PSR

Modelling power markets with multi-stage stochastic Nash equilibria

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ICSP 2016 – Búzios, Brazil

PUC RIO

June 2016

Agenda

- Key concepts
- Motivation and Literature Review
- Multi-stage economic dispatch and SDDP
- Revenue maximization and the MC-SDDP (MAXREV)
- Optimal day-ahead bidding (OPTBID)
- Single agent revenue (NASHBID)
- Multi-stage nash equilibria
- Case study: Panama

Key concepts

- Cost Based Power Markets X Bid Based Power Markets
  - Bid: Market Power
  - Cost: Monitoring costs
- Day ahead bidding
  - Bidding
  - Clearing
  - Pricing
- Price Takers X Price Makers
  - S.Borestein. J.Bushnell, F. Wolak, *Diagnosing Market Power in California’s Restructured Wholesale Electricity Market*, August 2000
  - F.Wolak, *An Effective Regulator is Needed for New Zealand Electricity Industry*, New Zealand Herald, April 2014.

Motivation: Problem Classes

		Market Power: No	Market Power: Yes
Time Coupling	**No**	**Thermal Price Taker**	**Thermal Price Maker**
	Yes	**Hydro Price Taker**	**Hydro Price Maker**

Motivation: the bidding problem

- Thermal Price Taker:
  - Gross and Finaly (2000)
    - Agents offer energy at their production cost

- Thermal Price Maker:
  - Barroso *et al.* (2006)
    - Bilevel problems converted to MPEC
    - Solved by MILP for instance

Motivation: the bidding problem

- Hydro Price Taker
  - Gjelsvik *et al.* (1999), Fosso *et al.* (1999)
    - SDDP+SDP
    - Offering costs for thermals and opportunity costs for hydros
  - Lino *et al.* (2003)
    - Water market for agents in the same cascade

- Hydro Price Maker
  - Flach *et al.* (2010)
    - Convexify the problem and use SDDP (3 to 5 years)
    - One Agent, quantity offer, needs Price Takers
  - Other works using shorter horizons with deterministic inflows

Goal

- Simulate the Hydro Price Maker:
- Multi Agent
- Price and Quantity Bid
- Do not require Price Takers

Multi-stage economic dispatch and SDDP

- Classical dispatch problem:
  - Objective:

$$\boldsymbol{min \sum c_j g_j + \beta(v_{t+1}, a_{t+1})}$$

Multi-stage economic dispatch and SDDP

- Classical dipatch problem:
  - Objective:

$$min \sum c_j g_j + \beta(v_{t+1}, a_{t+1})$$

  - Water Balance:

$$v_{t+1} = v_t + a_t - u - s$$

Multi-stage economic dispatch and SDDP

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$$v_{t+1} = v_t + a_t - u - s$$

  - Load Balance

$$\sum g_j + \sum \rho_i u_i = d - \sum r_k$$

Multi-stage economic dispatch and SDDP

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  - Objective:

$$min \sum c_j g_j + \beta(v_{t+1}, a_{t+1})$$

  - Water Balance:

$$v_{t+1} = v_t + a_t - u - s$$

  - Load Balance:

$$\sum g_j + \sum \rho_i u_i = d - \sum r_k$$

  - AR model (Inflow temporal dynamics):

$$a_{t+1} = \phi_1 a_t + \phi_2 a_{t-1} + \xi_{t+1}$$

Revenue maximization (MAXREV)

- New term and state in the Objective function:

$$\boldsymbol{min} \; -\boldsymbol{\pi_t^s E} + \sum \boldsymbol{c_j g_j} + \boldsymbol{\beta}(\boldsymbol{v_{t+1}}, \boldsymbol{a_{t+1}}, \boldsymbol{\pi_{t+1}^s})$$

- Changing the load balance

$$\sum \boldsymbol{g_j} + \sum \boldsymbol{\rho_i u_i} + \sum \boldsymbol{r_k} = \boldsymbol{E}$$

Revenue maximization (MAXREV)

- New term and state in the Objective function:

$$\min \; -\pi_t^s E + \sum c_j g_j + \beta(v_{t+1}, a_{t+1}, \pi_{t+1}^s)$$

- Changing the load balance

$$\sum g_j + \sum \rho_i u_i + \sum r_k = E$$

- π^s depends of scenarios

  $\Longrightarrow$ objective is saddle shaped

- Solution: represent prices by a Markov Model

MAXREV and the MC-SDDP

- Markov process for price: $\begin{pmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{pmatrix}$

- New Objective function with multiple future costs:

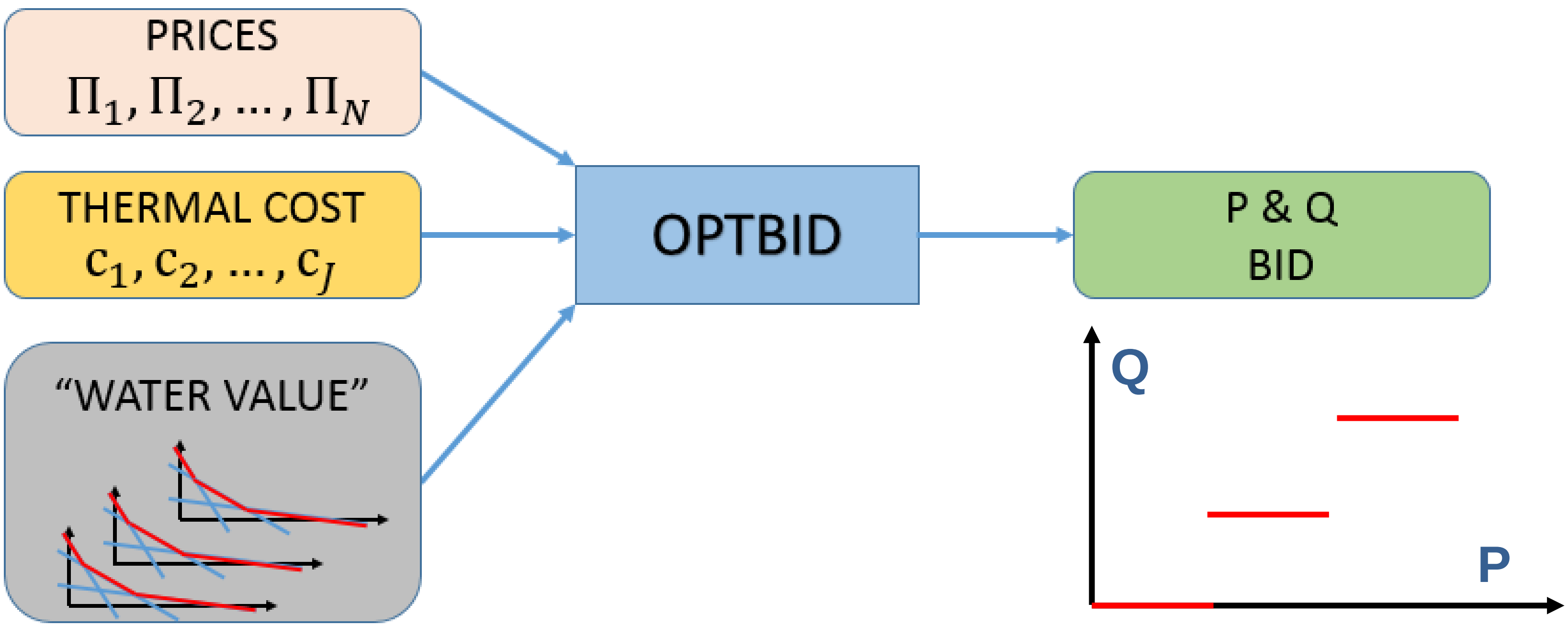
$$\min \; -\pi^s E + \sum c_j g_j \; + p_1 \beta^{k(s)\to k1}(v_{t+1}, a_{t+1})$$

$$+ p_2 \beta^{k(s)\to k2}(v_{t+1}, a_{t+1})$$

$$+ p_3 \beta^{k(s)\to k3}(v_{t+1}, a_{t+1})$$

Optimal day-ahead bidding (OPTBID)

- Detail the bidding strategy under uncertainty
  - Convert energy Quantity bid into Price and Quantity bid
- Procedure
  - Pre define a set of prices
  - Optimize the quantity of energy allocated to each price



Single (price maker) agent revenue

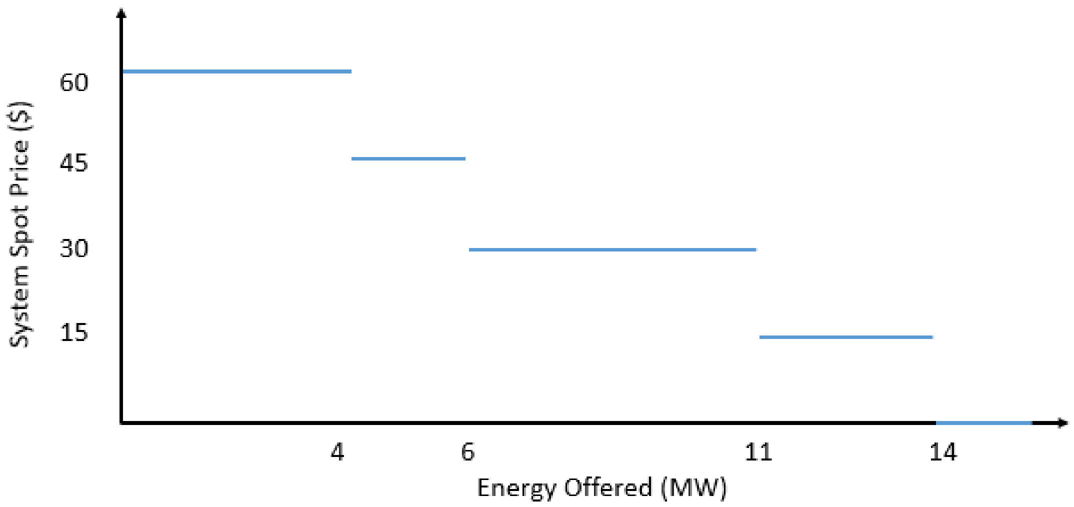
- Market Clearing

$$z(E) = \min \sum_{i \in -a} p_i e_i$$

$$s.t. \quad \sum e_i \leq d - E \leftarrow \pi(E)$$

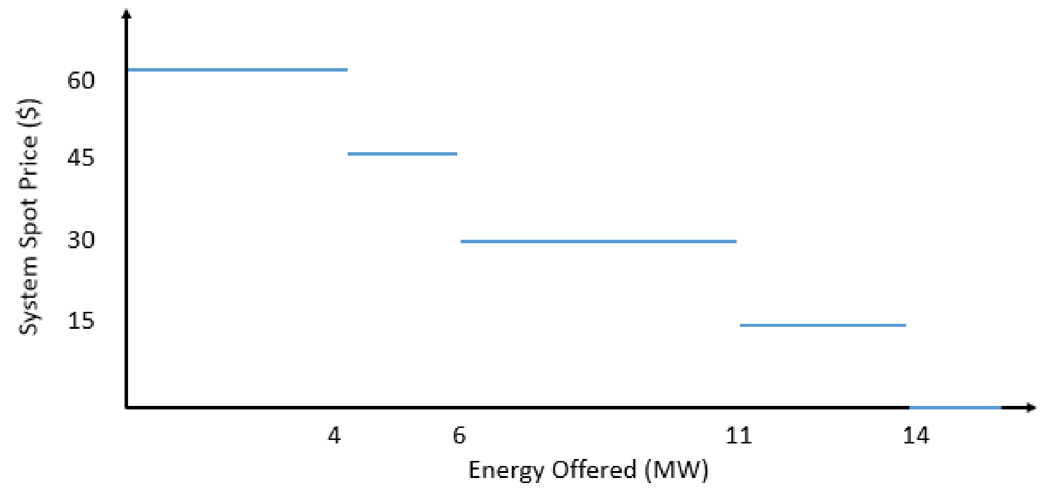
$$e_i \leq q_i$$

- Spot Price is affected by Price Maker offer

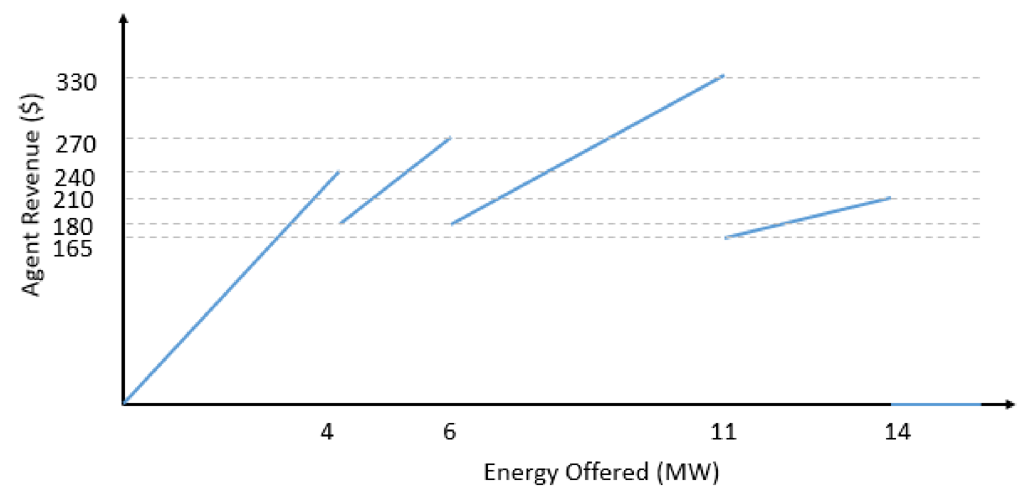


Single (price maker) agent revenue

- Spot

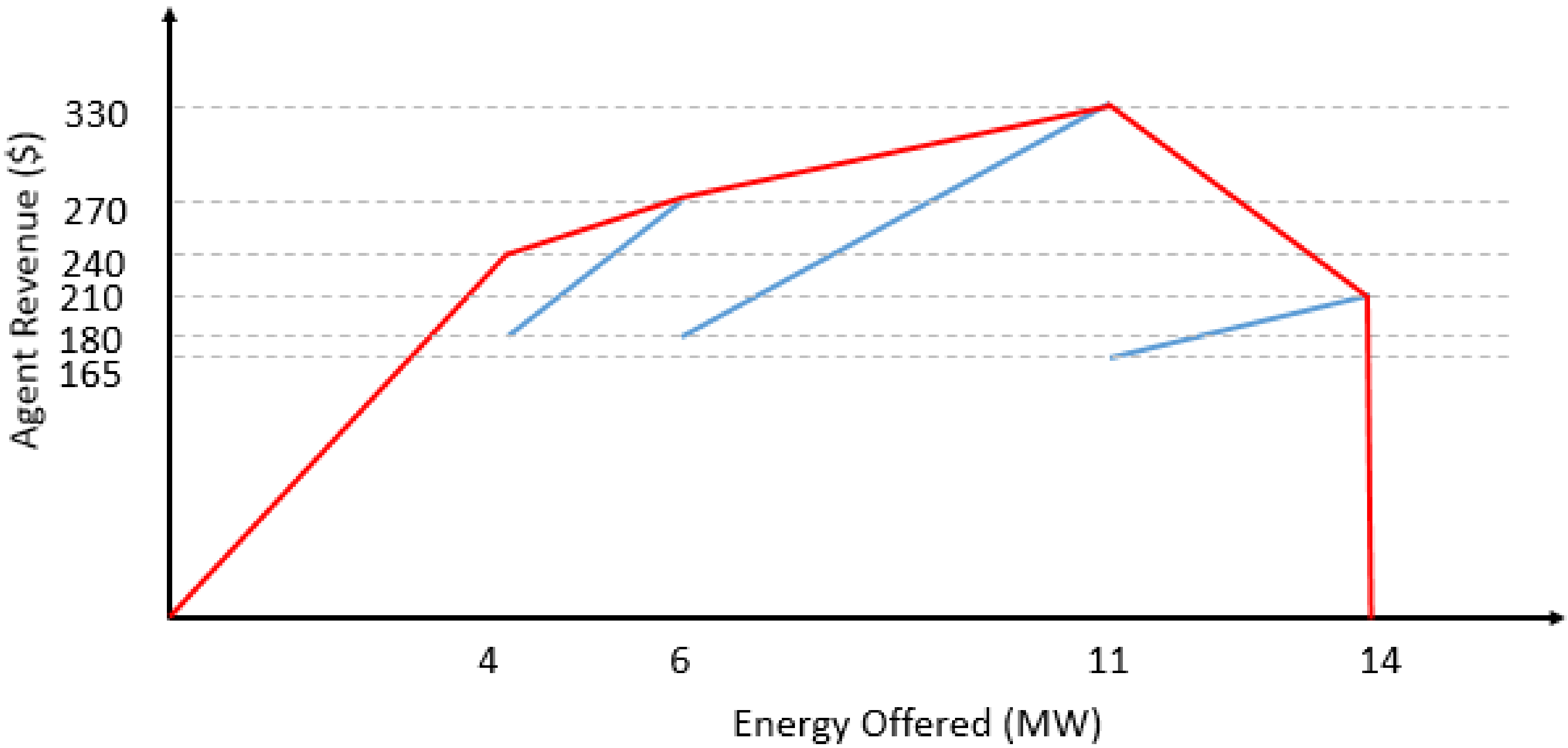


- Revenue: Spot*Energy



Single (price maker) agent revenue

- Concave Hull: $\boldsymbol{R(E)}$



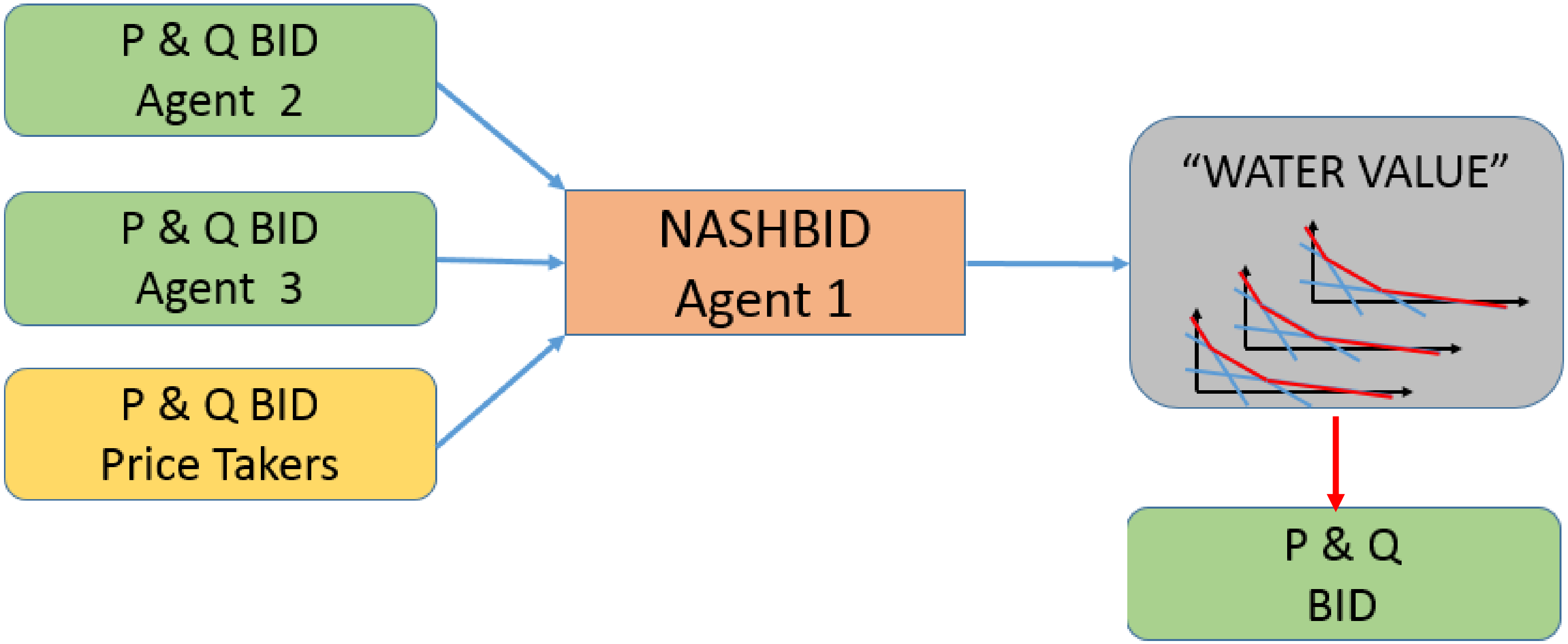
Convexified problem: NASHBID

- Same problem of the price taker produnction but now spot is a function of energy offered (also scenario dependent)

$$
\begin{aligned}
min\ -R^{s}(E)+\sum c_j g_j\ & +p_1\beta^{k(s)\rightarrow k1}(v_{t+1},a_{t+1}) \\
& +p_2\beta^{k(s)\rightarrow k2}(v_{t+1},a_{t+1}) \\
& +p_3\beta^{k(s)\rightarrow k3}(v_{t+1},a_{t+1})
\end{aligned}
$$

Multi-stage Nash equilibria

- Use NASHBID revenue maximization model to optimize some agent quantity bid strategy given the bids of the other agents

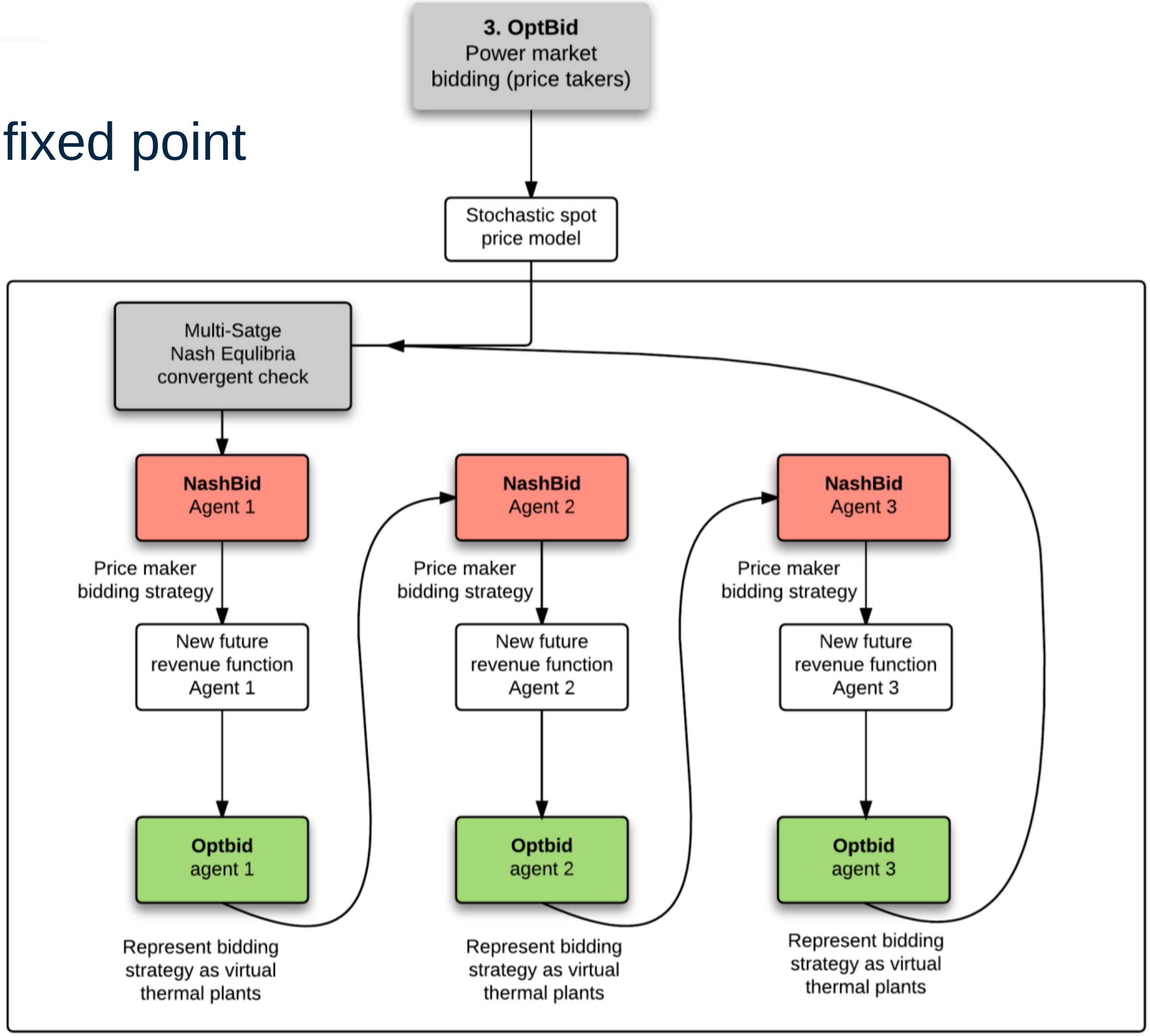


- Quantity bid are converted into price and quantity bids by OPTBID

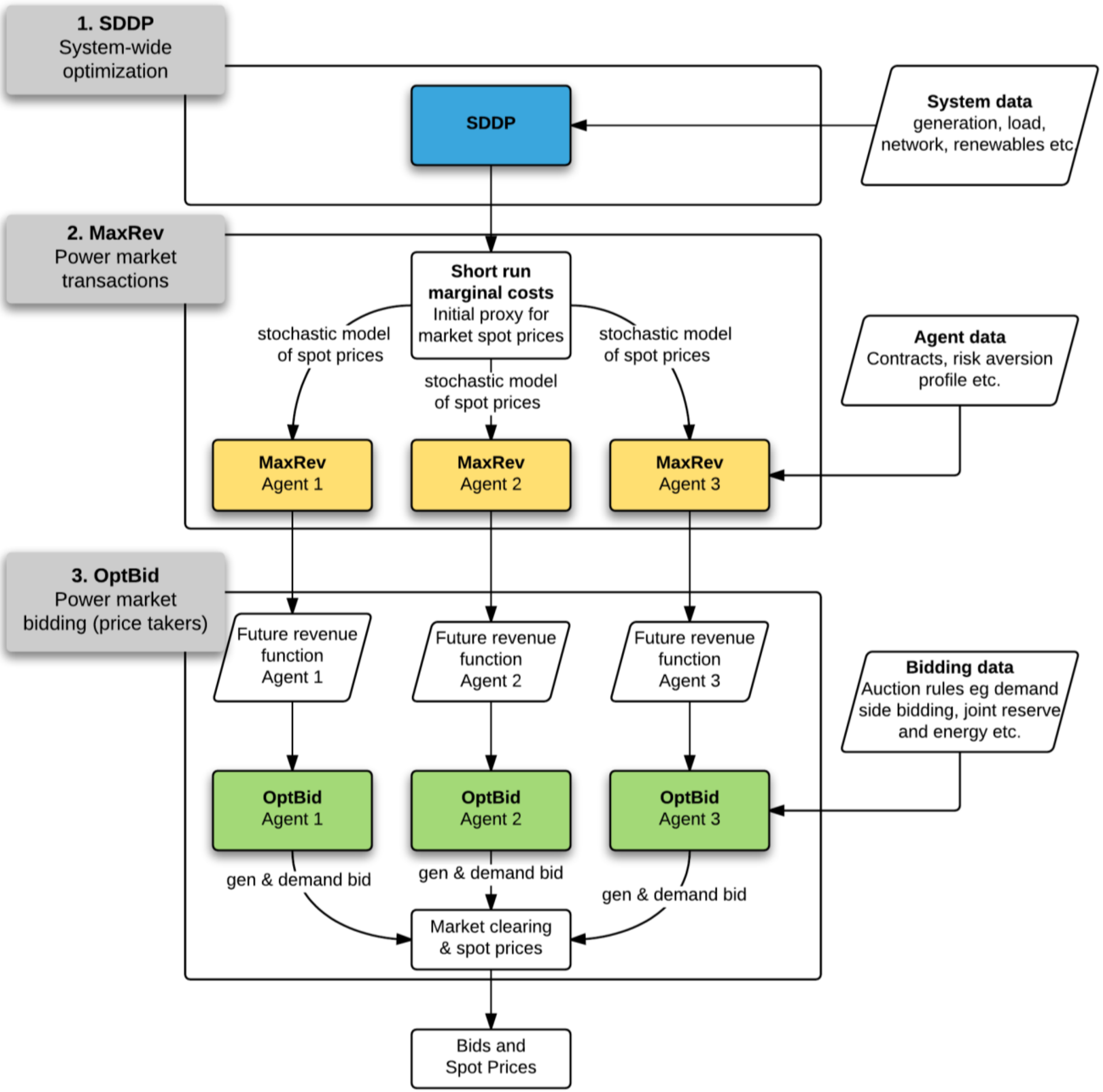
Simulating Multi-stage Nash equilibrium

- Procedure:

  Look for a fixed point



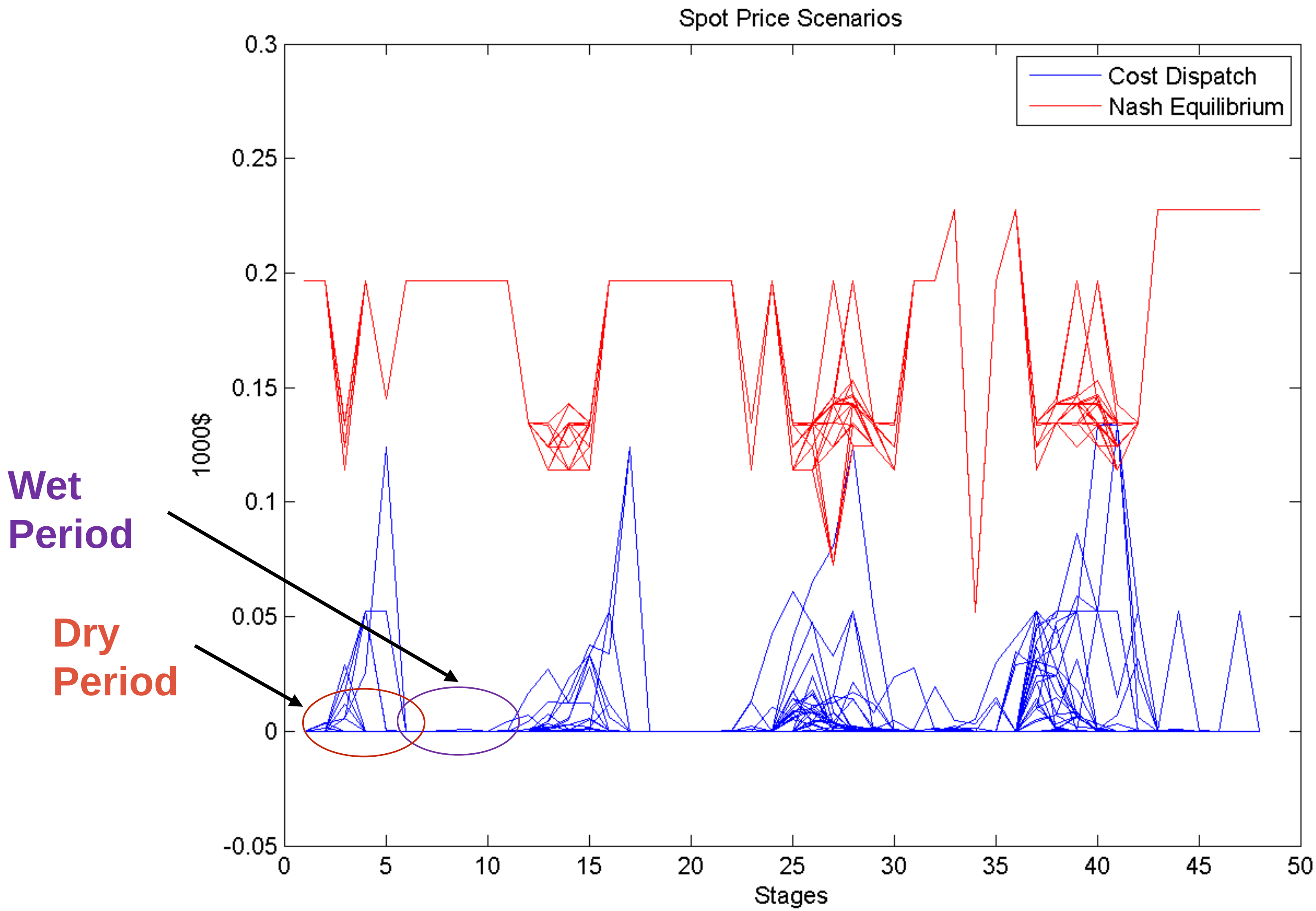
How do we Initialize bid strategies?



Case study : Panamá

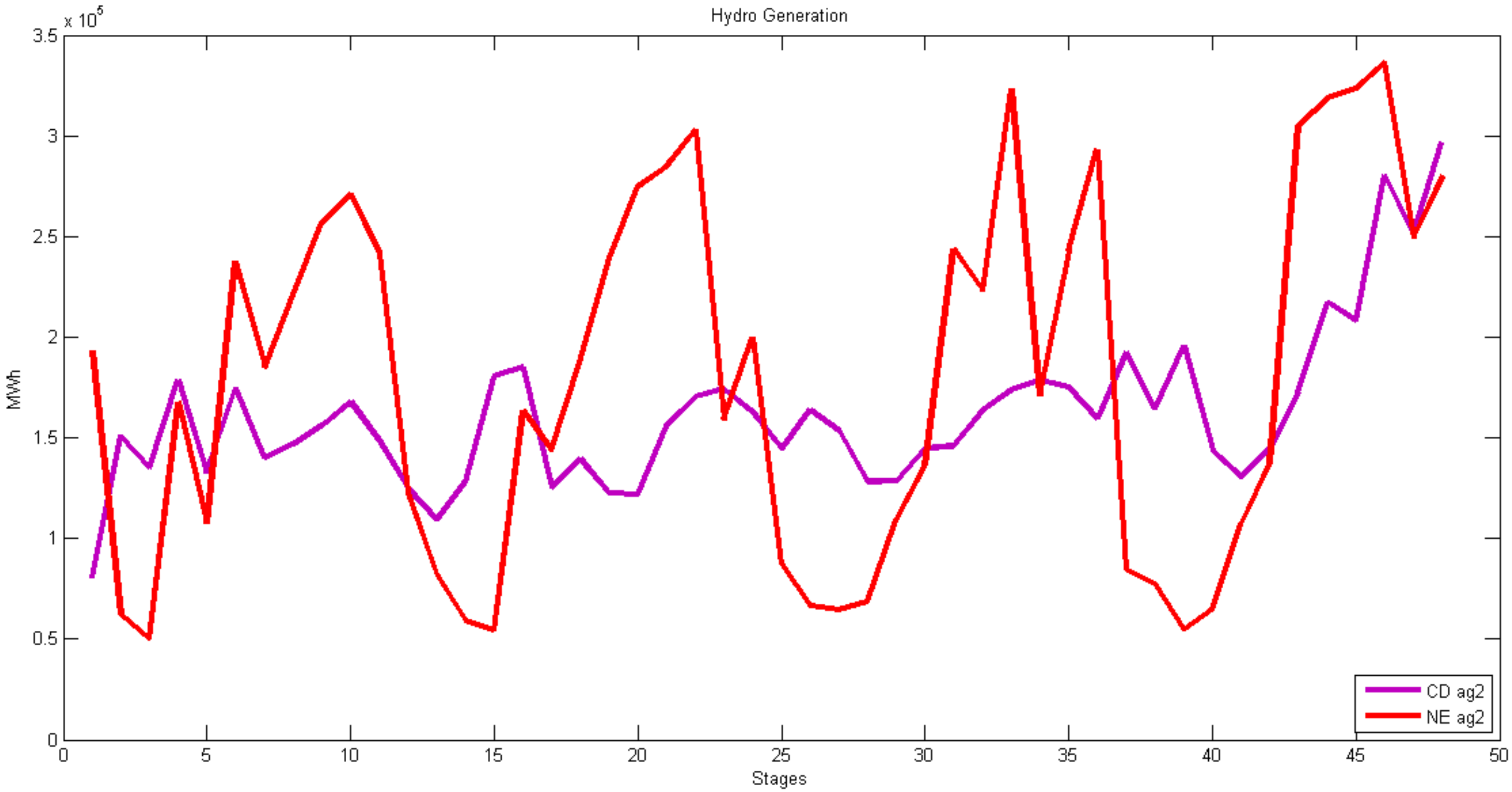
- Panama
- 42 hydros with one cascade
- 22 thermal plants
- We built 3 agents evenly distributing hydro plants
- Considering a smaller demand than the real one

Results: Spot Prices



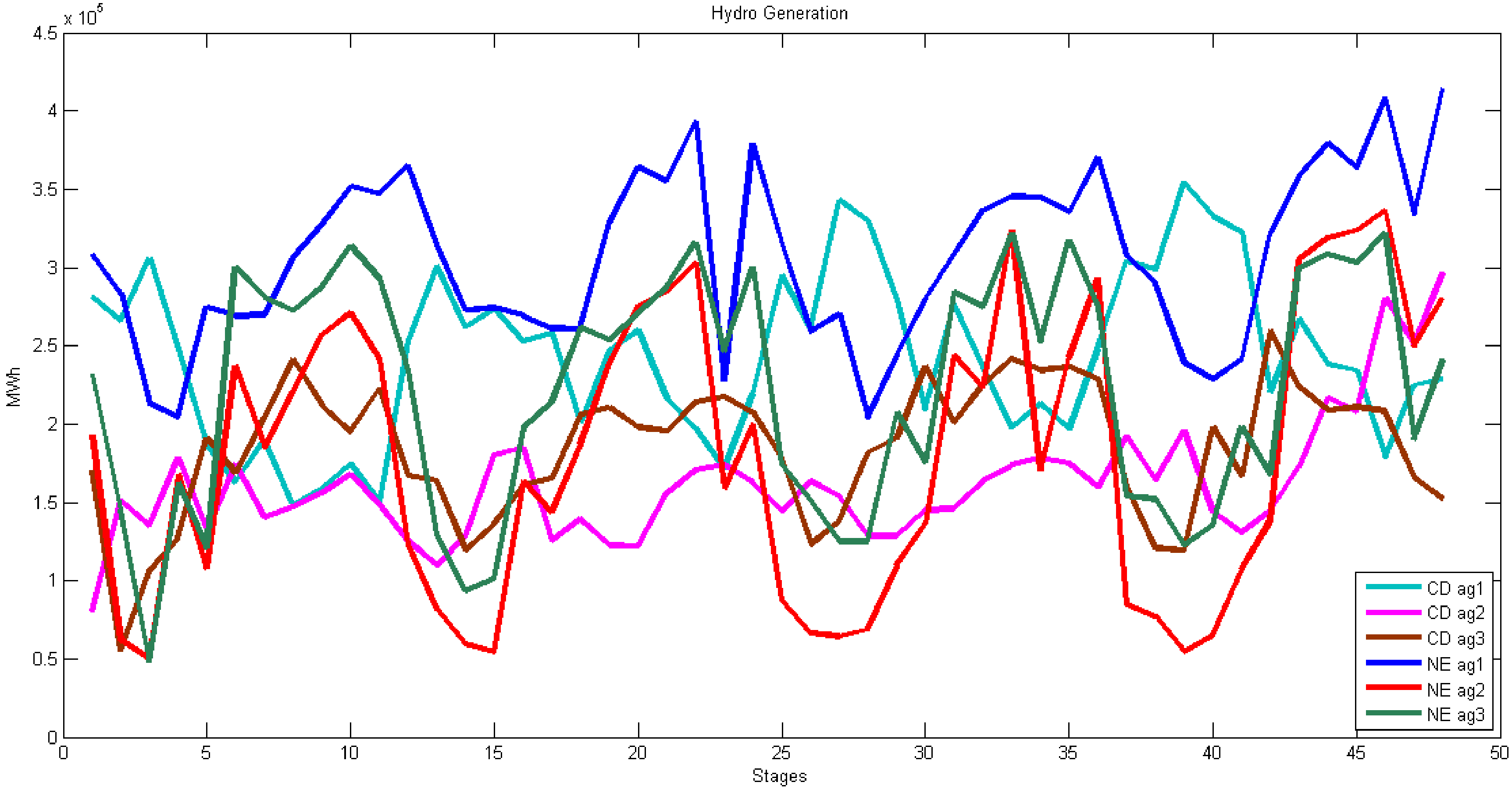
Results: Agents Revenue

Agent 2 hydro generation



Results: Agents Revenue

All agents hydro generation



Concluision

- Simulation procedure
- Price makers move water to optimize their revenues
- Spot prices significantly modified
- Future work:
  - Multiple equilibria
  - Agents with hydros in the same cascade
  - Simulating even larger power systems

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Thanks!

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