collected, satisfying
  $$D\pi r(x)^2 = x$$
- Thus, maximum range of wood collection is
  $$r(x) = \left(\frac{x}{\pi D}\right)^{1/2}$$
- Marginal costs of wood transportation is
  $$c_x(x) = ac_1 r(x) = ac_1 \left(\frac{x}{\pi D}\right)^{1/2}$$
- Transportation costs accumulate as wood is used:
  $$c(x) = \frac{ac_1}{\sqrt{\pi D}} \int_0^x \sqrt{x'}\,dx' = \frac{2}{3} \frac{ac_1}{\sqrt{\pi D}} x^{3/2}$$

Transport costs (2)

- This yields us regional dependent transport coefficient

$$t = \frac{ac_1}{\sqrt{\pi D}}$$

- The transportation costs are then

$$c(\boldsymbol{x}) = \frac{2}{3} t \left(\sum_{\tau \in T} x_\tau \right)^{3/2}$$

- The marginal costs are

$$\frac{\partial c(\boldsymbol{x})}{\partial x_\tau} = t \left(\sum_{\tau \in T} x_\tau \right)^{1/2}$$

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

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

Energy sector (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

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

- Combining to sectors with each other
- Forest owner's problem:
  - Optimization procedure
  - Estimation methods
- Industries' problem:
  - Investments
  - Technological change
  - Exogenous demand of final goods

Thanks !

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

$\longrightarrow$ 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)