Dealing with uncertainty and disruptive events in generation expansion planning models

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Context – Generation Expansion Models

- **Central planner** perspective
  - Minimize NPV total system cost (LP)

- **Long-term** energy planning
  - Planning horizon spanning multiple decades

- **Bottom-up** approach
  - Energy system modeled from technology level
  - No macro-economic feedbacks included

- Cf. TIMES
Context – Impact of Uncertainty

- Screening curve methodology...
- Sensitivity analysis...

Graphs showing the relationship between installed capacity, natural gas price, and total annualized costs for different power generation technologies.
Context - Stochastic programming

- **Aim:** Decide on a single set of investments now, while facing uncertainty in the future.

- Minimize **expected** NPV of total system cost

- First stage investment decisions are the same for every scenario
Research Questions

- How do investment decisions based on stochastic programming perform in comparison to other investment decisions?

- Does the occurrence of an unexpected shock have an impact on investment decisions?

- In this presentation: gas price uncertainty based on historical data
Determine first-stage investments based on:

- Scenario tree – 10 scenarios (Stochastic programming)
- Average Scenario (Deterministic)
- Worst Case Scenario (Deterministic)
Results – Stochastic Investments

First-stage investment decisions are identical for every scenario in the scenario-tree.

Other investments are allowed to differ between the scenarios.
Results – Stochastic vs Deterministic Average Scenario
Results – Stochastic vs Worst Case
Results – Out-of-Sample Analysis

Comparing cost distribution of 200 generated scenarios
Gas price shocks do have an impact on optimal investments.

From which probability do these shocks influence a SP solution?
Results - Gas Price Shock

1%

6%

15%
Conclusions

- In presented model setting:
  - Value of stochastic solution is strongly dependent on benchmark.
  - Difference between investment decisions based on SP and DA are small.
  - Compared to worst case scenario, SP has value on average.

- Concerning unexpected shocks:
  - Impact of gas price shocks on stochastic solution are limited.
  - Need for rethinking scenario tree structure?
Results – Stochastic vs Perfect Foresight

- High probability scenario (p = 0.16)

- Investment decisions are very much alike
Results – Stochastic vs Perfect Foresight

- Low probability scenario \( (p = 0.014) \)

- Investment decisions are different.
Results – Out-of-Sample Analysis

- Cost distribution of 200 newly generated scenarios
- EVPI is positive
Methodology – Scenario Generation

Historical data (TTF Hub):

Scenario sampling

\[ P_t = P_{t-1} + \Delta P_{P_t} \]
Methodology – Scenario Generation

Example: 5 Scenarios ...
Methodology - Scenario Reduction

Select N scenarios from original set by minimizing the Kantorovich distance between the original set and reduced set of scenarios.
Methodology - Scenario Reduction

Select first scenario

$$\omega_1 = \arg\min_{\omega} \sum_{\omega \in \Omega} \pi_\omega c(\omega, \omega')$$

Select N-1 scenarios according to the Kantorovich distance:

Redistribute probabilities of not selected scenarios to the scenario that is most alike.
Methodology – Scenarios

Example - 10 selected scenarios
Methodology - Overview

- Historical Data
  - Scenario Generation
    - Scenario Reduction
  - Stochastic Optimization
    - Investment Decisions
  - Deterministic Optimization
    - Investment Decisions
  - Deterministic Average Optimization
    - Investment Decisions

Out-of-sample testing
Methodology - Overview

- Historical Data
- Scenario Generation
- Scenario Reduction
- Exogenous Scenarios

- Operational Optimization
- Gas Price Shock

- Stochastic Optimization

- Investment Decisions

- Investment Performance
Gas price uncertainty – In-sample stability

Compare objective values of scenario trees with increasing cardinality.
Gas price uncertainty – Out-of-sample stability

Test first stage investment decisions on a large set of generated scenarios.
Stochastic Programming – Model Settings

Temporal representation.

Reduced set of scenarios is averaged in accordance with temporal structure.