High taxes on cloudy days - Dynamic state-induced price components in power markets
ENERDAY 2018
Background and Motivation

- **Energy policy objectives**
  - cut emissions to 80-95% below 1990 levels by 2050 *(European Commission, 2011)*
  - expansion of power generation from renewable sources, especially variable renewables like wind and solar

- **Economic consequences**
  - decreasing utilisation of variable renewables
  - unchanged demand for thermal backup capacities

Dynamization of state-induced price components aims to address these adverse effects
Fundamental Idea of Dynamization

Example for dynamization based on German power market data

- In case of dynamization state-induced price components are set proportional to wholesale prices
Qualitative analysis

Low demand and high supply from VRE → low state-induced price components

<table>
<thead>
<tr>
<th>No Dynamization</th>
<th>Dynamization</th>
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<tbody>
<tr>
<td>Costs/ benefits</td>
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\[\text{Merit-order supply curve}\]
\[\text{Demand curve without state-induced price components}\]
\[\text{Demand curve with state-induced price components}\]

- **Advantages:** Curtailment is avoided and welfare losses are decreased
- **Disadvantages:** Increased thermal generation from mid-load plants
Qualitative analysis

High demand and low supply from VRE → high state-induced price components

No Dynamization

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<tr>
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<td>Welfare losses</td>
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Dynamization

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■ Advantages: Decreased demand for peak-load capacities

■ Disadvantages: Welfare losses increase
Quantitative analysis

Model of the power market incorporating effects of taxation

(Stylized) bilevel optimization problem

Decision Variables

\(sup_{g,t}\): Supply of generator \(g\) in time period \(t\)

\(dem_{c,t}\): Demand of consumer \(c\) in time period \(t\)

\(eeg_t\): level of levy to finance renewables in period \(t\)

\(cap_{g\in TH}\): Capacity of thermal technology \(g\)

Bilevel problem

\[
\max_{sup, dem, eeg} \sum_{c,t} (MU_{c,t} - eeg_t) \cdot dem_{c,t} - \sum_{g,t} MC_g \cdot sup_{g,t}
\]

s.t. balancing equation

technical constraints incl. storage, DSM, trade etc.

\[
\sum_{g\in RE} revenue_g + \sum_{c,t} eeg_t \cdot dem_{c,t} = 0
\]

\[
cap_g \in \text{argmin}_{g \in \text{Thermal}} \{revenue_g, revenue_g \geq 0\}
\]
Quantitative analysis

Model of the power market incorporating effects of taxation

(Stylized) bilevel optimization problem

**Decision Variables**

\[ \text{sup}_{g,t}: \text{Supply of generator } g \text{ in time period } t \]
\[ \text{dem}_{c,t}: \text{Demand of consumer } c \text{ in time period } t \]
\[ \text{ee}_{gt}: \text{level of levy to finance renewables in period } t \]
\[ \text{cap}_{g \in \text{TH}}: \text{Capacity of thermal technology } g \]

**Bilevel problem**

\[ \max_{\text{sup, dem, eeg}} \sum_{c,t} (M U_{c,t} - \text{ee}_{gt}) \times \text{dem}_{c,t} - \sum_{g,t} M C_{g} \times \text{sup}_{g,t} \]

s.t. balancing equation

technical constraints incl. storage, DSM, trade etc.

**Linear**

**Non-linear**

NP-hard

\[ \sum_{g \in \text{RE}} \text{revenue}_{g} + \sum_{c,t} \text{ee}_{gt} \times \text{dem}_{c,t} = 0 \]

\[ \text{cap}_{g} \in \text{argmin}_{g \in \text{Thermal}} \{ \text{revenue}_{g}, \text{revenue}_{g} \geq 0 \} \]
Quantitative analysis

Iteration algorithm to solve non-linear parts of the model

- Linear programming to simulate decisions on dispatch and consumption
- Iterative approach to simulate investment decisions

**Input**
- Characteristics of demand
- Thermal power plants

**Iterative process**
- EEG levy
- Max social welfare
  s.t. balancing equation and technical constraints

**Output**
- Nash equilibrium state
Quantitative analysis

Application of the model

■ Policy framework

≡ Energy-only-market and carbon price
≡ Scarcity pricing when demand reaches maximum supply capacity
≡ For dynamization this levy is adjusted proportionally to hourly wholesale prices

■ Parameterization

≡ Largely decarbonized German energy system in 2050 according to Gerhardt et al., 2015

■ Computed indicators

≡ Integration costs: costs incurred by VRE on a system level (Hirth, 2013)
≡ Decarbonisation costs: costs of avoiding greenhouse gas emissions
Results

Change in generation quantities at a carbon price of 100 €/tCO₂ and -0.05 own-price elasticity of demand

- Curtailment and generation from peak-load power plants is decreased
- Overall generation increases by 5.2 TWh and emissions might increase
Results

Impact for different carbon prices and own-price elasticities of demand

- Effects increase with the own-price elasticity of demand
- Effects on decarbonisation costs are highly dependent on the respective mid- and peak-load technologies
Results

Impact of coal phase-out

**Integration Costs**

Change of integration costs [€/MWh]

**Decarbonisation Costs**

Change of decarbonisation costs [€/tCO₂]

- Adverse effects on emissions from shift towards mid-load power plants is avoided, if coal power plants are phased out
Conclusion

■ Findings
  ≡ Dynamization generally supports the integration of variable RE into the energy system
  ≡ Dynamization supports the overarching target of decarbonisation given the right policy framework

■ Outlook
  ≡ Potential of dynamization to avoid grid congestions and optimize grid utilisation (Smart-Grid)
Thank you for your attention.

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Mechanics of the short-term market simulation

costs/ benefits

Social welfare

production quantity

price

VOLL

quantity

merit-order supply curve
demand curve without state-induced price components
demand curve with state-induced price components
import
export
production quantity

costs
benefits

Social welfare

Mechanics of the short-term market simulation
Residual demand represents the share of demand covered by thermal power plants.

At a Nash equilibrium the revenue of every technology takes the smallest non-negative value possible.
Import and Export in the Short-Term Model

- merit-order supply curve
- potential import of neighbouring country
- potential export of neighbouring country

price [€/MWh]

quantity [GW]