Impact of Unit Failure on Forward Contracting

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Outline

- Introduction: unit availability
- Problem characterization
- Proposed solution
- Numerical simulations
- Future work

Power Producer

- Selling in the pool:
  - Risky because of the volatility of the prices
- Selling through forward contracts:
  - Hedging strategy against pool price volatility
  - Risky due to the probability of unit failure

Understanding the problem

- High pool prices volatility
- Risk-neutral producer

Generate energy → Sell energy in the pool

Expected profit ↑

Standard deviation of profit ↑

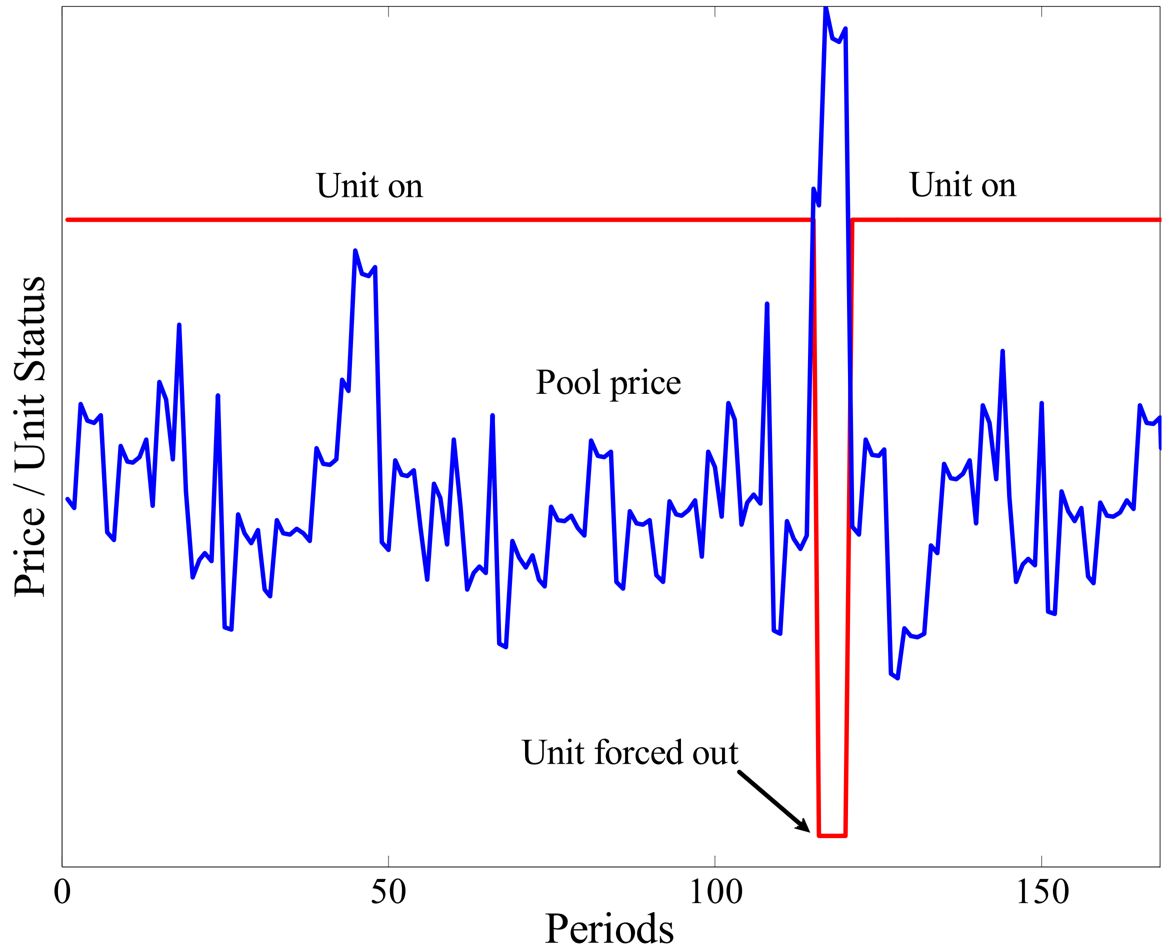
Understanding the problem

- High pool prices volatility
- Risk-averse producer
- Unit failures neglected

Generate energy → Sell energy through forward contracts

Problem: If the unit fails, the producer has to buy energy in the pool even if the price is high

Understanding the problem



Understanding the problem

- High pool prices volatility
- Risk-averse producer
- Unit failures considered

Generate energy → Sell limited energy through forward contracts

Expected profit ↓

Standard deviation of profit ↓

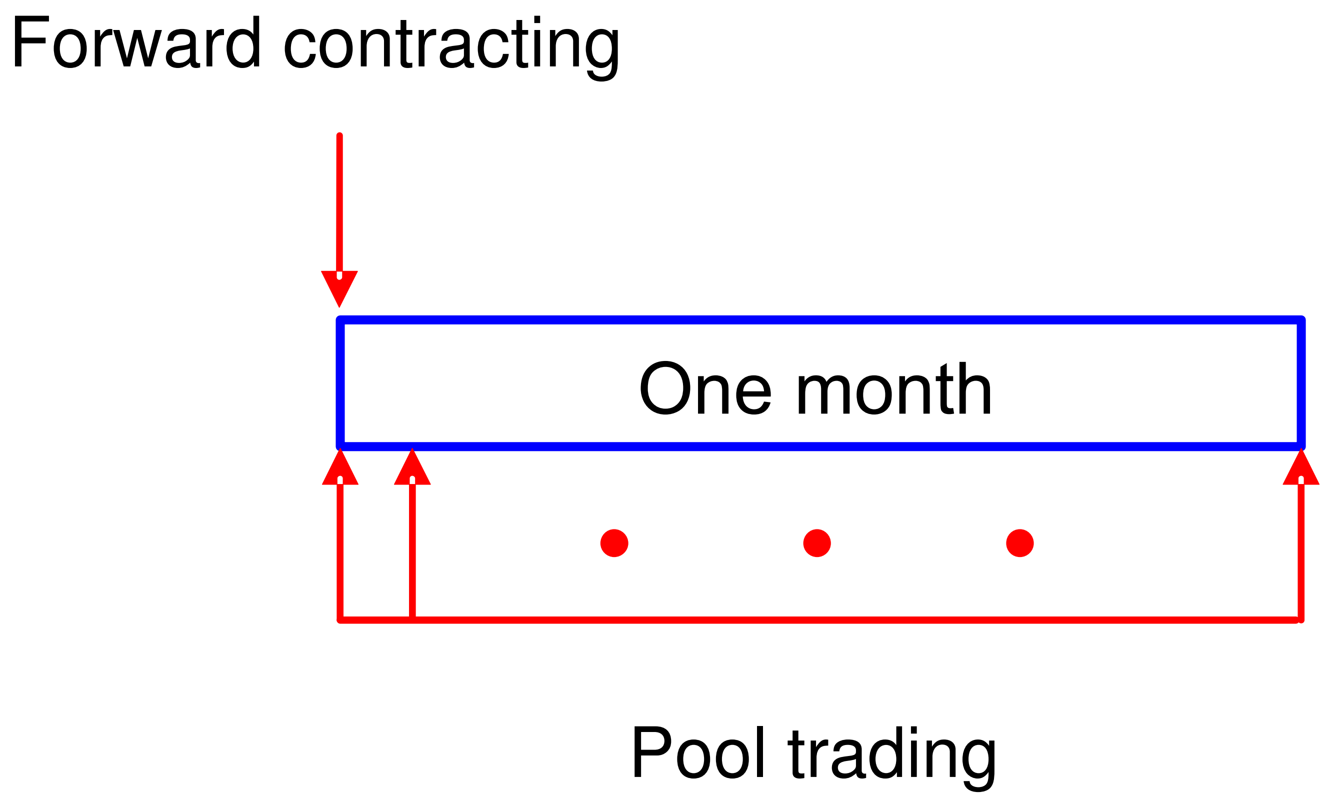
Aim

Analyze the effect of the unit failure on forward contracting decisions for different values of risk level

Decision Framework

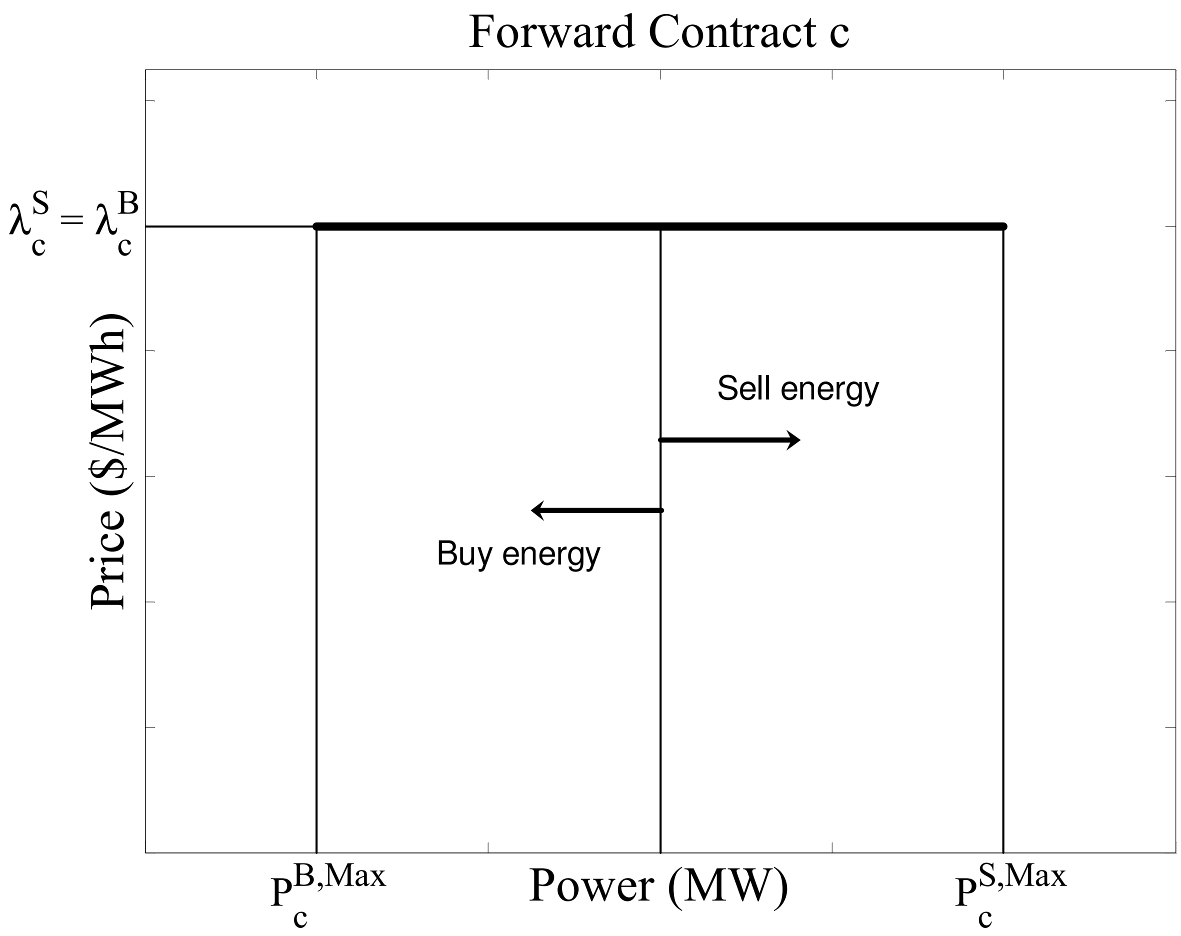
- Planning horizon: e.g. , one year
- Two decisions:
  - – Forward contracting at weekly / monthly /quarterly intervals
  - – Pool trading throughout the planning horizon

Decision Framework



Forward Contracting

- Buy/sell a fixed MW power quantity (up to a maximum) during a certain future time period at a specified price



Forward Contracting

- Advantages:
  - Hedging against pool price volatility
  - Lower standard deviation of profit
- Disadvantages:
  - Lower expected profit
  - Impossibility of selling energy through forward contracts if the unit is forced out

Uncertainty

- Uncertainty of pool price
- Uncertainty of unit availability

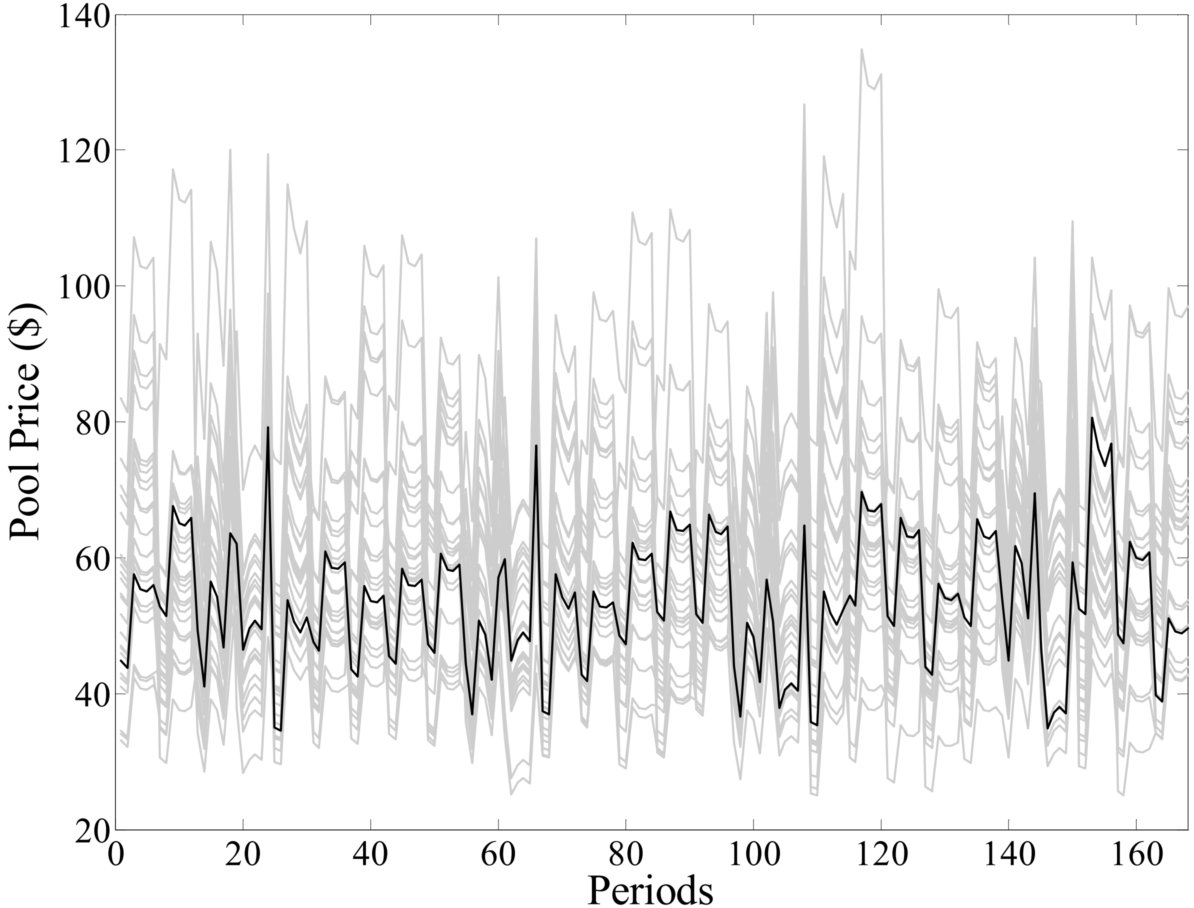
Modeling uncertainty

- Price uncertainty:
  - Scenario generation covering the study horizon
  - Scenario reduction
- Unit availability:
  - Scenario generation based on *MTTF* (Mean Time To Failure) and *MTTR* (Mean Time To Repair)
  - Scenario reduction

Characterizing price uncertainty

Pool price is treated as a stochastic variable:

Price scenario generation



Modeling unit availability

- Failure time modeled through an exponential distribution with mean *MTTF*
- Repair time modeled through an exponential distribution with mean *MTTR*

$$FOR\,(\%) = \frac{MTTR}{MTTF + MTTR} \times 100$$

Modeling unit availability

- We simulate *Up Time* and *Down Time* as:

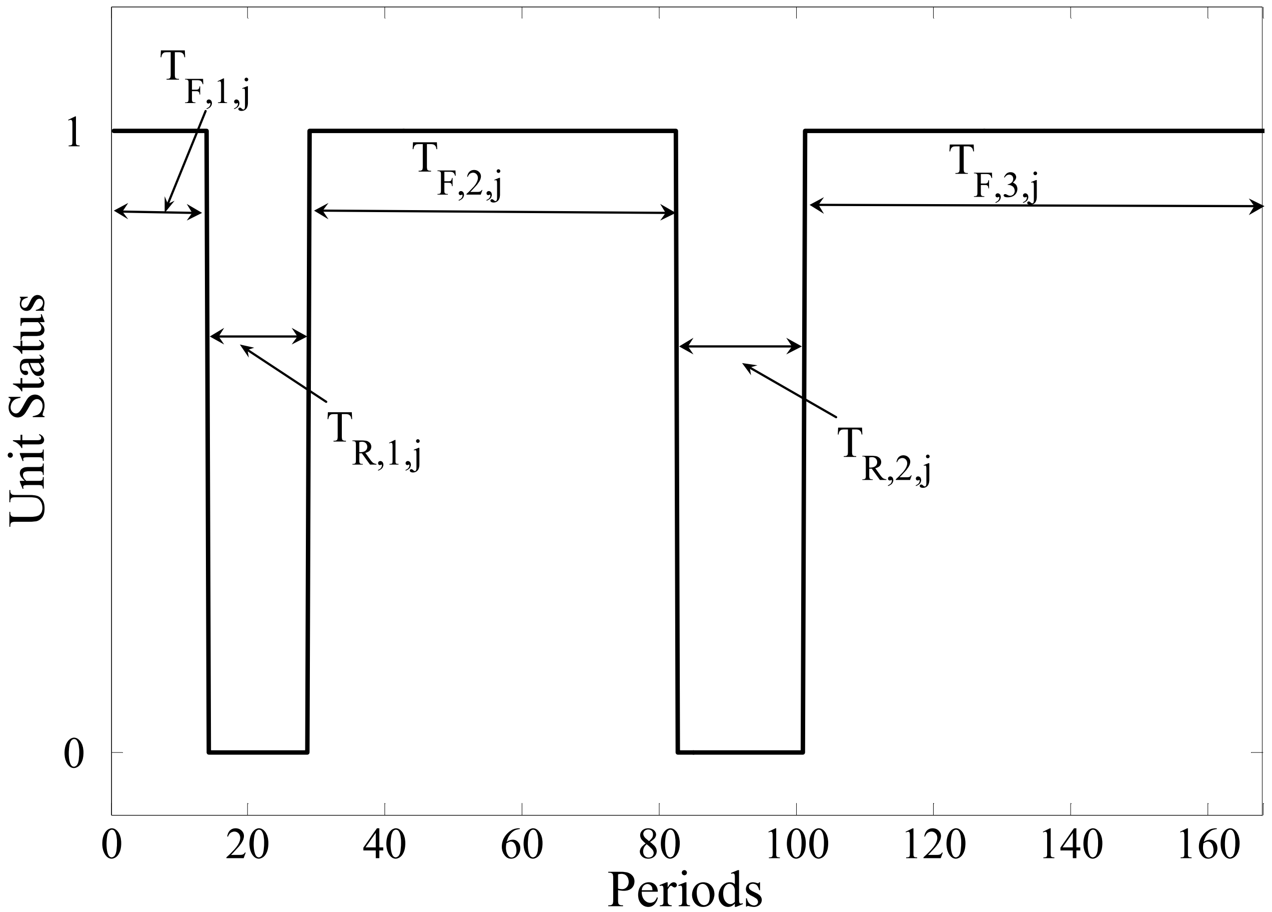
$$Up\ Time = -MTTF \times \log(u_1)$$

$$Down\ Time = -MTTR \times \log(u_2)$$

u_1 and u_2 are random variables uniformly distributed between 0 and 1

Modeling unit availability

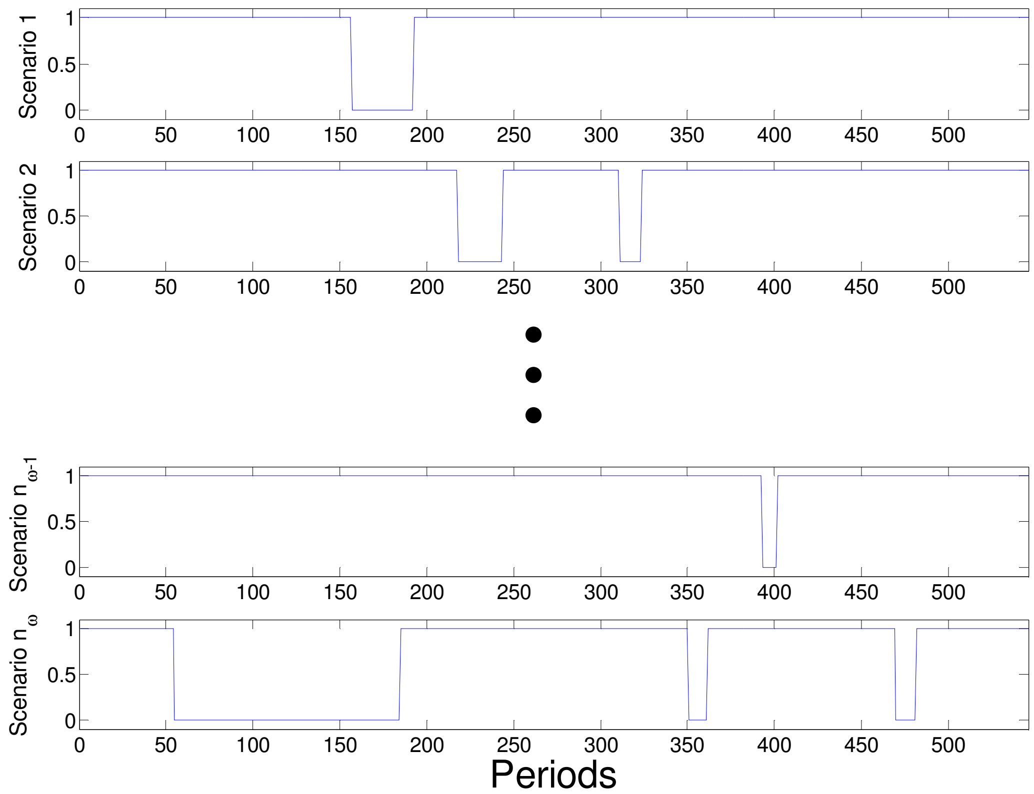
Scenario j



Modeling unit availability

Status of the unit is treated as a stochastic variable:

Unit status scenario generation



Scenario reduction

- Needed to attain problem tractability
- Reduction technique based on the O.F. of a problem with one scenario (*Fast forward selection method*)
- Assessment via observation of the evolution of the objective function value with the # of scenarios

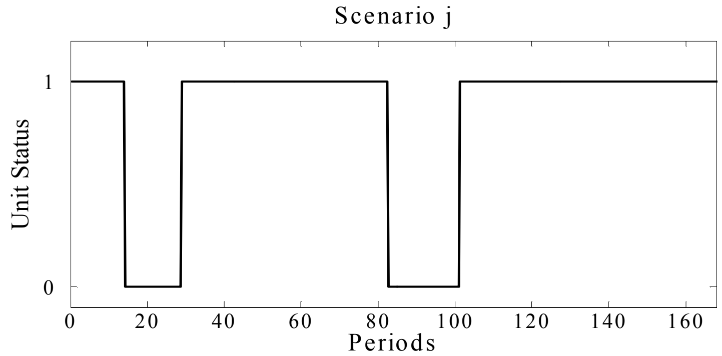
Model

- Two-stage stochastic programming approach:
  - Stochastic variables: pool price and unit availability
  - First stage variables: forward contracting decisions
  - Second stage variables: pool trading

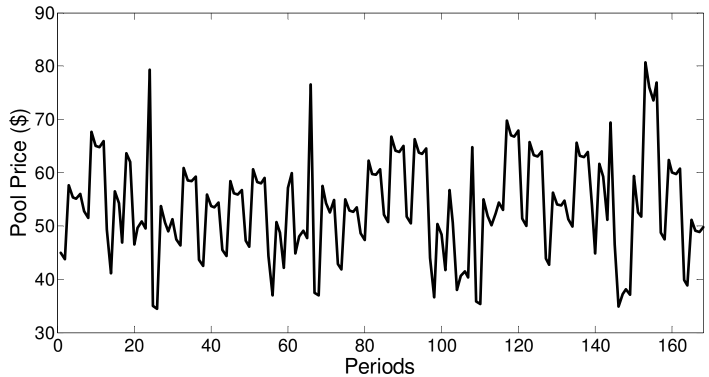
Model

- Each scenario of the optimization problem contains:

[1 0 0 1 0 1 1 1 … 0 1 1]

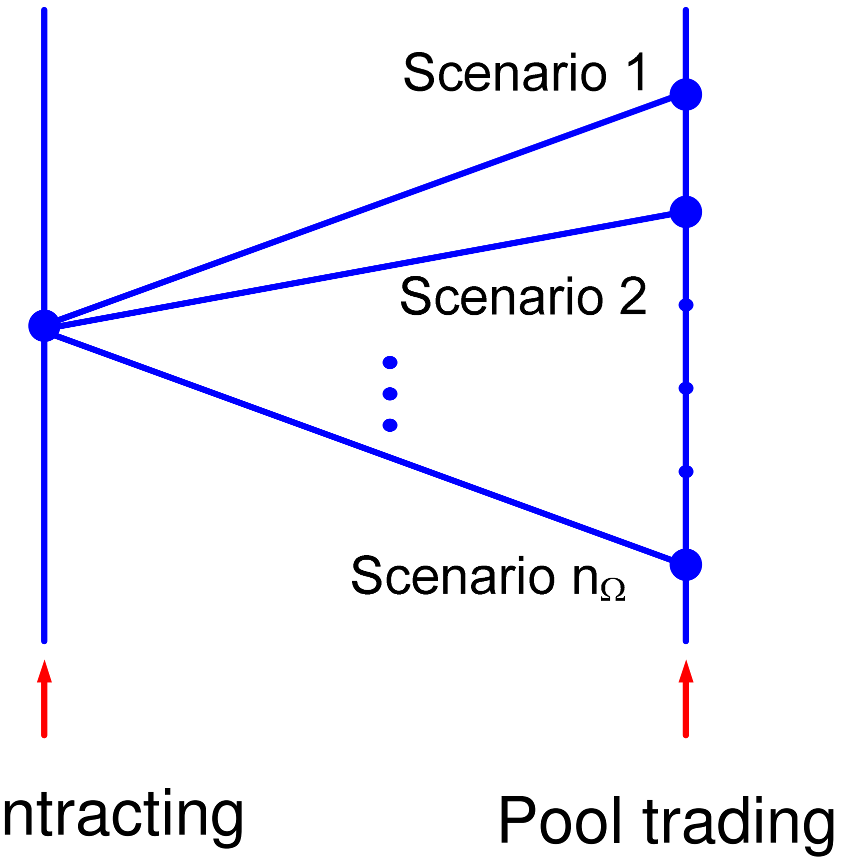


[24 37 41 …. 21 39 52]



Stochastic programming approach

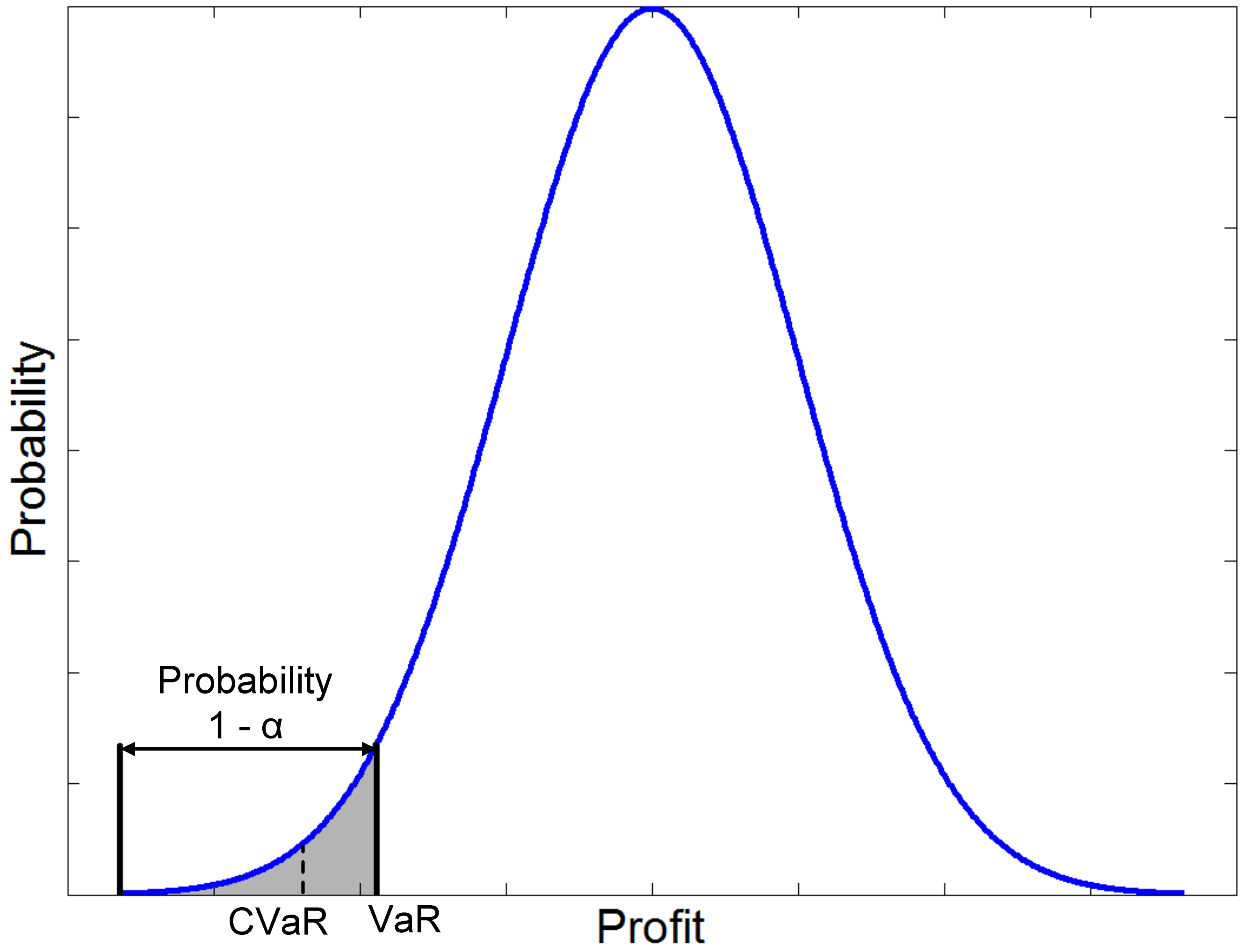
Two-stage stochastic programming: Scenario tree



Risk management

- Tradeoff between expected profit and risk due to profit variability
- Risk measure: CVaR (average profit in scenarios with lowest profit)
- CVaR advantage: linear formulation

Risk management



Problem formulation

- Maximize *Expected profit* + $\beta \times$ *CVaR*
- Subject to constraints associated with:
  - Energy balance
  - Forward contracts
  - CVaR

The tradeoff between expected profit and risk is enforced through the weighting factor $\beta \in [0,\infty)$

Expected profit

$$\text{E\{profit\}} = \text{E\{renenue from pool involvement} - \text{generation cost\}} +$$

$$+ \text{forward contract puchases} - \text{forward contract cost} =$$

$$= \sum_{\omega=1}^{N_W}\sum_{t=1}^{N_T}\pi_{\omega}\left(\lambda_{t\omega}^{P}E_{t\omega}^{P} - E_{t\omega}^{G}C\right) + \sum_{c=1}^{N_C}\lambda_c^S P_c^S\left(\sum_{t=T_c^0}^{T_c} L_t\right) - \sum_{c=1}^{N_C}\lambda_c^B P_c^B\left(\sum_{t=T_c^0}^{T_c} L_t\right)$$

Pool revenue

Generation cost

Forward contract income

Forward contract cost

Energy balance

$$E^{P}_{t\omega} + \sum_{c\in F_t} P^{S}_{c} L_t = \sum_{c\in F_t} P^{B}_{c} L_t + E^{G}_{t\omega} \qquad \forall t, \forall \omega$$

Energy sold in the pool

Energy sold through forward contracts

Energy bougth through forward contracts

Energy generated

Bounds

$$E_{t\omega}^{G} \leq k_{tw} P^{\max} L_t \qquad \forall t, \forall \omega$$

$$E_{t\omega}^{G} \geq k_{tw} P^{\min} L_t \qquad \forall t, \forall \omega$$

Availability Parameter

$$P_c^S, P_c^B \geq 0 \qquad \forall c$$

$$P_c^B \leq P_c^{B,\max} \qquad \forall c$$

$$P_c^S \leq P_c^{S,\max} \qquad \forall c$$

Risk measure (CVaR)

CVaR is incorporated in the objective function through a weighting parameter β

$$CVaR = \xi - \frac{1}{1-\alpha} \sum_{\omega \in \Omega} \pi_\omega \eta_\omega$$

$$- \sum_{t=1}^{N_T} \lambda_{t\omega}^P E_{t\omega}^P - \sum_{c=1}^{N_C} \lambda_c^S P_c^S \left(\sum_{t=T_c^0}^{T_c} L_t \right) + \sum_{c=1}^{N_C} \lambda_c^B P_c^B \left(\sum_{t=T_c^0}^{T_c} L_t \right) +$$

$$+ \sum_{t=1}^{N_T} E_{t\omega}^G C + \xi - \eta_\omega \le 0 \qquad \forall \omega$$

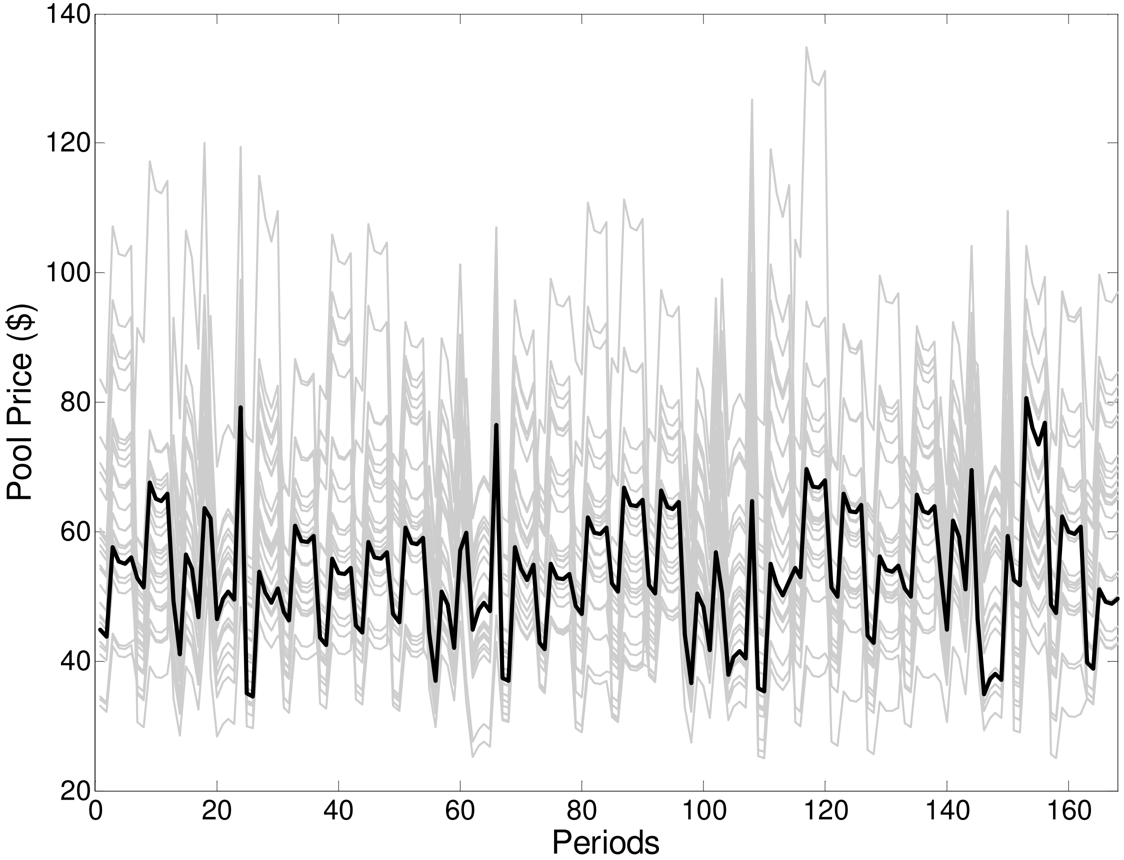
$$\eta_\omega \ge 0 \qquad \forall \omega$$

Numerical simulations.

Stochastic Variable Characterization

- One month (28 days)
- Each day is divided into 6 periods of 4 hours each
- Total number of periods: $28 \times 6 = 168$

Numerical simulations. Prices scenarios

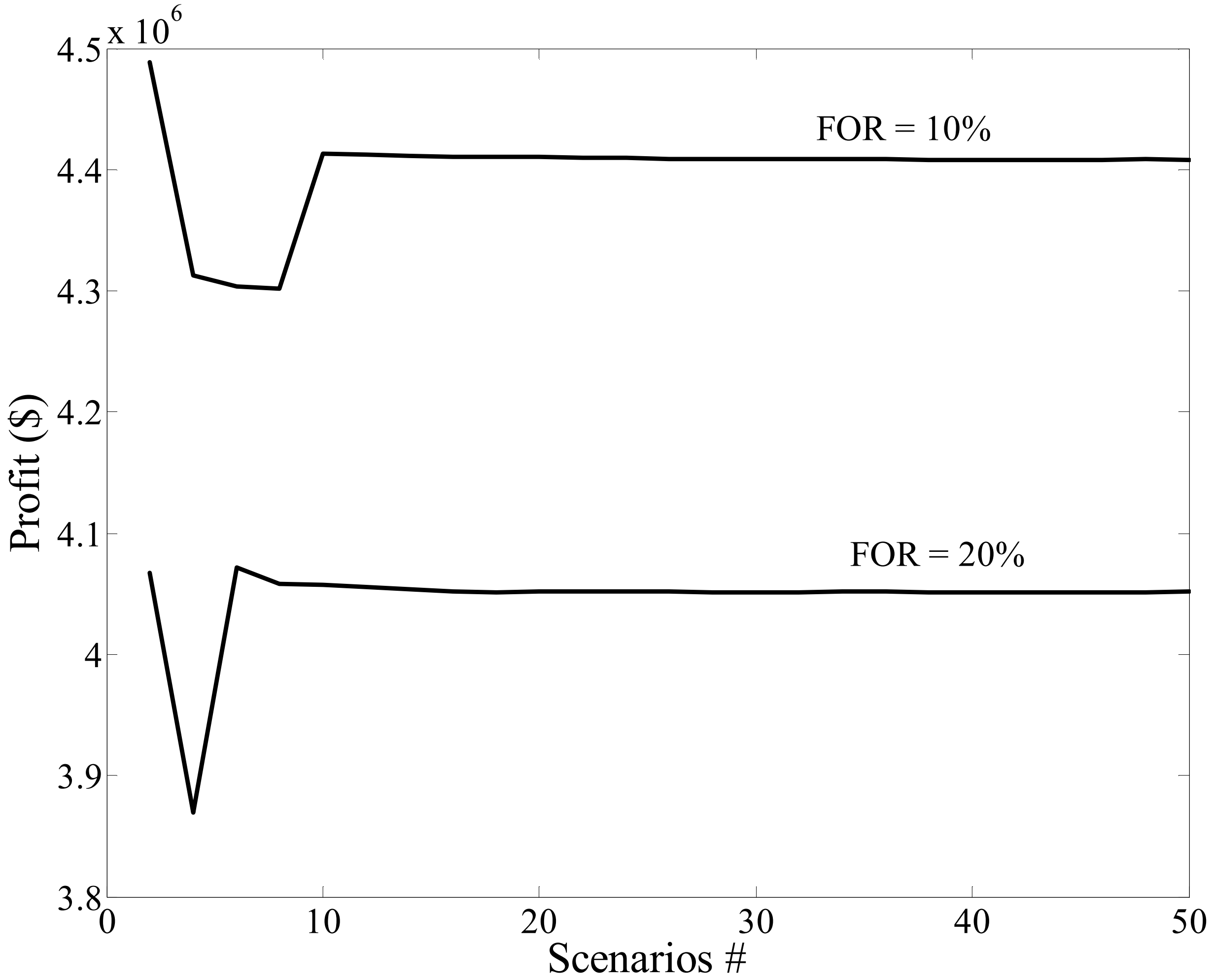


Original tree: 288 price scenarios → Final tree: 25 price scenarios

Numerical simulations. Unit Status

- Simulation for three different cases:
  - Case 1: *FOR* = 0% (no failure)
  - Case 2: *FOR* = 10% (*MTTF*=400 *MTTR*=40)
  - Case 3: *FOR* = 20% (*MTTF*=250 *MTTR*=60)
- Original tree: 5000 availability scenarios → Final tree: 50 availability scenarios

Numerical simulations. Reducing availability scenarios



Numerical simulations. Forward contracts

- One month decision framework
- Five forward contracts:
  – Fixed price for each contract
  – Maximum power that can be sold/bought
  – 4 contracts with a duration of 1 week
  – 1 contract with a duration of the whole month

Numerical simulations.
Forward contracts

# contract	$P_c^{S,Max}$	$P_c^{B,Max}$	λ_c^B	λ_c^S
1	100	100	52.88	52.88
2	100	100	50.75	50.75
3	100	100	53.60	53.60
4	100	100	53.25	53.25
5	50	50	52.57	52.57

<table>
<tr><th>Week 1</th><th>Week 2</th><th>Week 3</th><th>Week 4</th></tr>
<tr><td>Contract 1</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Contract 2</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Contract 3</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Contrat 4</td></tr>
<tr><td colspan="4">Contract 5</td></tr>
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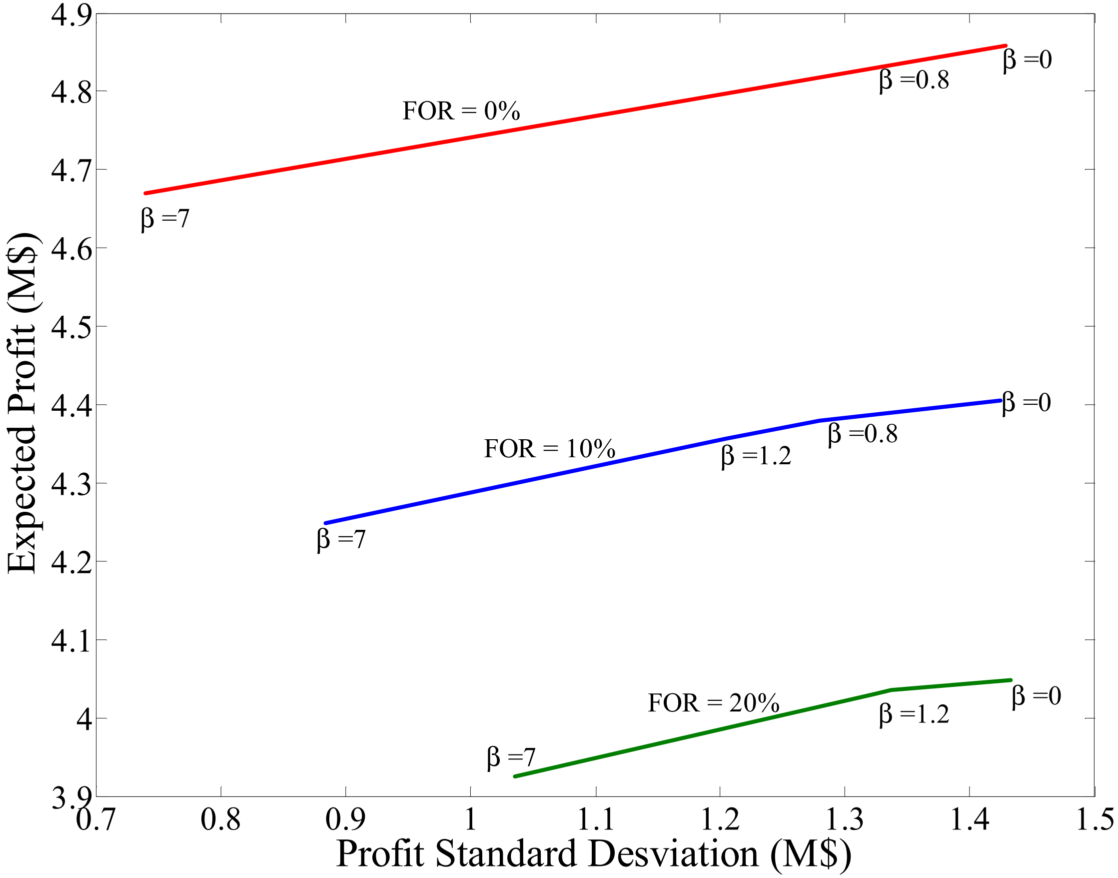
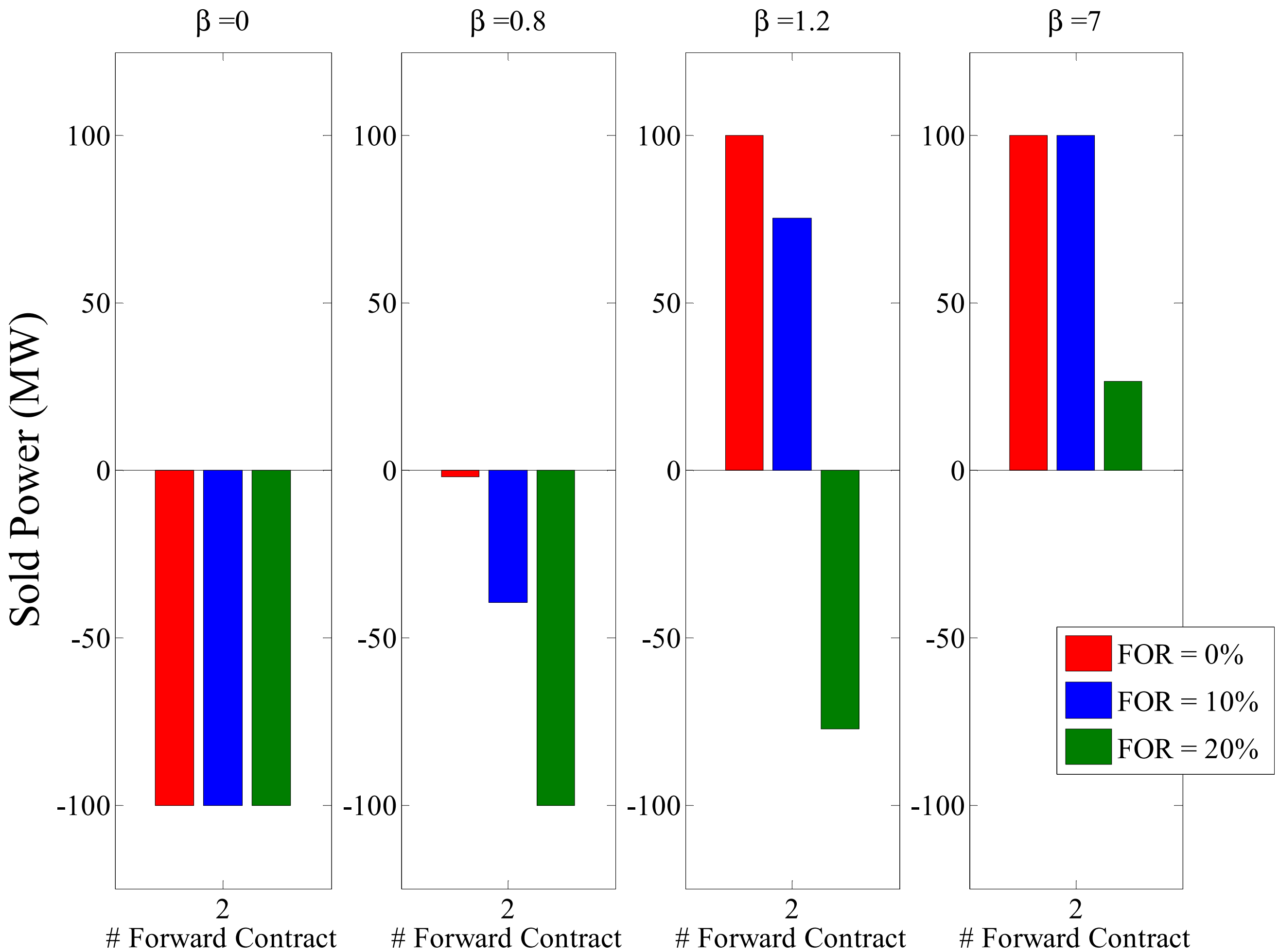
Results



$$\beta\uparrow\Rightarrow\begin{cases}\text{expected profit}\downarrow\\ \text{profit standard desviation}\downarrow\end{cases}$$

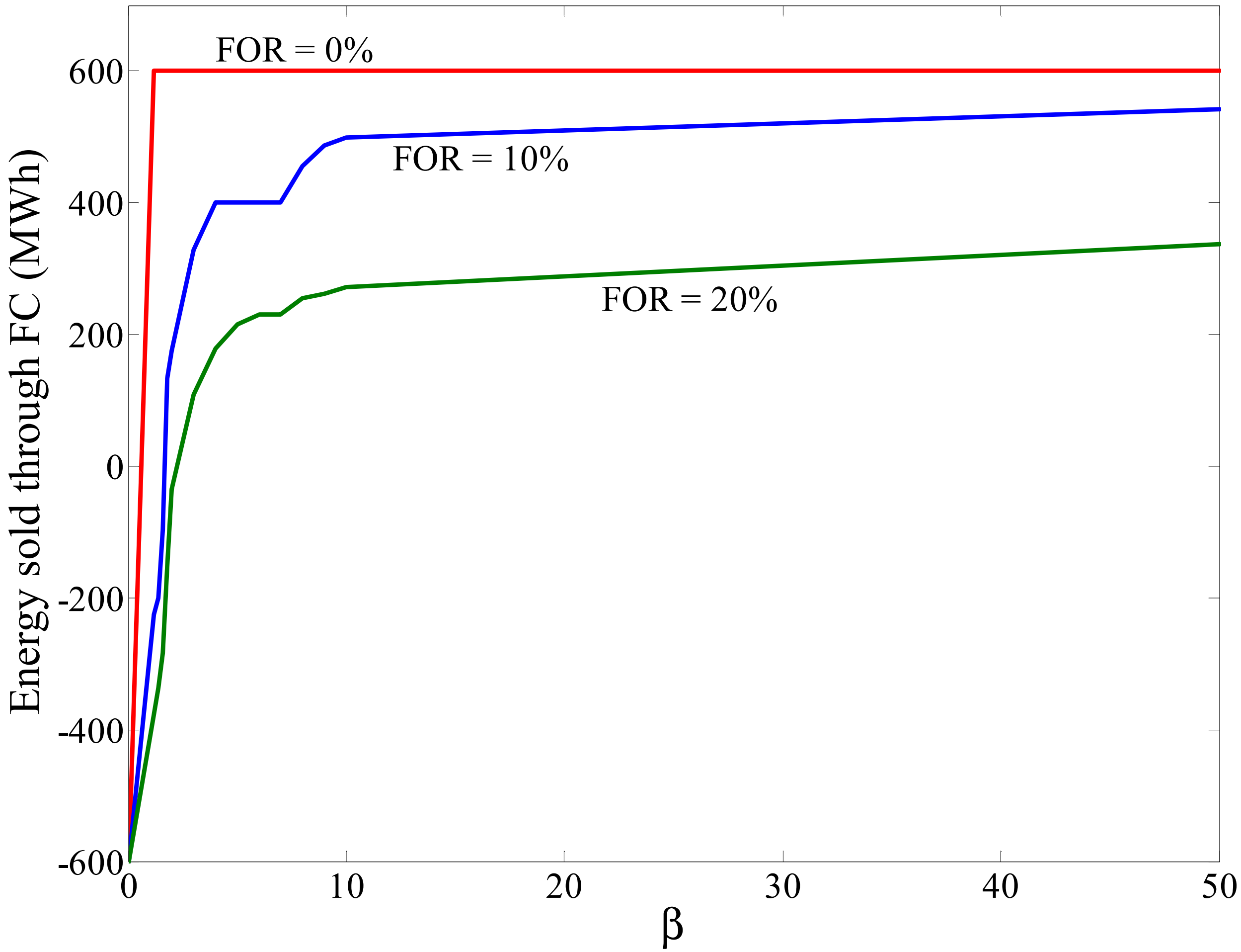
$$FOR\uparrow\Rightarrow \text{expected profit}\downarrow\downarrow$$

Results



The higher the FOR, the lower the energy sold through FC

Results



The producer sells less energy through forward contracts if the possibility of a unit failure increases

Conclusion

- The energy sold through forward contracts by a unit decreases if its FOR increases

Simulation Data

- GAMS: cplex solver
- 2,6 GHz
- Linear optimization problem with continuous variables
- $4.2 \cdot 10^5$ variables
- $6.3 \cdot 10^5$ constraints
- Solution time: 3 minutes

Future work

- Forward contracts with increasing prices
- Include financial options
- Possibility of selling to end users directly ("gentailer")
- Analyze different scenario reduction techniques

Thanks for your attention!

GSEE: http://www.uclm.es/area/gsee/