EnergyVille

Limitations of optimization models for long-term planning - representing market designs, policy interventions and agent behavior

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Long-term energy-system or power-system optimization models: two perspectives

- E.g., MARKAL/TIMES, ReEDS, etc.

- Social perspective:
  - Normative/prescriptive
  - Maximize welfare/minimize cost

- Private agents' perspective
  - Descriptive
  - Maximize total surplus/minimize cost
  - Market equilibrium

Research question

What are the limitations of optimization models in representing the market equilibrium?

- Policy interventions
- Market designs
- Agent behavior

Optimization models - what càn be done

Optimization Problem

$$\min_{cap_i, gen_{i,t}} \quad \sum_t \sum_i \left(cap_i FC_i + \sum_t (gen_{i,t} MC_i \Delta_t) \right)$$

$$s.t. \quad cap_i - gen_{i,t} \geq 0 \quad (\gamma_{i,t}) \quad \forall i, t$$

$$gen_{i,t} \geq 0 \quad \forall i, t$$

$$cap_i \geq 0 \quad \forall i$$

$$\sum_i gen_{i,t} \Delta_t = q_t \Delta_t \quad (p_t^{el}) \quad \forall t$$

KKT Conditions

$$p_t^{el} \Delta_t \leq MC_{i,t} \Delta_t + \gamma_{i,t} \quad \perp \quad gen_{i,t} \geq 0$$

→ Only generate electricity if the price for electricity covers variable costs

$$\sum_t (\gamma_{i,t}) \leq FC_i \quad \perp \quad cap_i \geq 0$$

→ Only invest if infra-marginal rents cover fixed costs

$$cap_i - gen_{i,t} \geq 0 \quad \perp \quad \gamma_{i,t} \geq 0$$

→ Infra-marginal rents can only be positive when generating at rated capacity

$$\sum_i gen_{i,t} \Delta_t = q_t \Delta_t$$

Optimization models - what càn be done

Optimization Problem

$$\min_{cap_i, gen_{i,t}} \sum_t \sum_i \left(cap_i FC_i + \sum_t (gen_{i,t} MC_i \Delta_t) - \sum_t (gen_{i,t} S_i \Delta_t) \right)$$

$$\begin{aligned}
s.t. \quad & cap_i - gen_{i,t} \geq 0 \quad (\gamma_{i,t}) \quad \forall i,t \\
& gen_{i,t} \geq 0 \quad \forall i,t \\
& cap_i \geq 0 \quad \forall i \\
& \sum_i gen_{i,t} \Delta_t = q_t \Delta_t \quad (p_t^{el}) \quad \forall t
\end{aligned}$$

KKT Conditions

$$p_t^{el} \Delta_t + S_i \Delta_t \leq MC_{i,t} \Delta_t + \gamma_{i,t} \quad \perp \quad gen_{i,t} \geq 0$$

$$\sum_t (\gamma_{i,t}) \leq FC_i \quad \perp \quad cap_i \geq 0$$

$$cap_i - gen_{i,t} \geq 0 \quad \perp \quad \gamma_{i,t} \geq 0$$

$$\sum_i gen_{i,t} \Delta_t = q_t \Delta_t$$

→ Only generate electricity if the price for electricity + feed-in premium covers variable costs

→ Only invest if infra-marginal rents cover fixed costs

→ Infra-marginal rents can only be positive when generating at rated capacity

Optimization models - what càn be done

Policy interventions

- RES support schemes: e.g., feed-in premium
- Carbon tax
- Technology acceptance
- Etc.

Market design/ imperfections

- Capacity payment, capacity market
- Emission trading markets, green certificate markets
- Non-level playing field: eligibility criteria, product definition, market access
- Incomplete markets: e.g., zonal pricing
- Etc.

Agent behavior

- Rational, perfect information (risk neutral), price-takers

Optimization models - what cannot be done

Policy interventions

- RES support schemes: e.g., feed-in tariff, minimum price for green certificates
- Grandfathering of emission allowances

Market design/ imperfections

- Net metering
- Average price contracts

Agent behavior

- Strategic behavior
- Risk-averse behavior
- Heterogeneous costs of capital (hurdle rate)

Duality

- Role of linking constraints in optimization models
  - Enforce physical/political constraints
  - Represent markets (dual variable reflects the price)

- Examples:
  - Supply-demand balance: $\sum_i gen_{i,t} = q_t \quad \left(p_t^{el}\right) \quad \forall t$

- Implication: no decoupling possible between the physical/political constraint and the corresponding market
  - All variables appearing in physical/political constraints valued according to the dual variable of that constraint (+ a constant)
  - Variables not appearing in a physical/political constraint cannot be valued according to the endogenously determined price

Optimization models - what cannot be done

Policy interventions

- RES support schemes: e.g., feed-in tariff, **minimum price for green certificates**
- Grandfathering of emission allowances

Market design/ imperfections

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Example: minimum price for green certificates

- Suppliers have obligation

- Generators can decide to sell their certificates:
  - To the market (suppliers): q_i^{SUP} @ p^{GC}
  - To the DSO: at guaranteed minimum price: q_i^{DSO} @ $P^{GC,DSO}$

- Issue: in an optimization model: every green certificate generated will be implicitly valued at the market price

$$\sum_i \sum_t (q_i^{DSO} + q_i^{SUP}) \geq D^{GC} \quad (p^{GC})$$

Alternative models

- Mixed Complementarity Problems (MCP)
  - + more flexible
  - - Computation time increases
- Parametrized optimization problems (iteratively solving optimization problems)
  - + Small barrier for implementation
  - - Computation time, convergence
- Dedicated solution techniques
  - + reduce computation time
  - - low flexibility

Optimization models – relevance of what cannot be done

Policy interventions

- RES support schemes: e.g., feed-in tariff, minimum price for green certificates
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Optimization models – relevance of what cannot be done

Policy interventions

- RES support schemes: e.g., feed-in tariff, minimum price for green certificates
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Agent behavior

- Strategic behavior
- **Risk-averse behavior**
- **Heterogeneous costs of capital (hurdle rate)**

Conclusions and further research

- Optimization models cannot distinguish between physical/political constraints and the corresponding markets
- Certain market designs, policy interventions and behavioral elements cannot be represented
- Particularly the impact of behavioral elements (heterogeneous cost of capital, risk averseness) deserves further attention in long-term optimization models