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Investment decisions in liberalized electricity markets considering capacity payments

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Outline

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Introduction

Motivation

- The sustainable and **high-quality supply of electric energy** is a key ingredient of every modern-day society

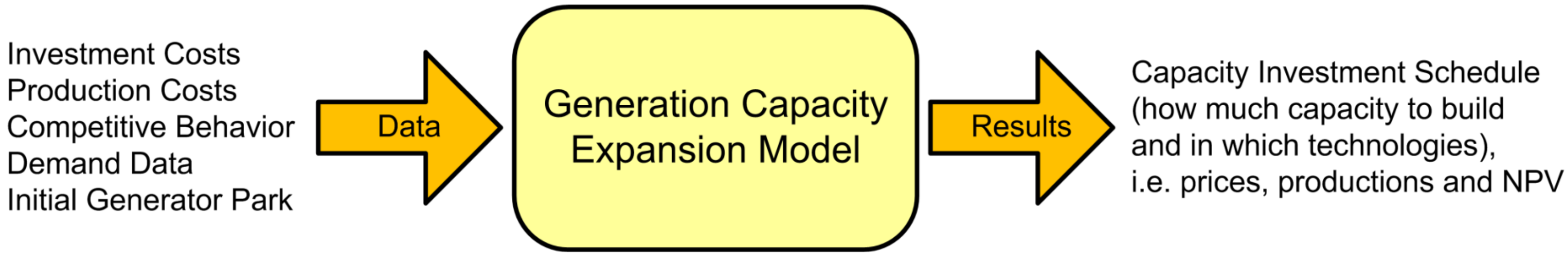
- The **liberalization** of electricity markets has made capacity expansion planning more challenging

- The supply of energy involves complex tasks, i.e. :
  - Network planning
  - Management of assets
  - **Long-term generation capacity expansion planning**

Tasks that arise when managing available generation assets and deciding upon the construction of new capacity depending on system and market requirements within a time horizon up to 40 years.

Literature Review (I)

Data & Results:



- Regulated systems
  - Optimization – Cost minimization (Dyner and Larsen, 2001)
  - Multicriteria decision methods (Merrill and Schweppe, 1984)

- **Liberalized systems**
  - Uncertainty emphasis: decision theory, risk management, scenario analysis, real options theory.
  - Market emphasis: **game theory**, system dynamics, multi-agent based simulation.

Literature Review (II) – Game theory

- <u>Simplification:</u> consider investment and production decision simultaneously (open loop, one-stage, one-shot models) leads to Mixed Complementary Problem **(MCP)** schemas (Ventosa et al, 2002)

- <u>Uncoupled investment and production decision</u>
  - More complex formulations (closed loop, two-stage, two-shot)
  - Mathematical Programming with Equilibrium Constraints **(MPEC)** for example if the decisions of a single agents are considered (Gabriel et al., 2010), (Hobbs et al., 2000), (Wogrin et al., 2011)
  - Consideration of every agent decisions as a superior equilibrium leads to a extremely complex formulation: Equilibrium Problem with Equilibrium Constraints **(EPEC)**. See (Ralph and Smeers, 2006), (Murphy and Smeers, 2005)
  - **Advantages**: more realistic (temporal separation of investment decisions and production decisions in the market)

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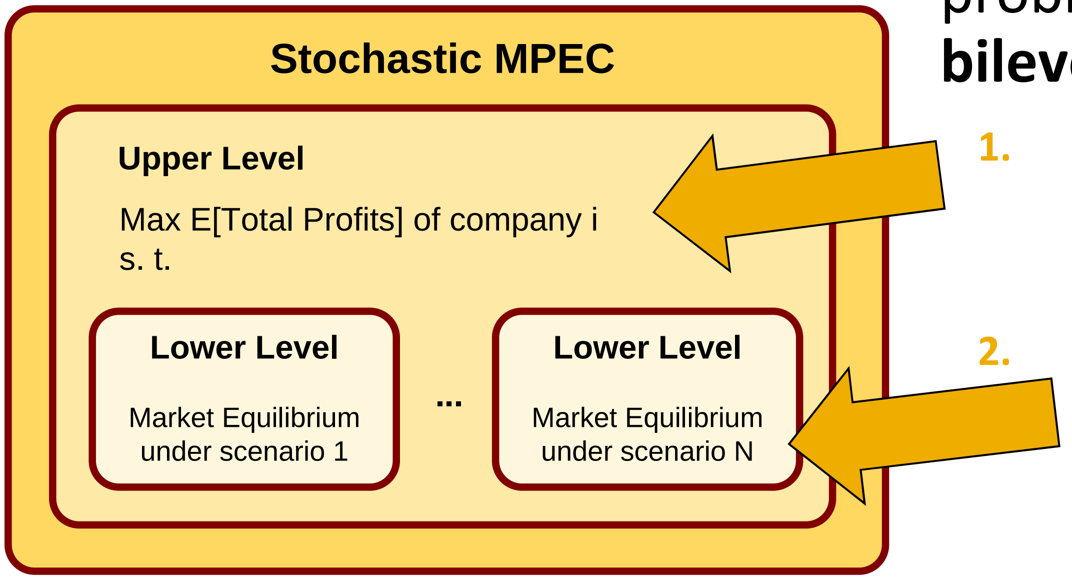
Model Description

Our approach

- We propose a **stochastic bilevel model** to analyze long-term decisions in **liberalized** frameworks and formulate it as a stochastic **MPEC** for one GenCo.
- Upper level corresponds to **profit maximization**
- The **electricity market** (lower level) is represented using **conjectured price responses** (includes Cournot, and perfect competition and different degrees of oligopoly as particular cases)
- If all GenCos face an MPEC at the same time, this leads us to an **EPEC**
- **Uncertainty in demand growth** is incorporated via different scenarios
- **Capacity payments** are considered

Bilevel Structure

- The generation capacity expansion problem has an innate **two-stage structure**
  1. **Investment decisions** are taken
  2. **Energy productions** in the market, which are limited by the previously decided capacity, are determined



- Hence generation capacity problem can be modeled as **bilevel** problem
  1. **Upper level** corresponds to maximization of **total profits** of a generation company (GenCo)
  2. **Lower level** corresponds to **market equilibrium**

Stochastic Bilevel Scheme – 1 GenCo

Stochastic MPEC

Upper Level

Max E[Total Profits] of company i
s. t.

Lower Level
Market Equilibrium under scenario 1

…

Lower Level
Market Equilibrium under scenario N

$$\max_{x_{ijy}} \sum_s W_s \Big\{ \sum_y \frac{1}{(1+F)^y} \Big[\sum_{jl} T_{yl}(p_{yls} - \delta_j) q_{ijyls} - \sum_j \beta_{ijy}(x_{ijy} - x_{ij(y-1)}) + \sum_j \gamma_j (x_{ijy} + K_{ijy}) \Big] + \mathrm{RV}_{is} \Big\}$$

Probability of scenario; Discount factor; Production cost; Investment cost; Capacity; Capacity Payment; Residual value

Market Equilibrium Model

Company 1
Max$_{\{q1\}}$ Market Profits$_1$
s. t. $0 <= q_1 <= x_1$

…

Company i
Max$_{\{qi\}}$ Market Profits$_i$
s. t. $0 <= q_i <= x_i$

…

Company $_I$
Max$_{\{qI\}}$ Market Profits$_I$
s. t. $0 <= q_I <= x_I$

$$d = s - \alpha p$$

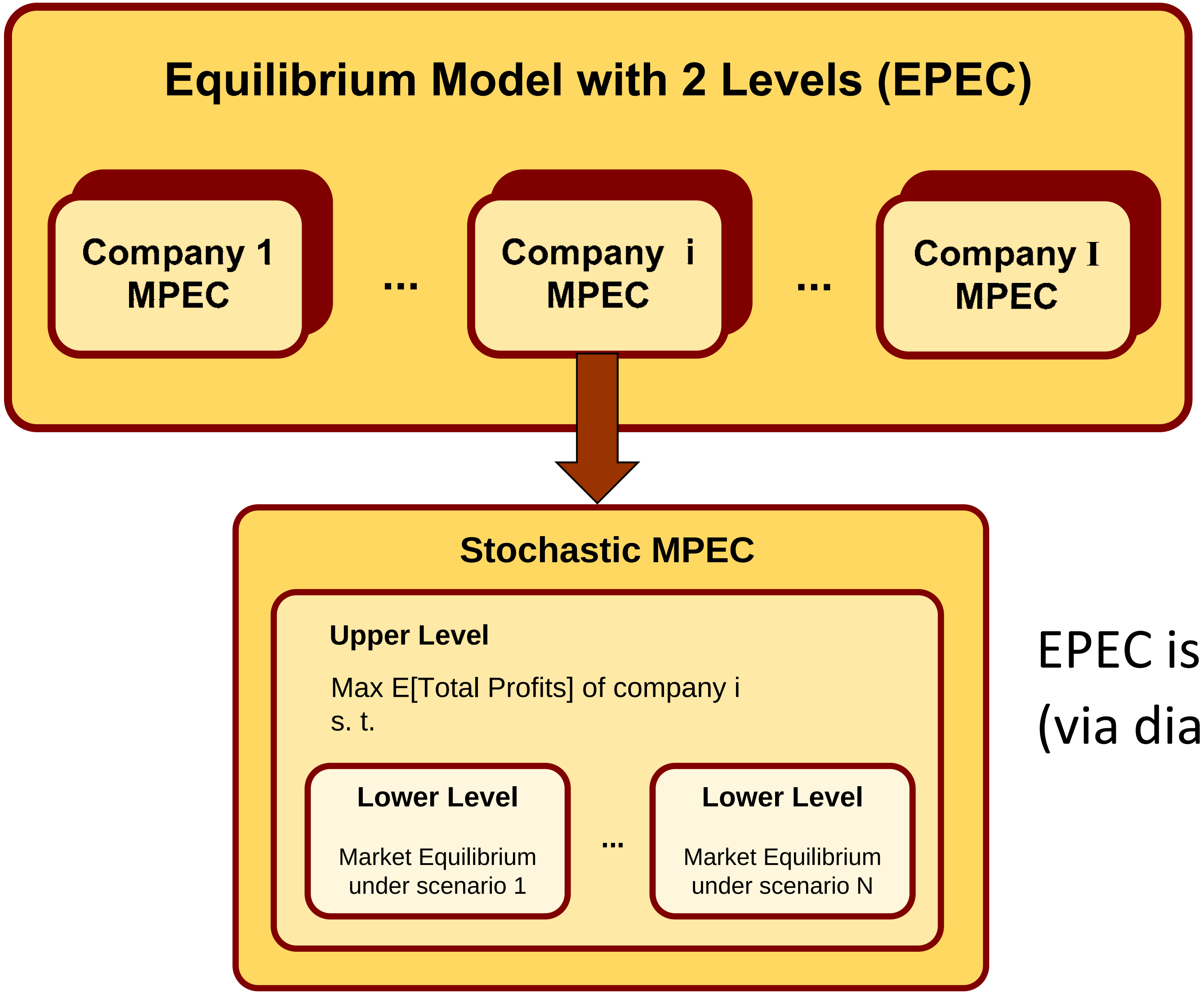
Demand intercept; Demand; Demand slope

Relation Price - Demand

$$\frac{\partial \pi_i}{\partial q_i} = p + q_i \frac{\partial p}{\partial q_i} - \frac{\partial C_i(q_i)}{\partial q_i} = p - q_i \theta_i - \frac{\partial C_i(q_i)}{\partial q_i} = 0$$

Production; Price; Marginal cost; Conjectured price response

Stochastic Bilevel Scheme – all GenCos



EPEC is solved iteratively (via diagonalization).

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Case Study

Case Study Data

- Stylized electric power system; discount factor = 9%
- 2 identical GenCos; 4 technologies (NU, Coal, CCGT, GT)
- Time horizon of 15 years; 6 load levels per year
- 3 scenarios of demand growth (high, average, low)
- 3 cases of different strategic behavior in the market (Cournot, perfect competition and intermediate situation)

INSTALLED GENERATION CAPACITY OF FIRM 1 AND FIRM 2 [GW]

Technology	$y_1 - y_4$	$y_5 - y_9$	$y_{10} - y_{15}$
NU	3.85	3.6	2.05
CO	4.6	2.9	0.3
CCGT	10.5	10.5	8.7
GT	0	0	0

PRODUCTION AND INVESTMENT COSTS

	Production Cost δ [€/MWh]	Investment Cost β [€/kW]
NU	9.5	3,600
CO	33.7	1,508
CCGT	36.8	760
GT	54.7	350

DEMAND INTERCEPT D_0 IN YEAR 1 [GW] AND ANNUAL LOAD LEVEL DURATIONS T [H]

	l_1	l_2	l_3	l_4	l_5	l_6
D^0	57.6	51.68	45.44	39.2	32.80	25.12
T	240	1,520	2,380	2,380	1,600	640

PROBABILITY [P.U.] AND DEMAND GROWTH [%] OF SCENARIOS

	s_1	s_2	s_3
W_s	0.2	0.5	0.3
$\%_{D^0}$	2.7	1.8	1.2

Case Study Results – Cournot case

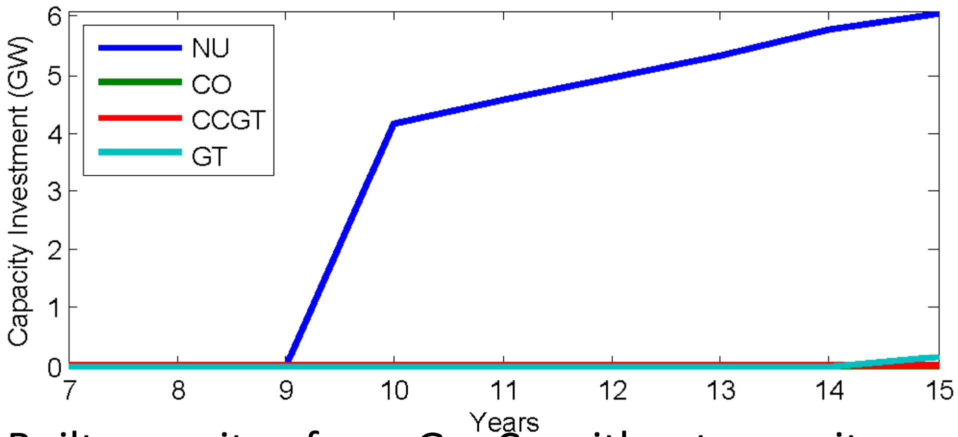

Fig: Built capacity of one GenCo without capacity payments.

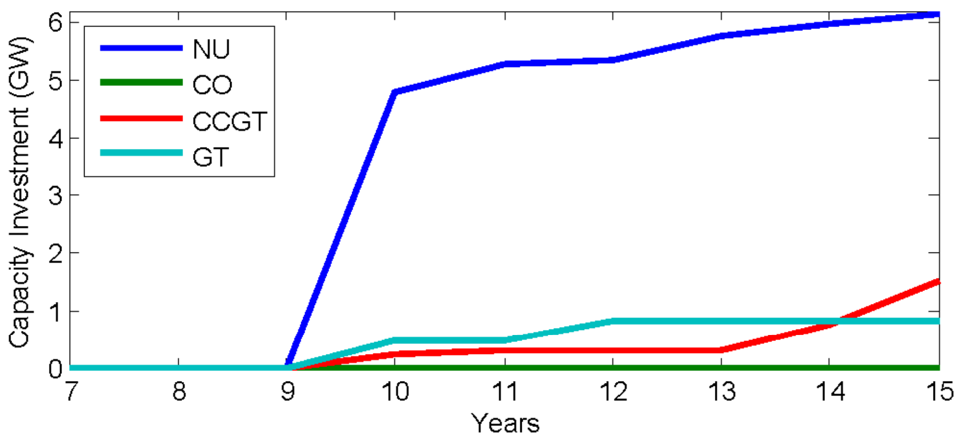

Fig: Built capacity of one GenCo without capacity payments (NU 20, CO 8.75, CCGT 20, GT 20 €/kW).

	without	with
y_1	1.9	1.9
y_2	1.8	1.8
y_3	1.7	1.7
y_4	1.6	1.6
y_5	1.43	1.43
y_6	1.36	1.36
y_7	1.31	1.31
y_8	1.25	1.25
y_9	1.20	1.20
y_{10}	1.03	1.12
y_{11}	1.02	1.11
y_{12}	1.01	1.10
y_{13}	0.99	1.10
y_{14}	0.98	1.09
y_{15}	0.97	1.09

Table: Average annual investment capacity index under Cournot w/wo capacity payments

Comment: Such a large investment in nuclear plants may be not realistic. Additional considerations such as national policies are likely to reduce it.

Case Study Results – Perfect Competition & Intermediate

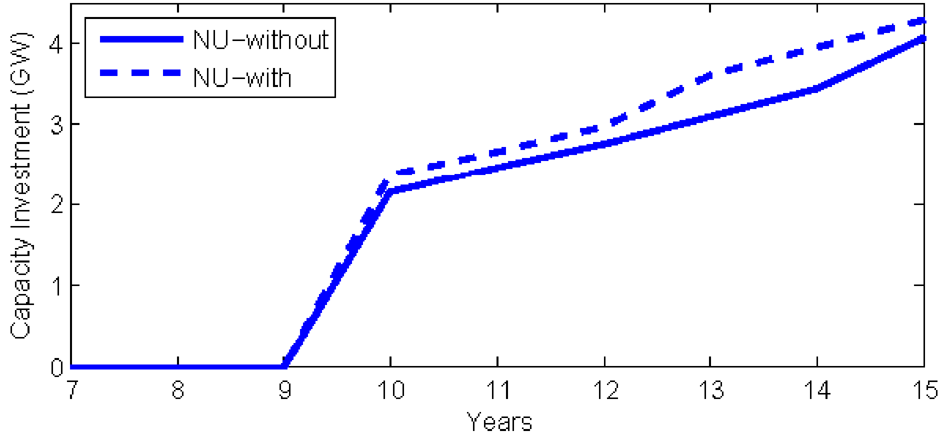

Fig: Built capacity of one GenCo w/wo capacity payments under perfect competition.

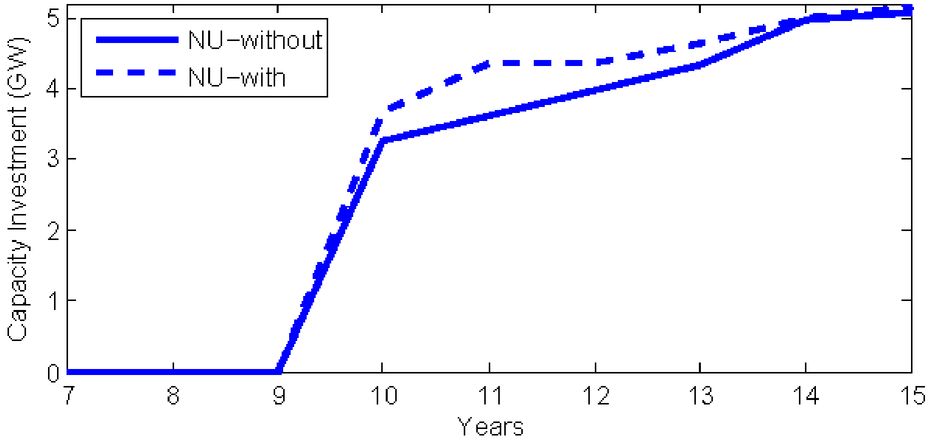

Fig: Built capacity of one GenCo w/wo capacity payments under intermediate strategic behavior.

	without	with
y_1	1.9	1.9
y_2	1.8	1.8
y_3	1.7	1.7
y_4	1.6	1.6
y_5	1.43	1.43
y_6	1.36	1.36
y_7	1.31	1.31
y_8	1.25	1.25
y_9	1.20	1.20
y_{10}	0.89	0.91
y_{11}	0.88	0.89
y_{12}	0.87	0.88
y_{13}	0.85	0.88
y_{14}	0.84	0.87
y_{15}	0.84	0.86

Table: Average annual investment capacity index under perfect competition w/wo capacity payments.

Case Study Results – Price Comparison

(M€)	Profits (without CP)	Profits (with CP)
s1	77846	80900
s2	56381	59140
s3	43911	46604
Exp.	56911	59731

Table: Profits under perfect competition.

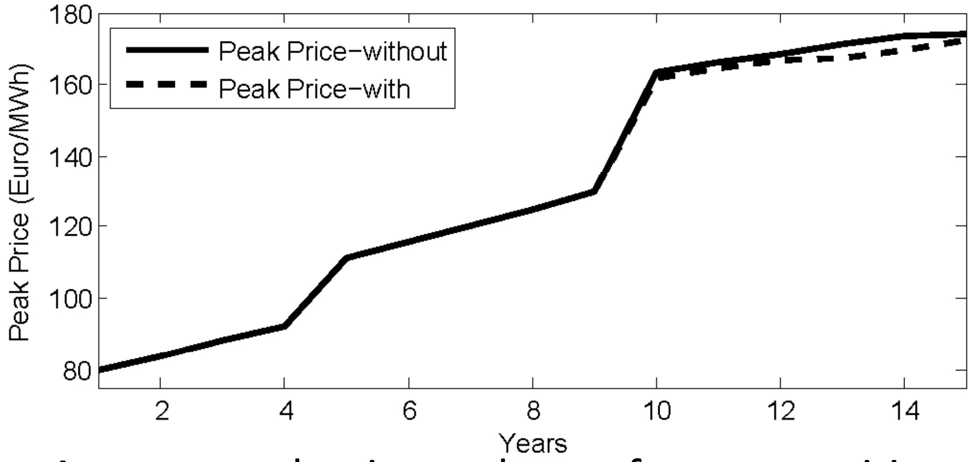

Fig: Average peak price under perfect competition.

(M€)	Profits (without CP)	Profits (with CP)
s1	94727	96714
s2	75849	78639
s3	65955	69102
Exp.	76657	79393

Table: Profits under Cournot.

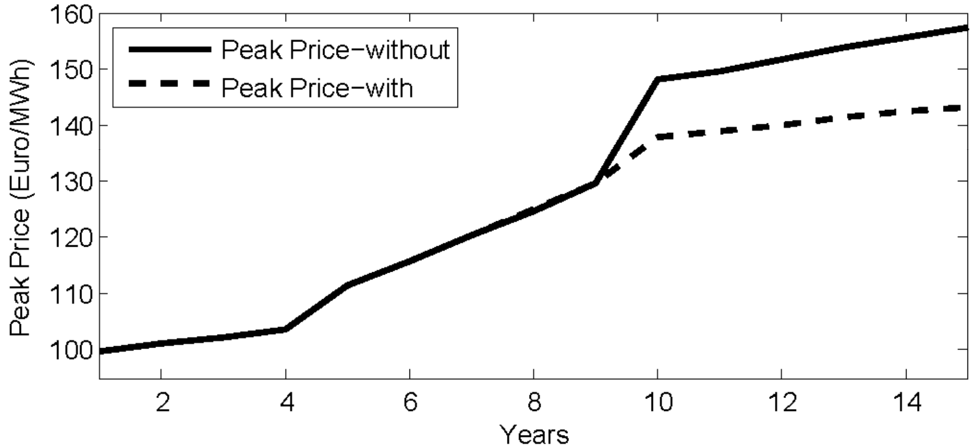

Fig: Average peak price under Cournot.

4

Conclusions

Conclusiones

- We introduced a **stochastic bilevel problem** that supports the investment decision making process of GenCos in a liberalized framework.
- In upper level the investing agent maximizes its net present value considering capacity payments.
- **Electricity market** (lower level) is represented using **conjectured price responses** (includes Cournot, and perfect competition and different degrees of oligopoly as particular cases).
- Stochasticity allows to merge several possible scenarios of possible investments of competitors and spot market behavior.
- We observe the **impact** that the introduction of **capacity payments** has on investment decisions and market prices.
  - More aggressive strategic behavior in spot market leads to lower investments
  - Impact of capacity payments is dependent on strategic behavior

Thank you for your attention!

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