Options to Hedge Against Producer Risks in Electricity Markets

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Outline

- Introduction
- Model
- Case study
- Conclusions

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Introduction

- How do electricity options work?
- How can electricity options be modeled?
- How do electricity options reduce price risk?
- How do electricity options reduce availability risk?
- When is an option contract more profitable than a forward contract?

Introduction

Pool market

(price risk)

Introduction

Pool market
(price risk)

Futures market
(fixed price)

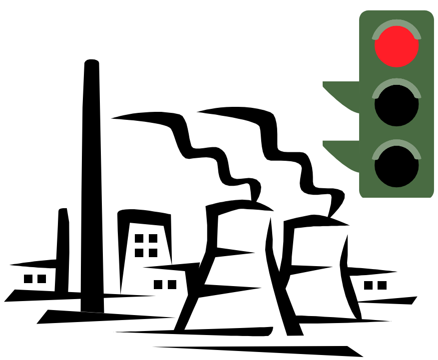
Introduction

Pool market

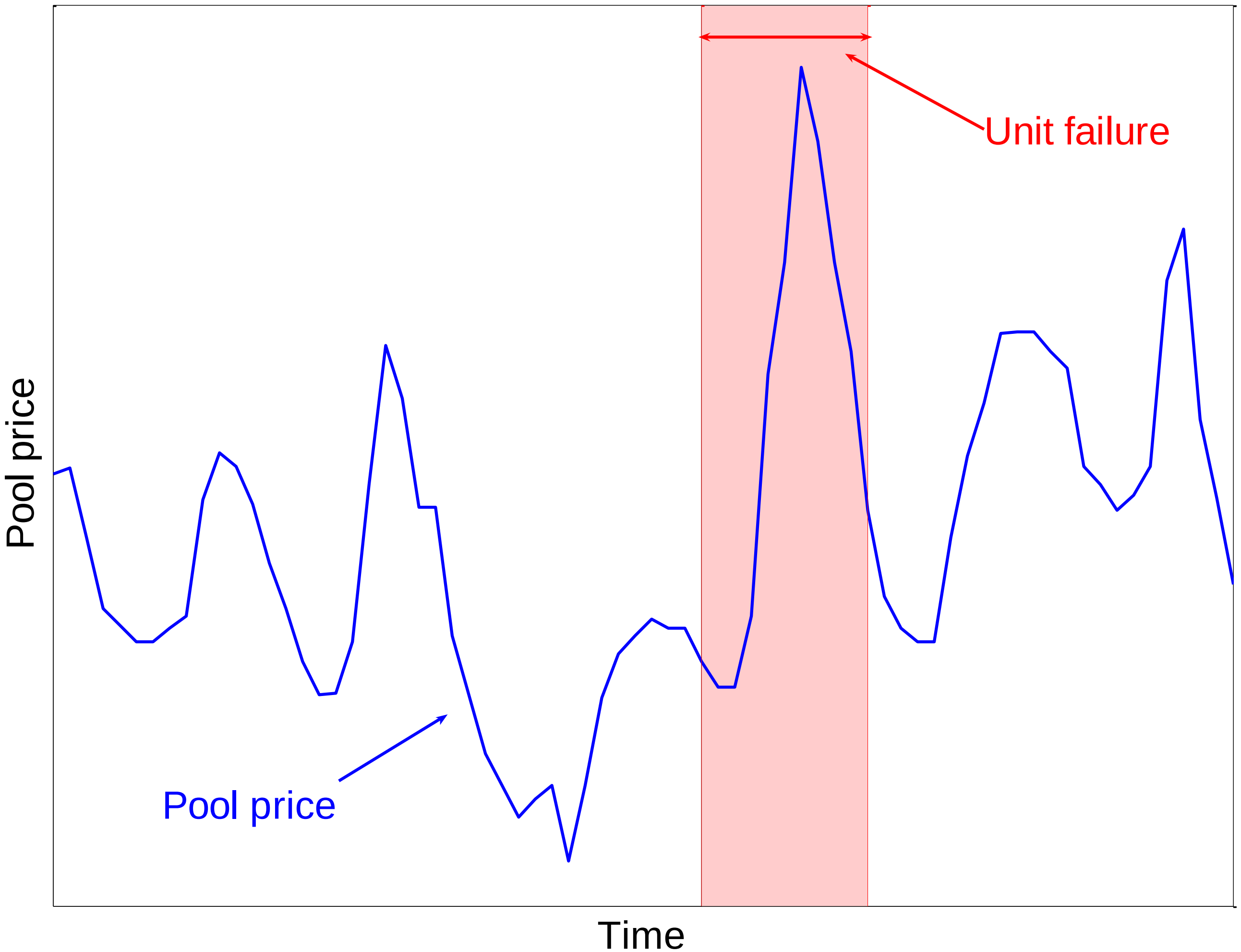
(price risk)

Production unit

(availability risk)



Introduction



Introduction

Pool market
(price risk)

Production unit
(availability risk)

Futures market
(fixed price)

?

Introduction

Forward contract	Option contract
➢ Fixed price	➢ Fixed price
➢ Obligation to buy/sell	➢ Right to buy/sell
➢ No cost	➢ Option price

Introduction

Option contract

- Two positions (buyer and seller of the option)
- Put options (right to sell)
- Call options (right to buy)
- European options (exercised at expiration)
- American options (exercised any time until expiration)

Introduction

Option contract

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Introduction

Option contract

Name	Best Bid	Best Ask	No. of Contr.	Last Price	Abs. Change	Last Time	Last Vol.	Settl. Price
Nov-10	-	-	-	-	-	-	-	48.52
Dec-10	47.00	47.15	85	-	-	-	-	47.07
P 4300	-	-	-	-	-	-	-	0.058
P 4400	-	-	-	-	-	-	-	0.134
P 4500	-	-	-	-	-	-	-	0.281
P 4600	-	-	-	-	-	-	-	0.542
P 4700	-	-	-	-	-	-	-	0.955
P 4800	-	-	-	-	-	-	-	1.536
P 4900	-	-	-	-	-	-	-	2.267
P 5000	-	-	-	-	-	-	-	3.110
P 5100	-	-	-	-	-	-	-	4.024

Introduction

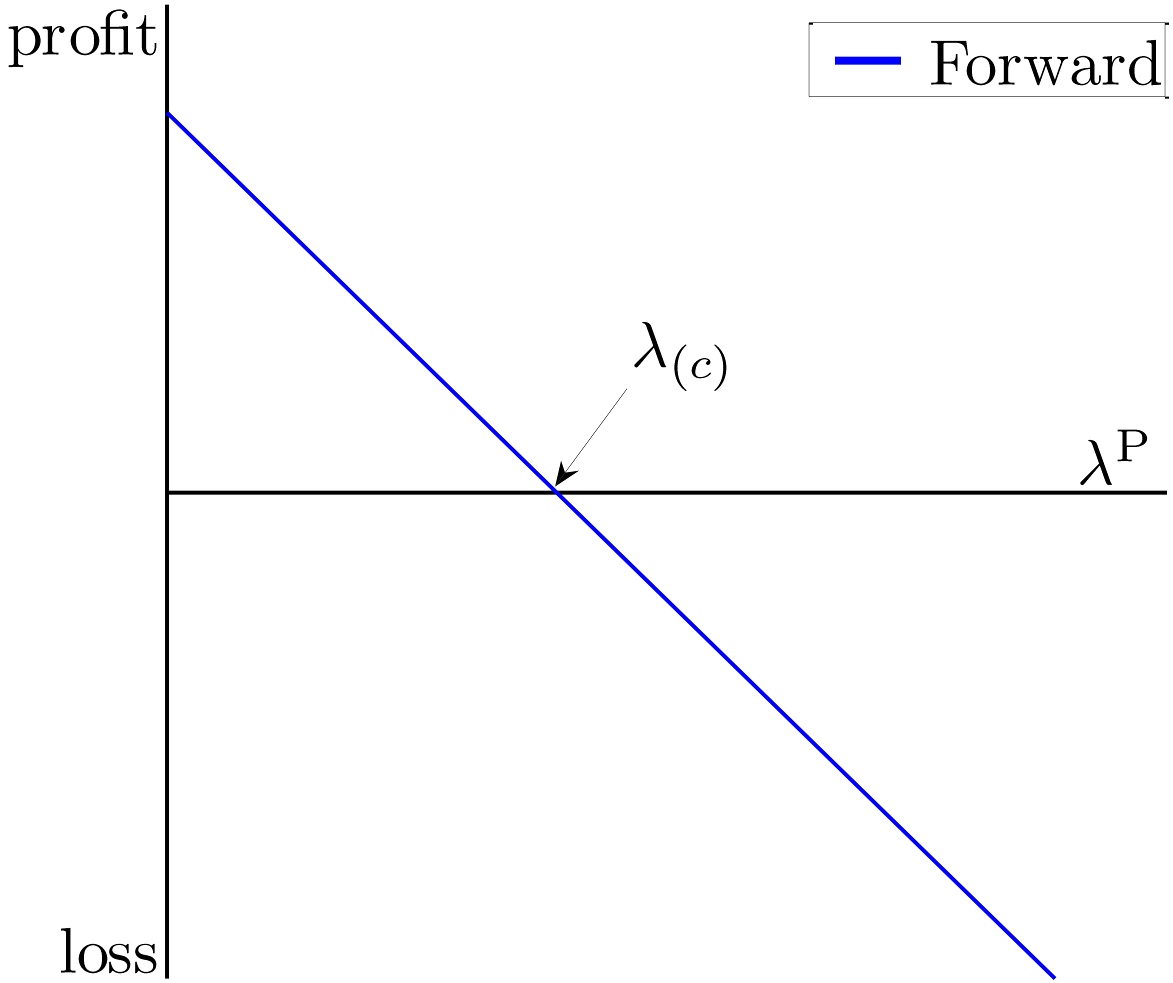
Basic idea

Period 1 | Period 2

Sign a forward contract to sell electricity during period 2

Obligation to sell the agreed electricity at the agreed price

Introduction



Introduction

Basic idea

Period 1 | Period 2

Sign a put option to sell electricity during period 2

Introduction

Basic idea

Period 1

Period 2

Sign a put option to sell electricity during period 2

Option is exercised to hedge against low prices

Introduction

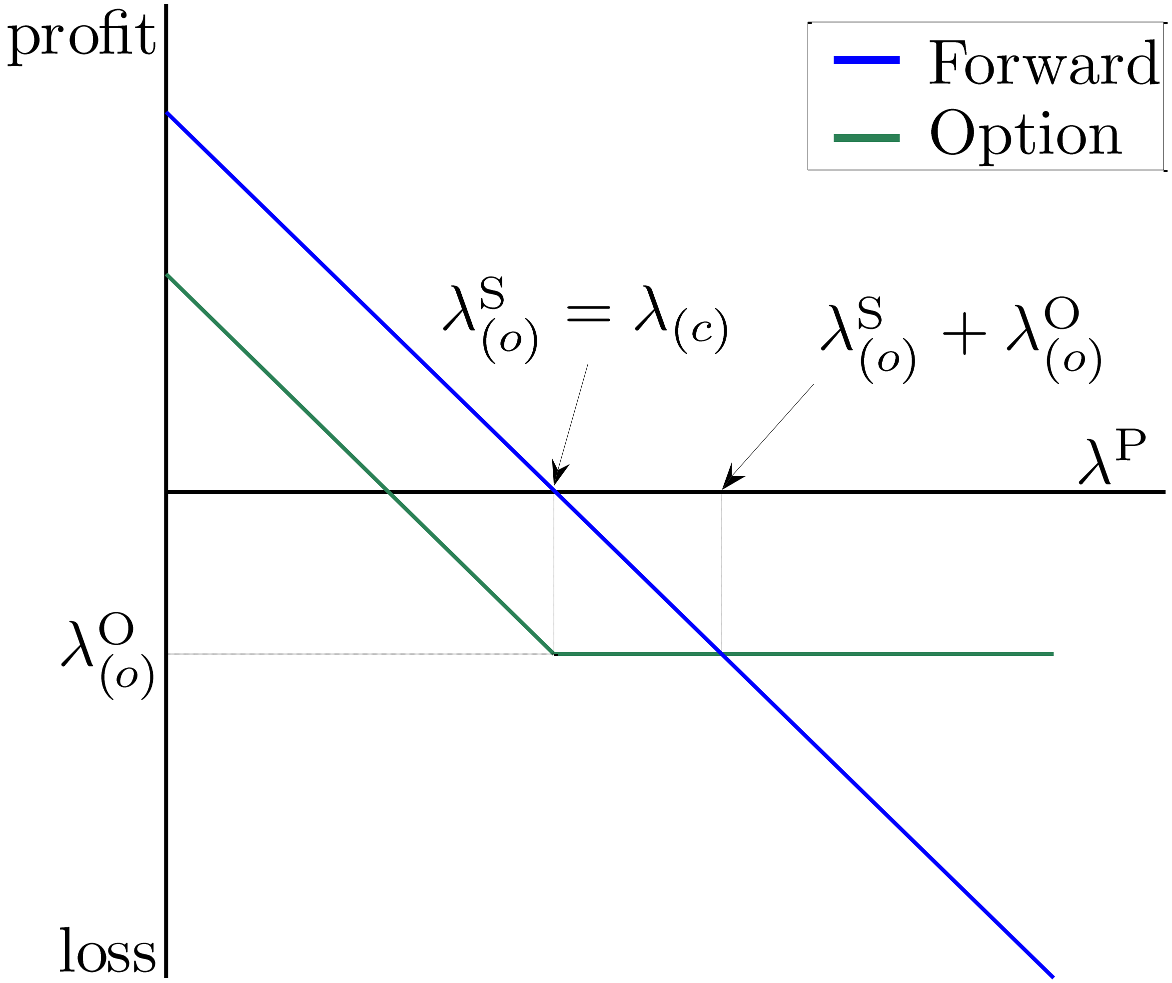
Basic idea

Period 1	Period 2

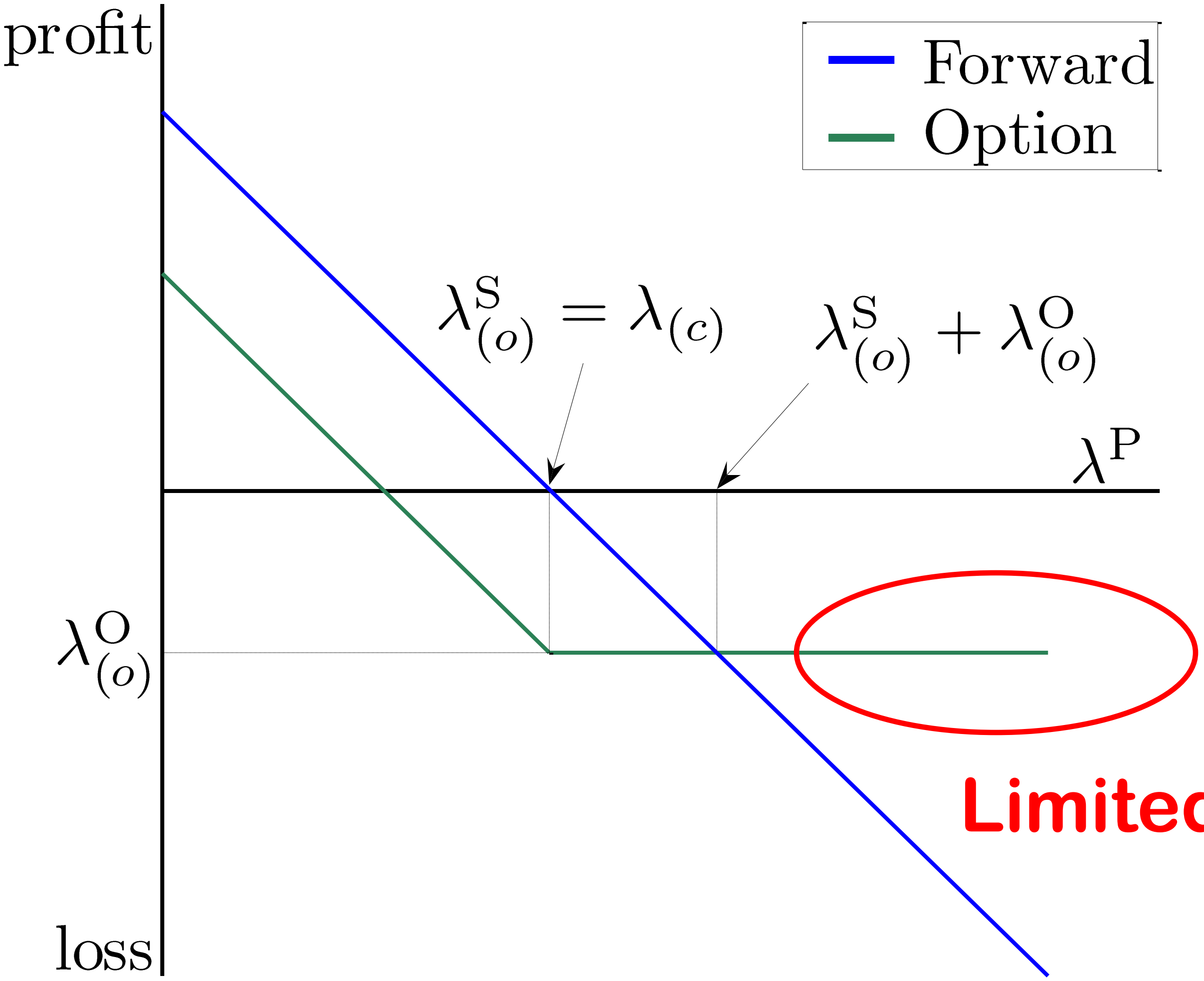
Sign a put option to sell electricity during period 2

Option is not exercised to obtain high profits

Introduction



Introduction



Limited losses!

Introduction

Basic idea

Period 1 | Period 2

Sign a put option to sell electricity during period 2

Option is not exercised to hedge against unit failures

Introduction

Basic idea

Period 1

Period 2

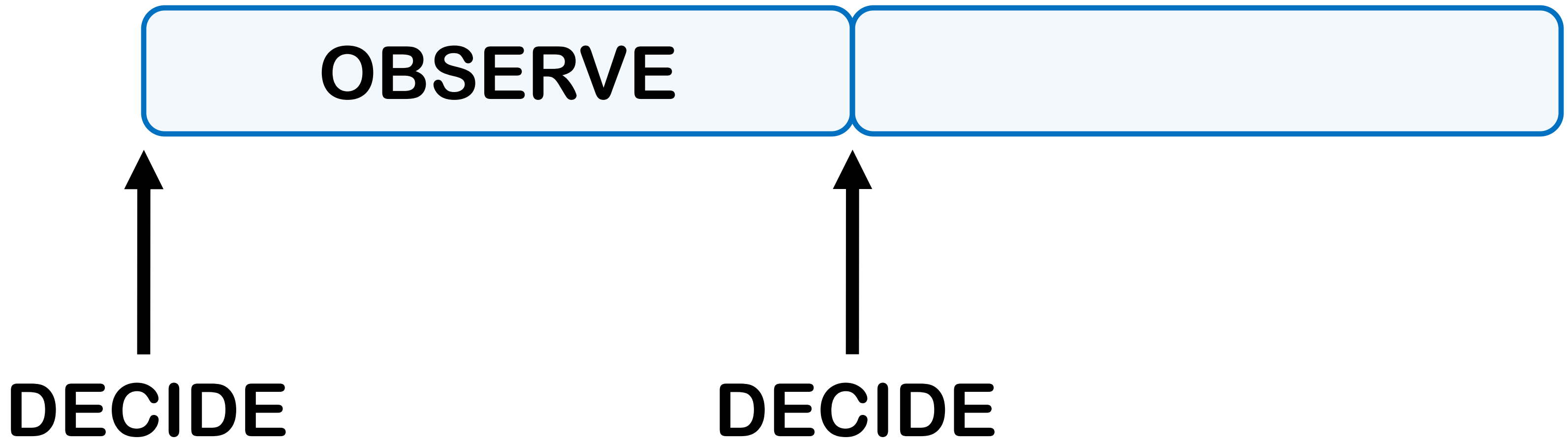
Sign a put option to sell electricity during period 2

Option is exercised

Introduction

- How do electricity options work? ✓
- How can electricity options be modeled?
- How do electricity options reduce price risk?
- How do electricity options reduce availability risk?
- When is an option contract more profitable than a forward contract?

Introduction



Multi-stage stochastic programming

Introduction

Period 1	Period 2

First-stage decisions:

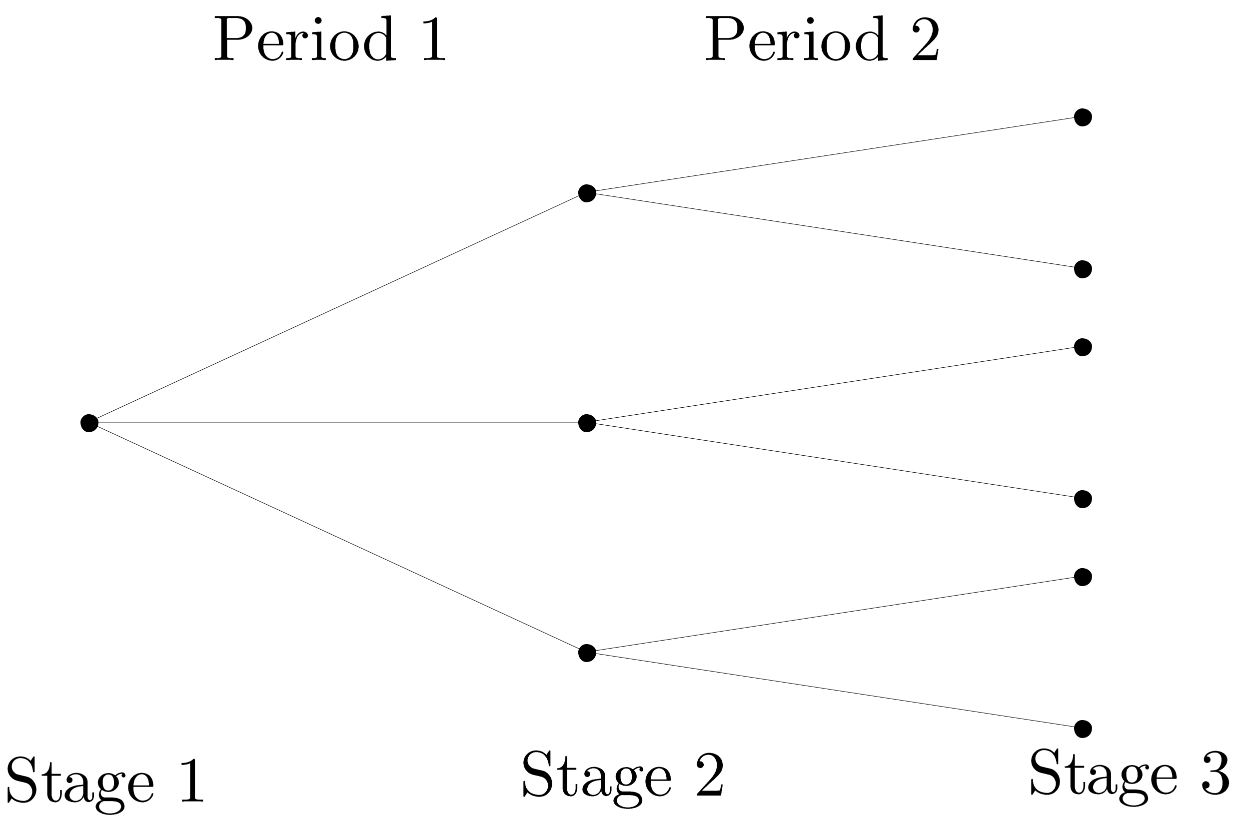
- Option purchase
- Forward contracting

Second-stage decision:

- Option exercise

Introduction

Scenario tree



Introduction

- How do electricity options work? ✓
- How can electricity options be modeled? ✓
- How do electricity options reduce price risk?
- How do electricity options reduce availability risk?
- When is an option contract more profitable than a forward contract?

Aim

Analyze electricity options to manage the two main risks faced by power producers: price and availability risks.

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Model

Sources of uncertainty

Pool prices

Unit availability

Forward contracts

Option contracts

Model

Sources of uncertainty

Pool prices | Unit availability

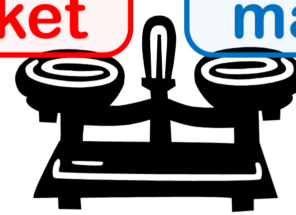
Forward contracts

Option contracts

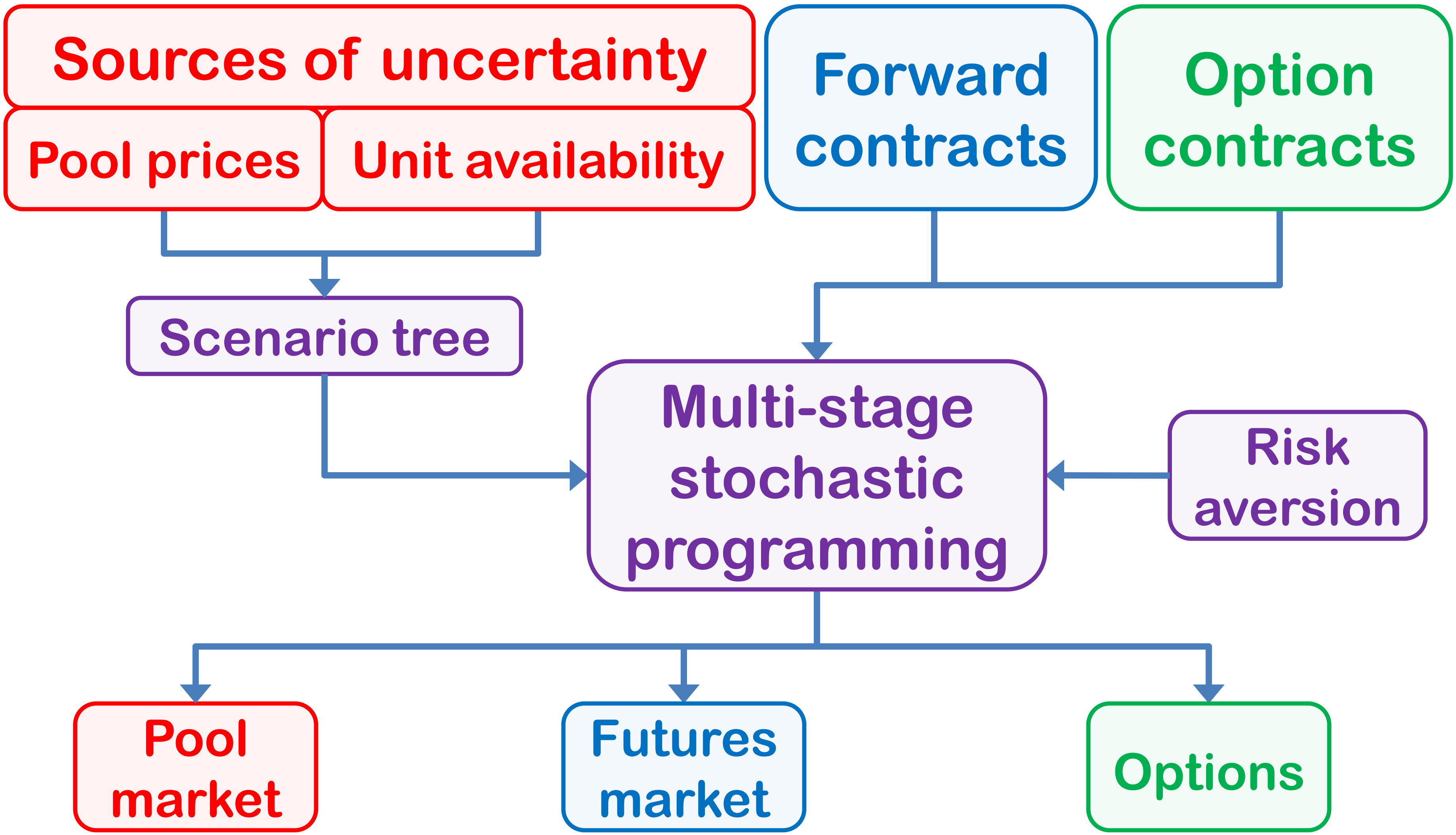
Options

Pool market

Futures market



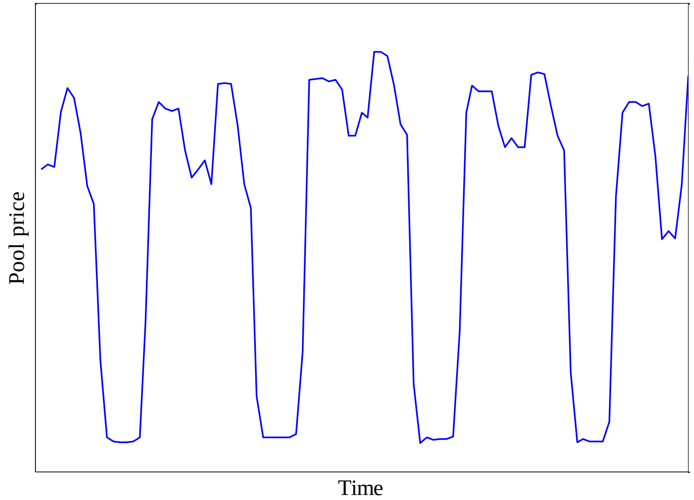
Model


Sources of uncertainty
Pool prices
Unit availability
Forward contracts
Option contracts
Scenario tree
Multi-stage stochastic programming
Risk aversion
Pool market
Futures market
Options

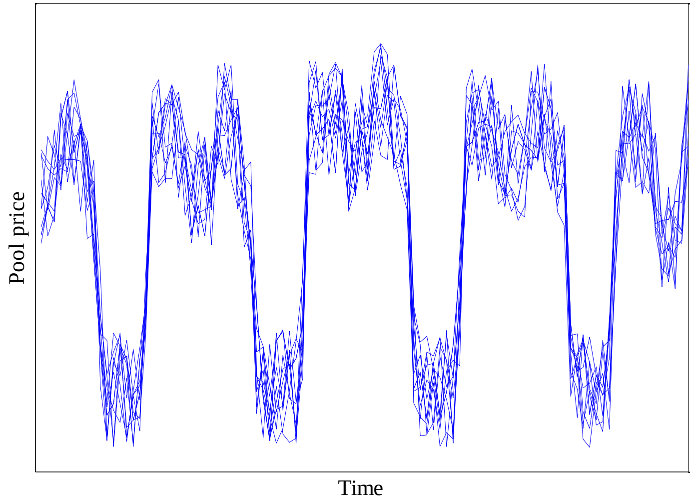
Model

Pool prices

Historical data



Pool price scenarios

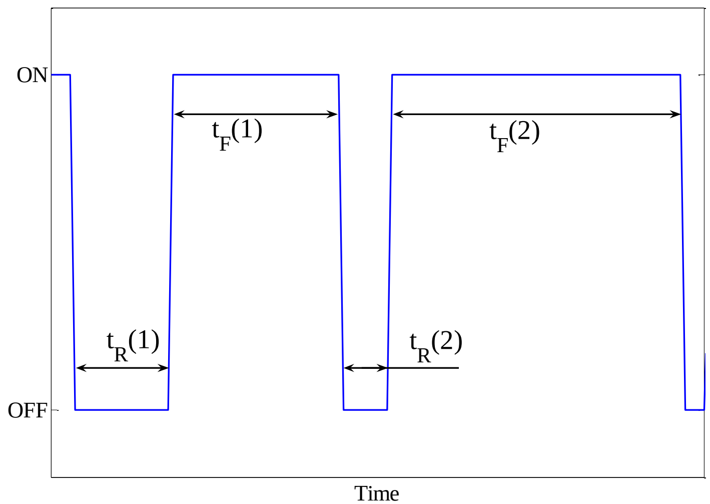


Time series model

Model

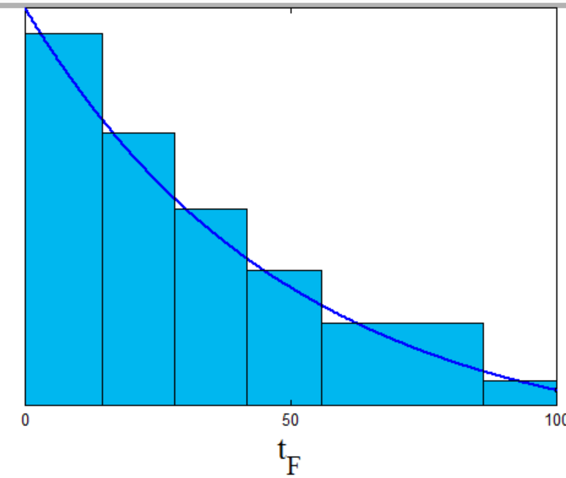
Unit availability

Historical data



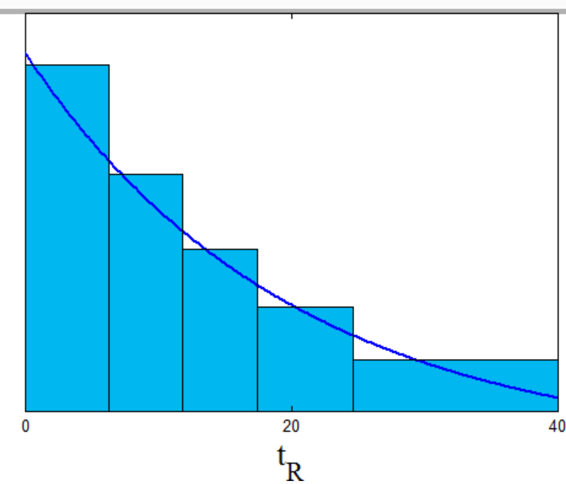
$$\text{FOR}(\%) = \frac{\text{MTTR}}{\text{MTTR} + \text{MTTF}}$$

Failure time series = 20, 35, ...



~ exp(MTTF)

Repair time series = 12, 8, ...



~ exp(MTTR)

Model

Unit availability

$$\left.\begin{array}{l} t_F \sim \exp(MTTF) \\ t_R \sim \exp(MTTR) \end{array}\right\} \; p(u_t = \mathbf{1}) = \frac{\mu}{\lambda+\mu} + \frac{\mu(u_{\mathbf{0}} - \mathbf{1}) + \lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}$$

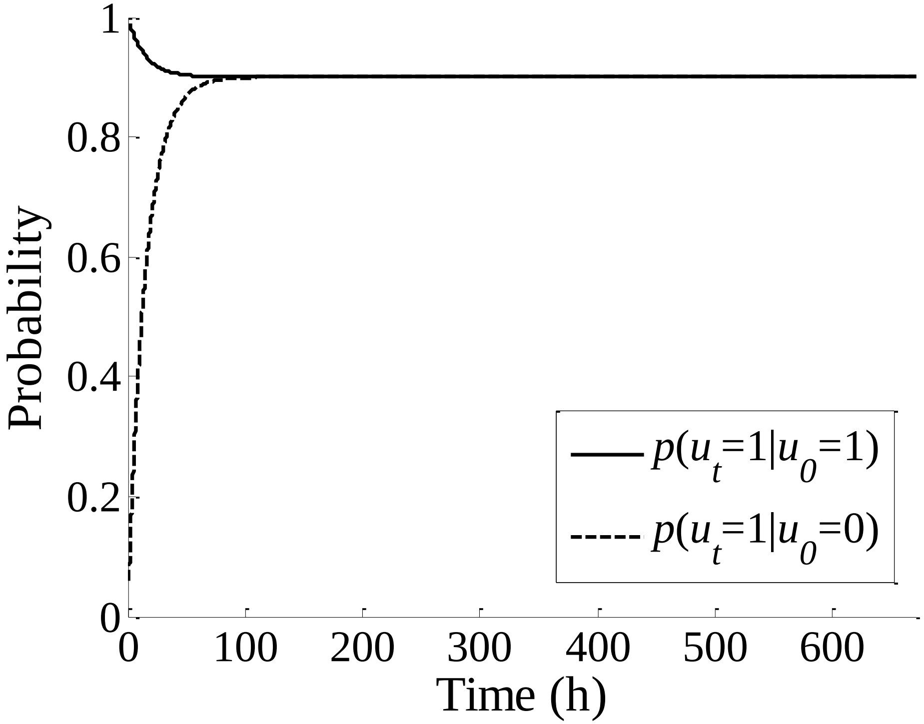
$$\lambda = \frac{\mathbf{1}}{MTTF} \qquad \mu = \frac{\mathbf{1}}{MTTR}$$

Model

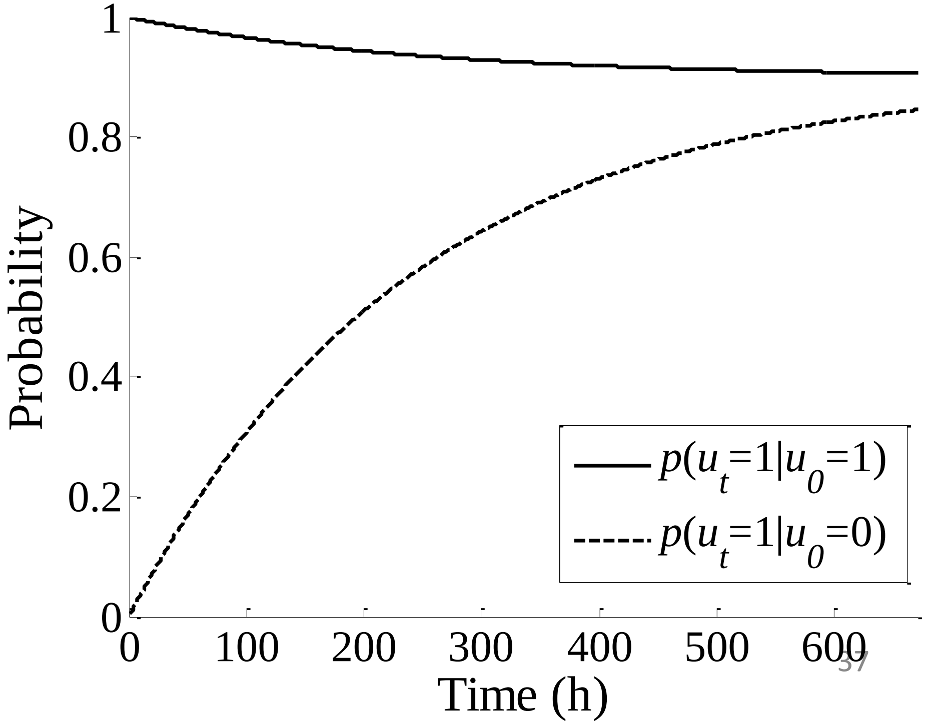
Unit availability

$$\left.\begin{array}{l} t_F \sim \exp(\text{MTTF}) \\ t_R \sim \exp(\text{MTTR}) \end{array}\right\} p(u_t = \mathbf{1}) = \frac{\mu}{\lambda+\mu} + \frac{\mu(u_0 - \mathbf{1}) + \lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}$$

MTTF<<T



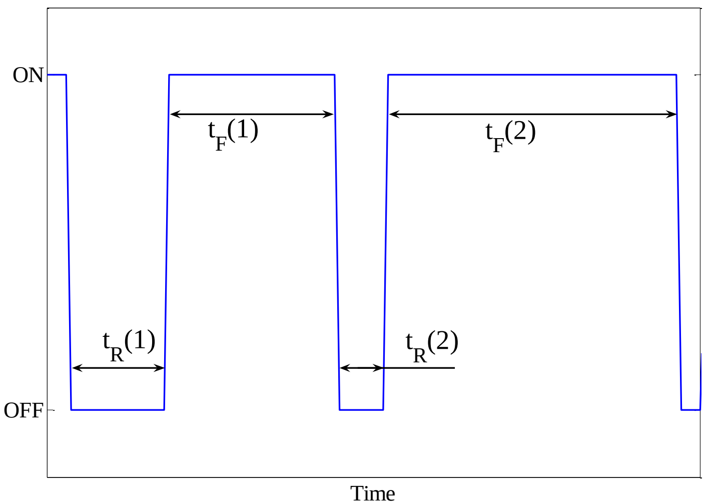
MTTF>>T



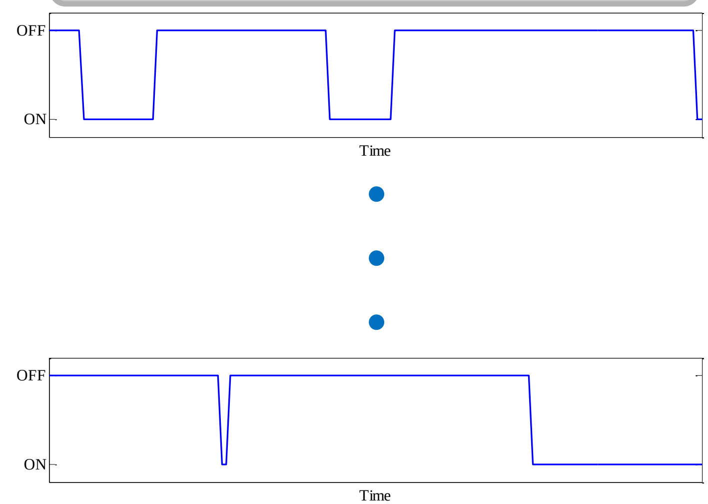
Model

Unit availability

Historical data



Availability scenarios



$$t_F \sim \exp(MTTF)$$
$$t_R \sim \exp(MTTR)$$

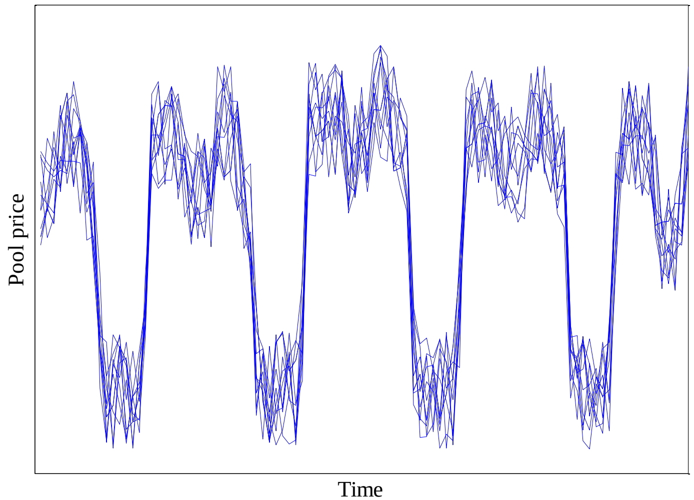
Model

Sources of uncertainty

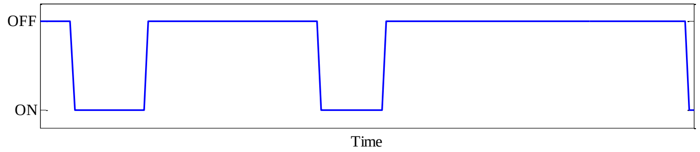
Pool prices | Unit availability

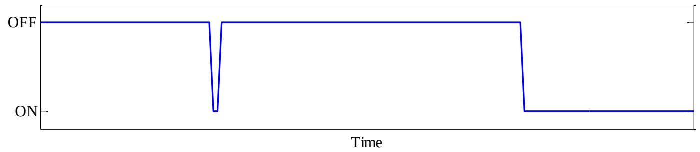
Scenario tree

Pool price scenarios



Availability scenarios





Model

Forward contracts

- Specified quantity (MW)
- Fixed price
- Future delivery period

Model

Option contract

- Specified quantity (physical delivery)
- Strike price
- Option price
- Time period covered
- Time to decide whether it is exercised

Model

Stochastic programming

Objective function

Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

Constraints

Production unit bounds

Energy balances

Forward and option constraints

Nonanticipativity constraints

Model

Stochastic programming

Objective function

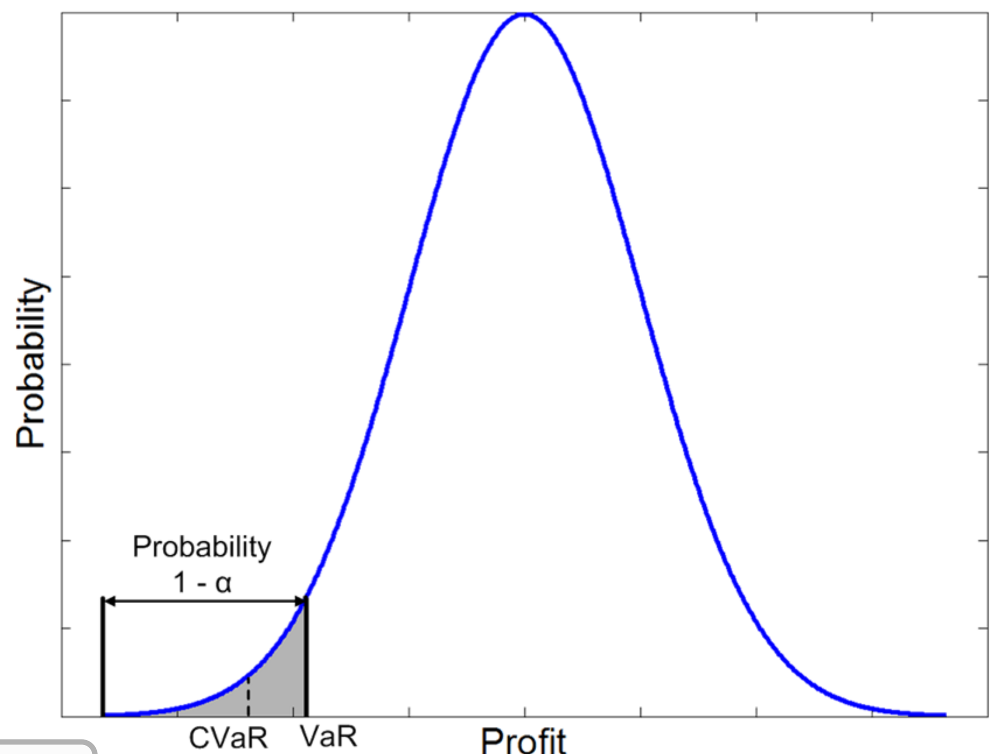
Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

Risk aversion

$$\text{CVaR}_{\alpha} = \zeta - \frac{1}{1-\alpha}\sum_{\omega=1}^{N_W} \pi_{\omega}\eta_{\omega}$$

$$-\,profit_{\omega} + \zeta - \eta_{\omega} \leq 0$$

$$\eta_{\omega} \geq 0$$



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Production unit bounds

Energy balances

Forward and option constraints

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Objective function

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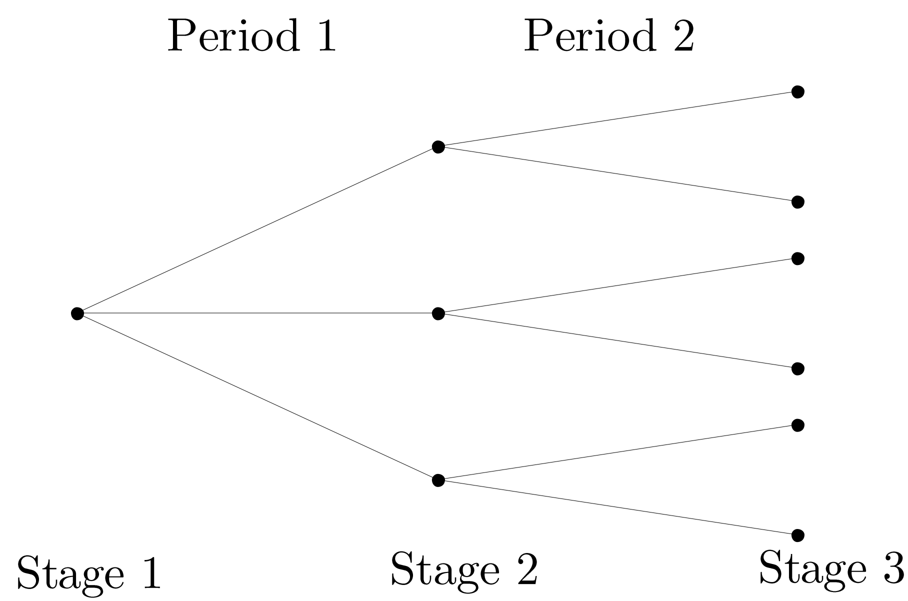
Constraints

- Production unit bounds
- Energy balances
- Forward and option constraints
- Nonanticipativity constraints



Second-stage decicions are made knowing the scenario realization during period 1 but still facing uncertainty related to period 2.

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Case study

- 2 months (P1 = first month, P2 = second month)
- Generating unit
  - Pmax = 350 MW, Pmin = 50 MW, C = 12 €/MWh (linear)
  - Three FOR values: 0, 5 and 10%
- 30 pool-price scenarios (ARIMA)
- 30 availability scenarios for each value of FOR
- 2 forward contracts, one for each month
- 1 put option spanning the second month

Case study

- (a) sell 350MW during the second month at 21€/MWh. No re-trading in stage 2.
- (b) buy a put option to sell 350MW during the second month at 21€/MWh. Option price = 0.1€/MWh

Case study

α	FOR = 0%		FOR = 5%		FOR = 10%	
	(a)	(b)	(a)	(b)	(a)	(b)
0	5.087	5.418	4.984	5.314	4.878	5.209
0.5	5.078	5.117	4.872	4.970	4.664	4.860
0.9	5.078	5.055	4.549	4.649	4.374	4.499

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OPTION > FORWARD

Case study

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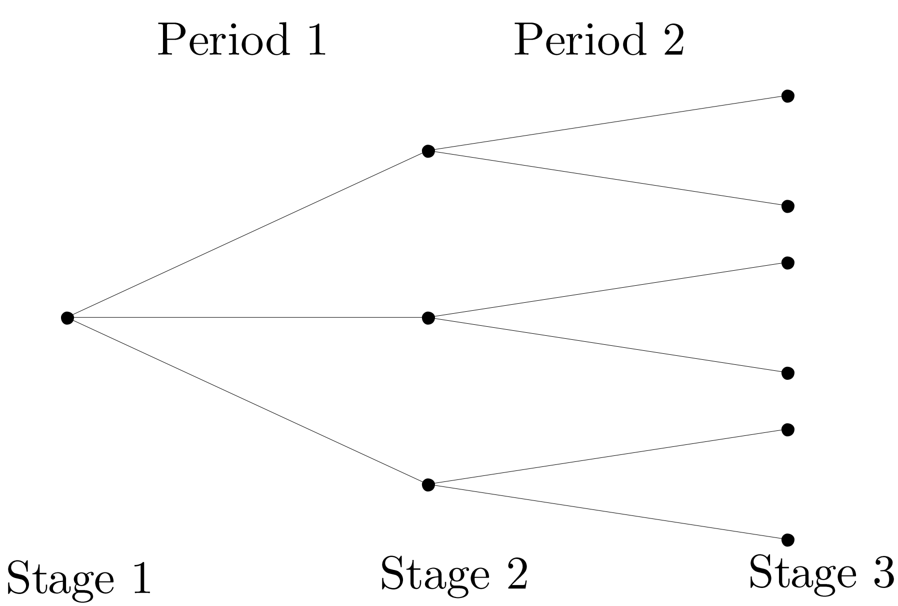

$E_2\{\lambda^P\}$	$y_{o\omega}$
22.41	0
22.58	0
22.64	0
20.97	1
24.39	0
21.85	0
22.35	0
20.28	1
26.01	0
22.04	0

Case study

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OPTIONS reduce price risk

Case study

- How do electricity options work? ✓
- How can electricity options be modeled? ✓
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- How do electricity options reduce availability risk?
- When is an option contract more profitable than a forward contract?

Case study

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↑ risk aversion → **OPTION** ≈ **FORWARD**

Case study

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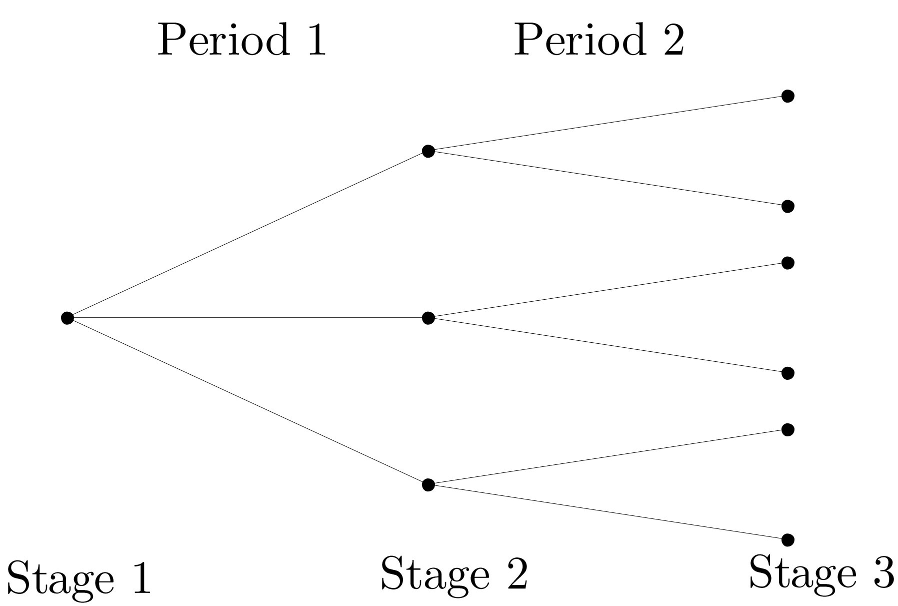

$E_2\{\lambda^P\}$ / k_{NT1}	26.01	20.97	20.28
1	0	1	1
0	0	0	1
1	0	1	1
1	0	1	1
1	0	1	1
1	0	1	1
1	0	1	1
1	0	1	1
1	0	1	1
1	0	1	1

Case study

α	FOR = 0%		FOR = 5%		FOR = 10%	
	(a)	(b)	(a)	(b)	(a)	(b)
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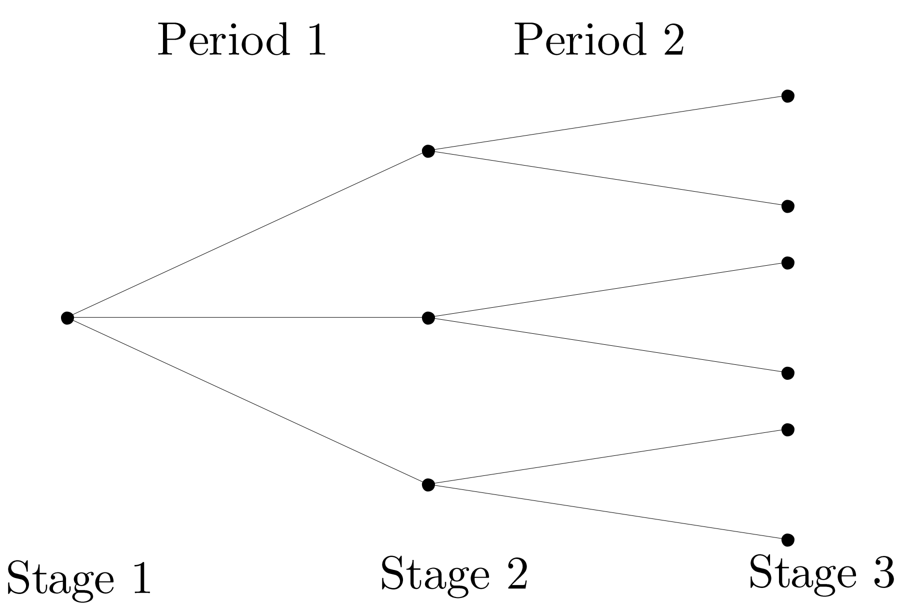

$E_2\{\lambda^P\}$	26.01	20.97	20.28
k_{NT1}			
1	0	1	1
0	0	0	1
1	0	1	1
1	0	1	1
1	0	1	1
1	0	1	1
1	0	1	1
1	0	1	1
1	0	1	1
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Case study

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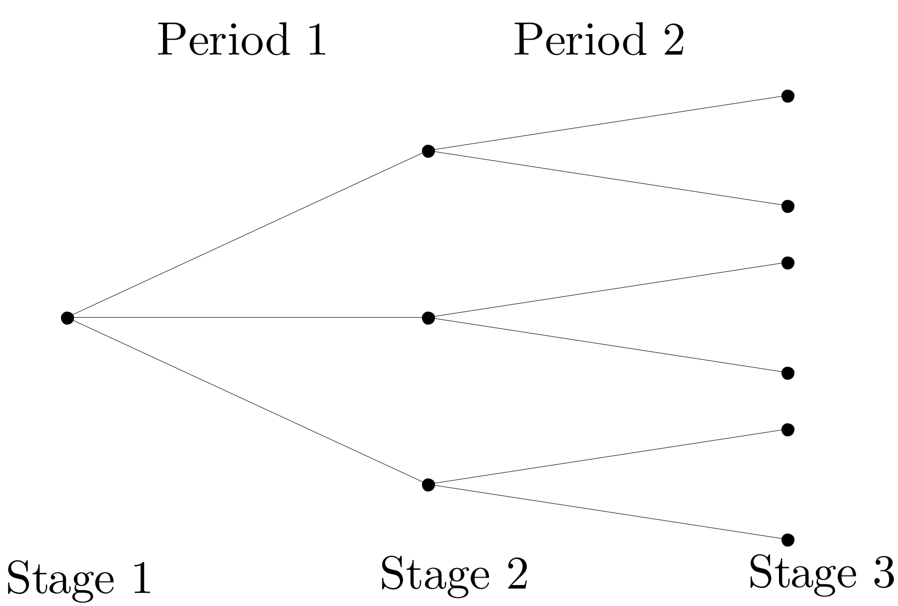

$E_2\{\lambda^P\}$	26.01	20.97	20.28
k_{NT1}			
1	0	1	1
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1	0	1	1
1	0	1	1
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1	0	1	1
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1	0	1	1
1	0	1	1

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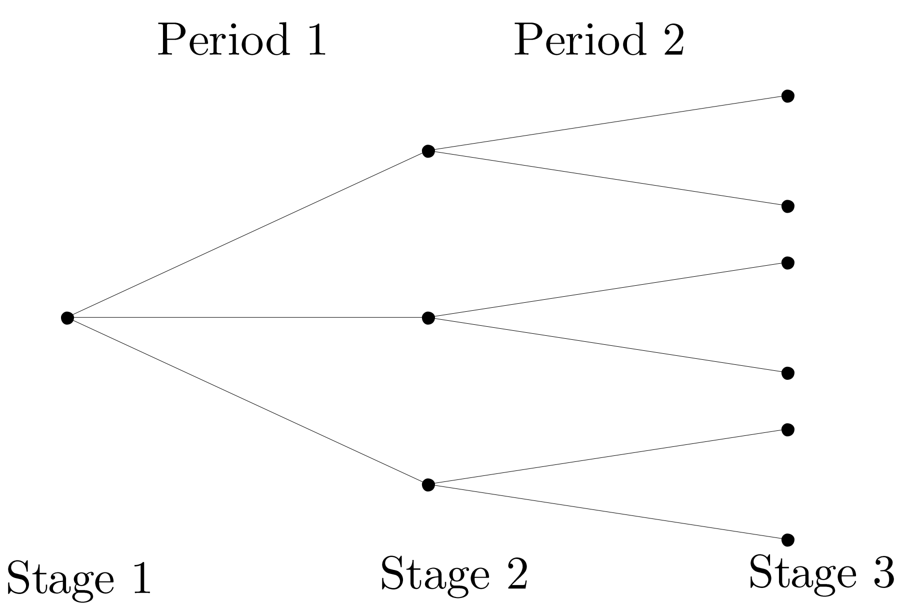

$E_2\{\lambda^P\}$	26.01	20.97	20.28
k_{NT1}			
1	0	1	1
0	0	0	1
1	0	1	1
1	0	1	1
1	0	1	1
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1	0	1	1
1	0	1	1
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OPTIONS reduce availability risk

Case study

- How do electricity options work? ✓
- How can electricity options be modeled? ✓
- How do electricity options reduce price risk? ✓
- How do electricity options reduce availability risk? ✓
- When is an option contract more profitable than a forward contract?

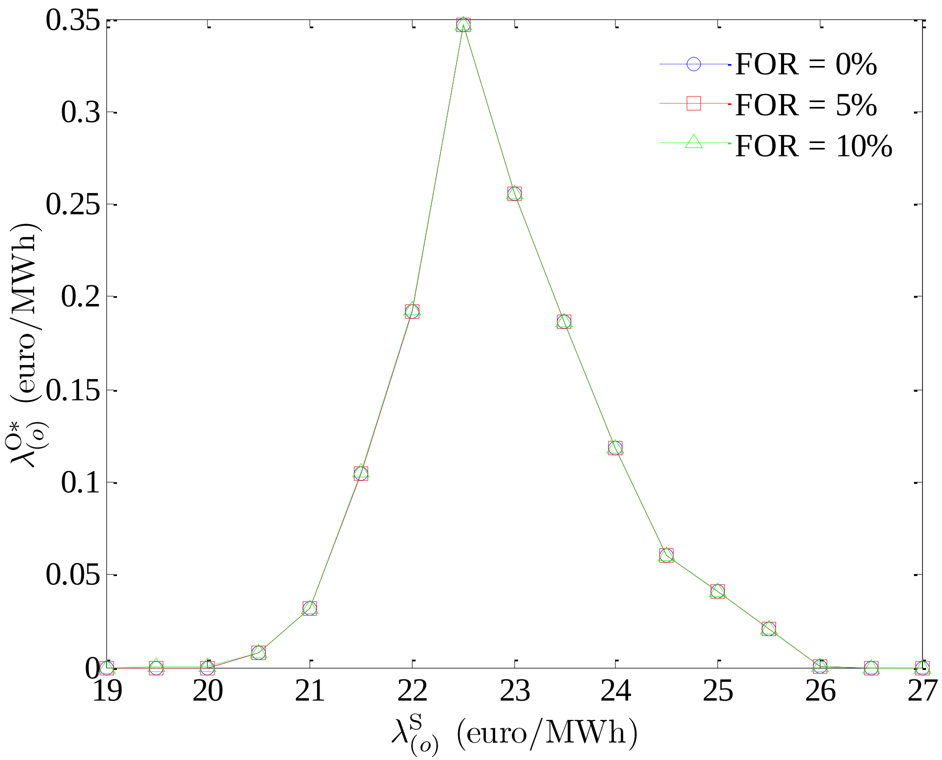
Case study

- **MAXIMUM OPTION PRICE that the power producer is willing to pay for a given option contract.**

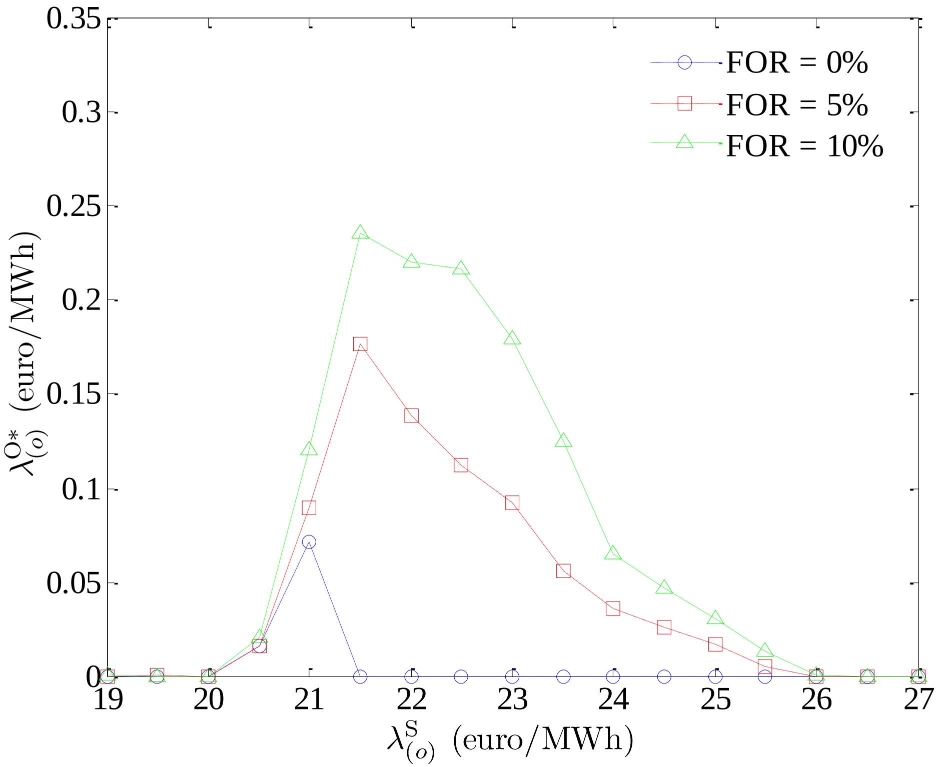
Case study

➢ **MAXIMUM OPTION PRICE**

α = 0



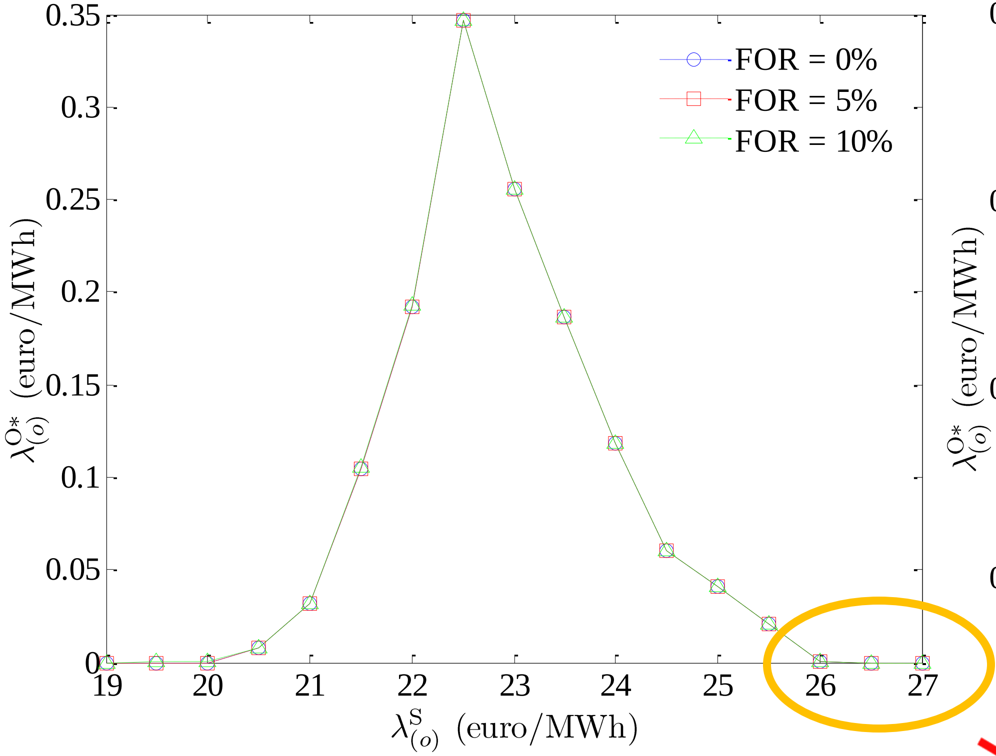
α = 0.5



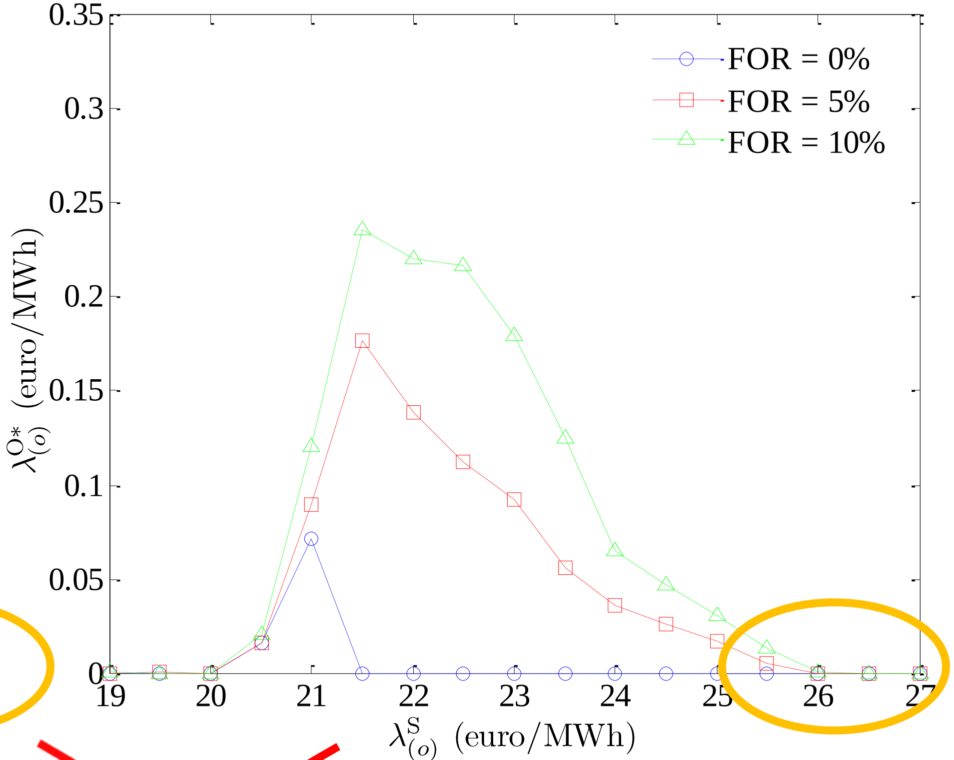
Case study

➢ **MAXIMUM OPTION PRICE**

α = 0



α = 0.5

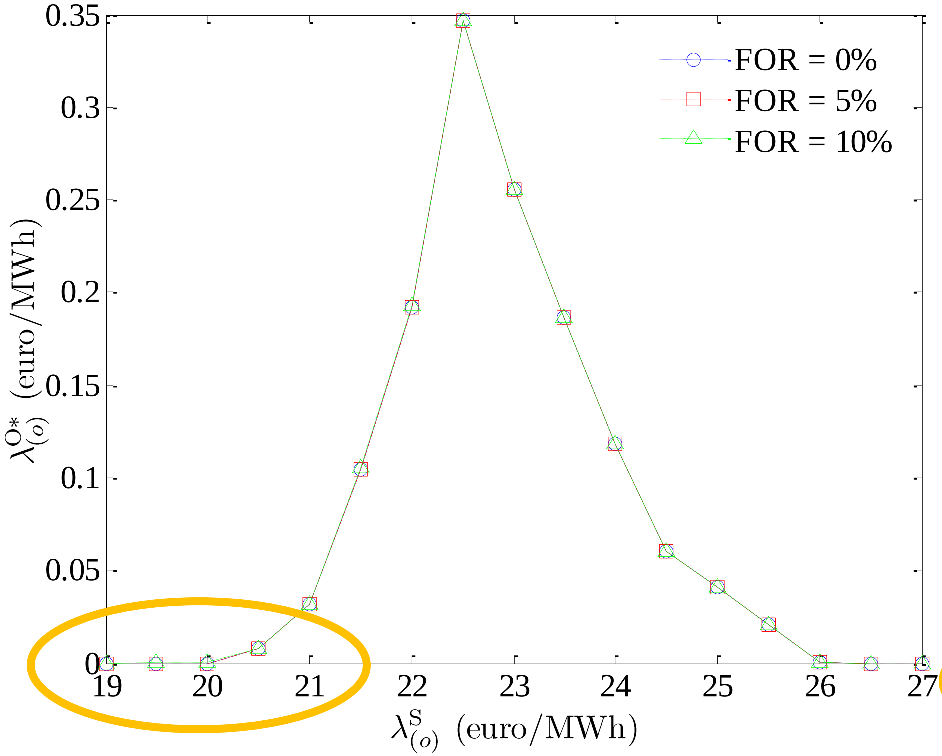


Strike price >> Spot **~~OPTION~~ FORWARD**

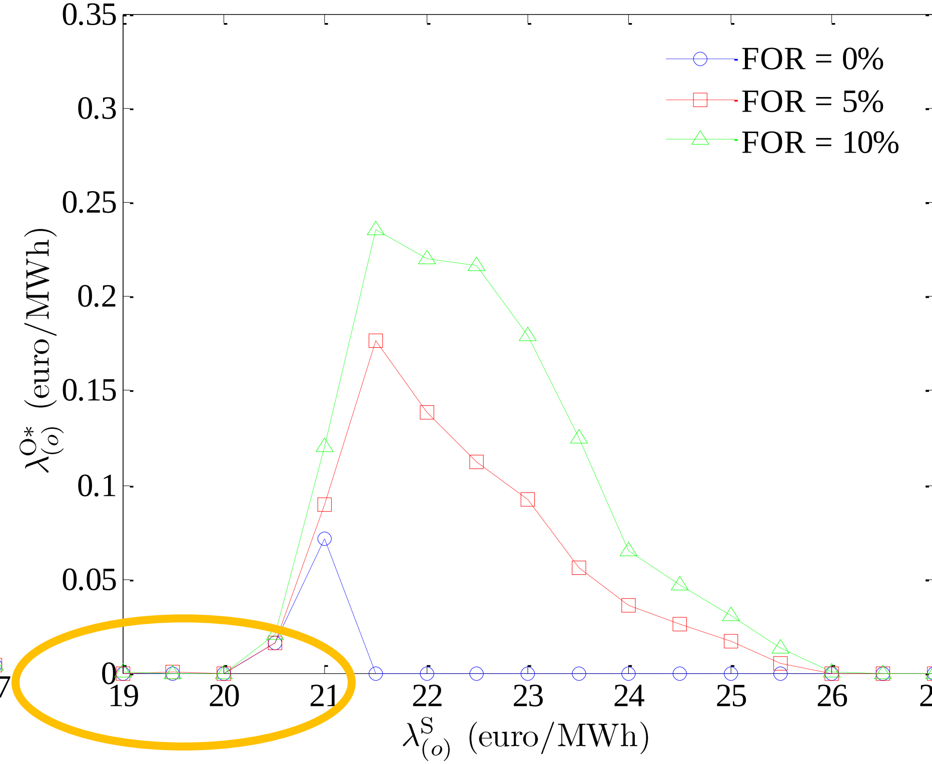
Case study

➢ **MAXIMUM OPTION PRICE**

α = 0



α = 0.5

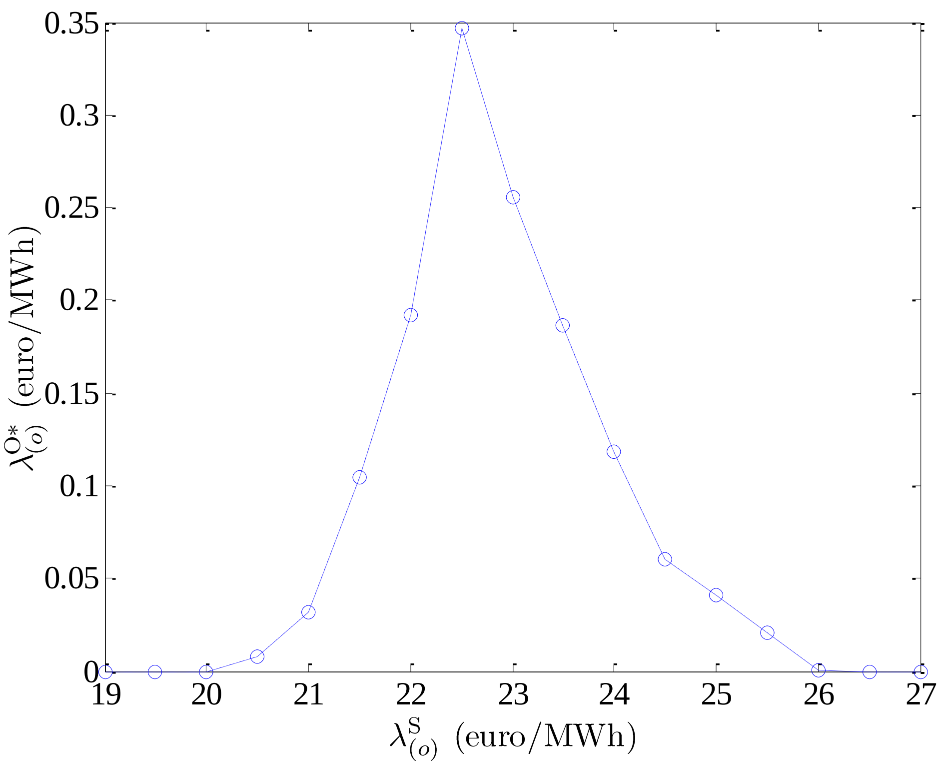


Strike price << Spot ~~OPTION~~ ~~FORWARD~~

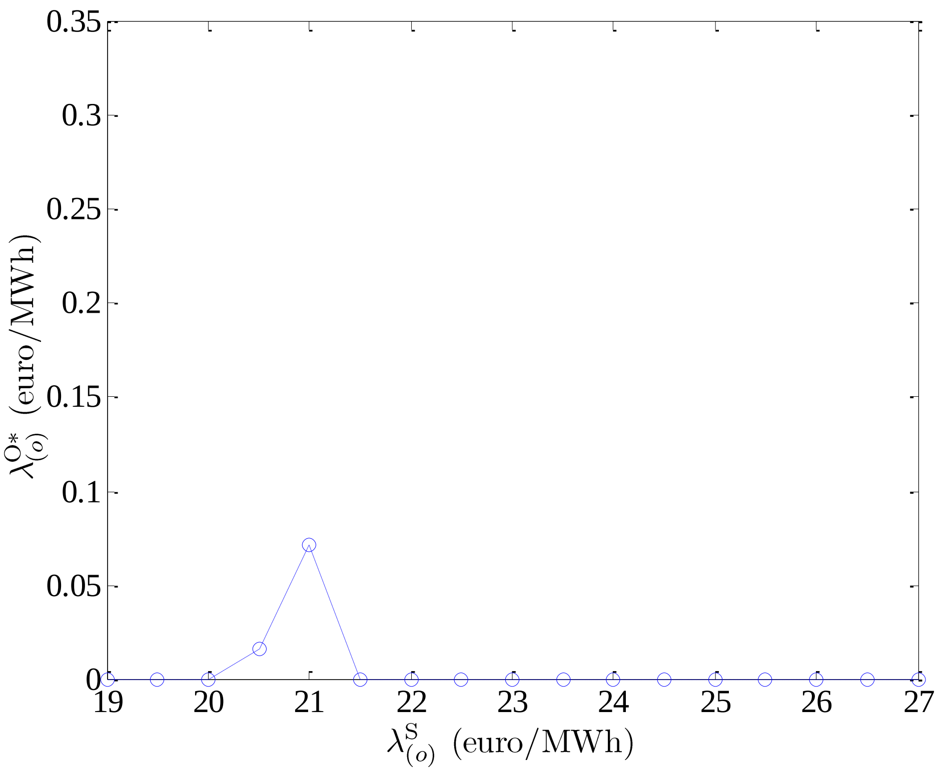
Case study

➢ **MAXIMUM OPTION PRICE**

α = 0



α = 0.5

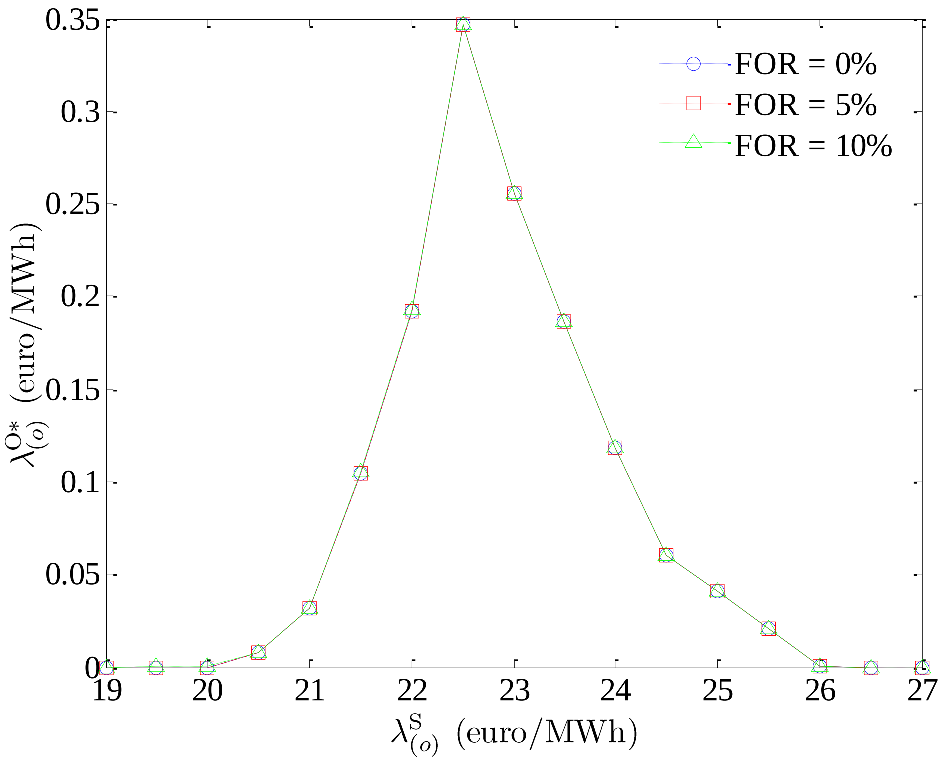


↑ risk aversion →**OPTION ≈ FORWARD**

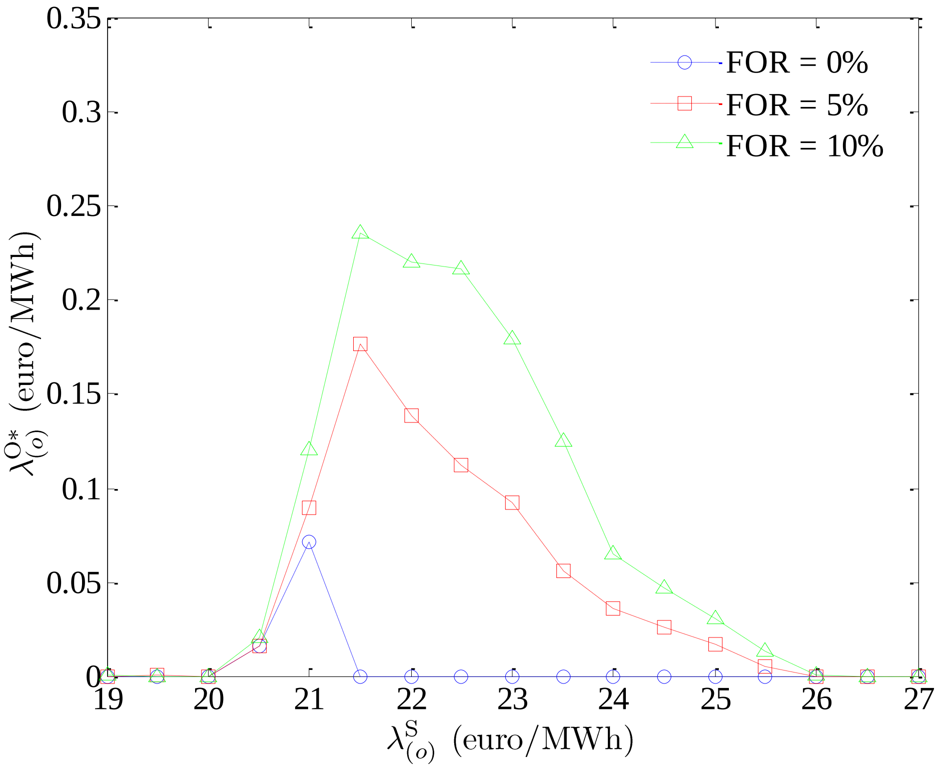
Case study

➢ **MAXIMUM OPTION PRICE**

α = 0



α = 0.5



FOR not relevant

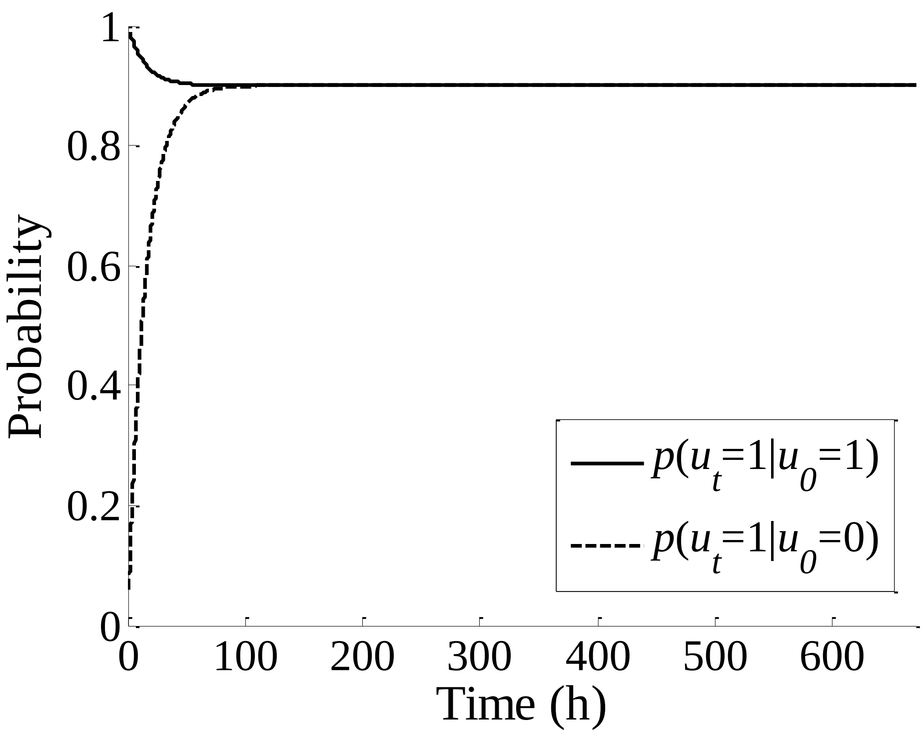
↑FOR→OPTION

Model

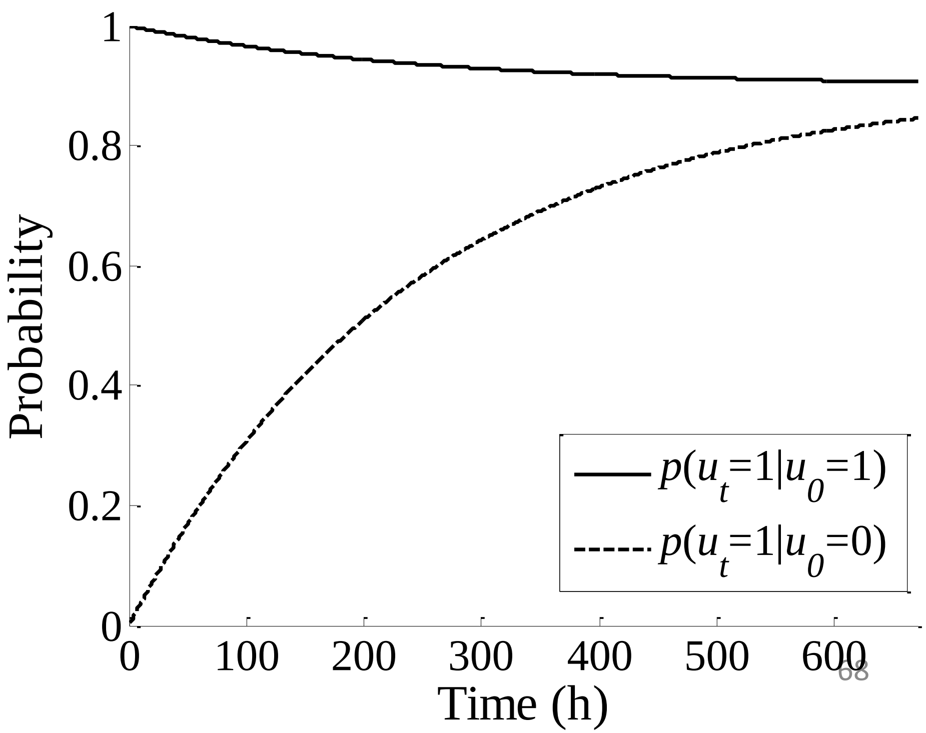
Unit availability

$$\left.\begin{aligned} t_F &\sim \exp(\mathrm{MTTF}) \\ t_R &\sim \exp(\mathrm{MTTR}) \end{aligned}\right\} p(u_t = 1) = \frac{\mu}{\lambda+\mu} + \frac{\mu(u_0 - 1) + \lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}$$

MTTF<<T



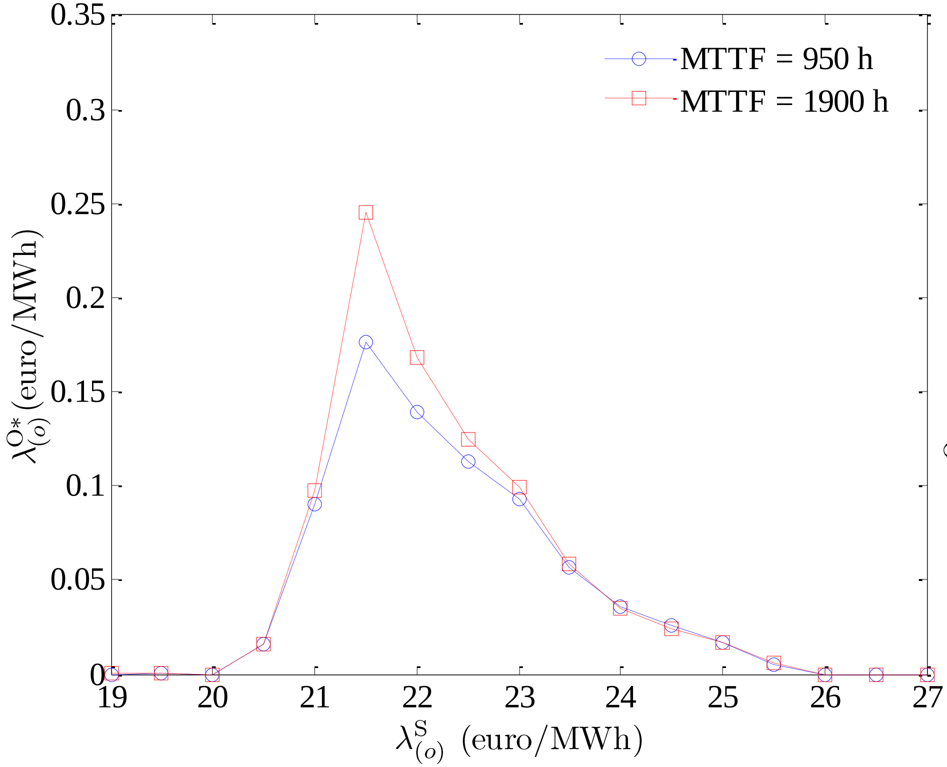
MTTF>>T



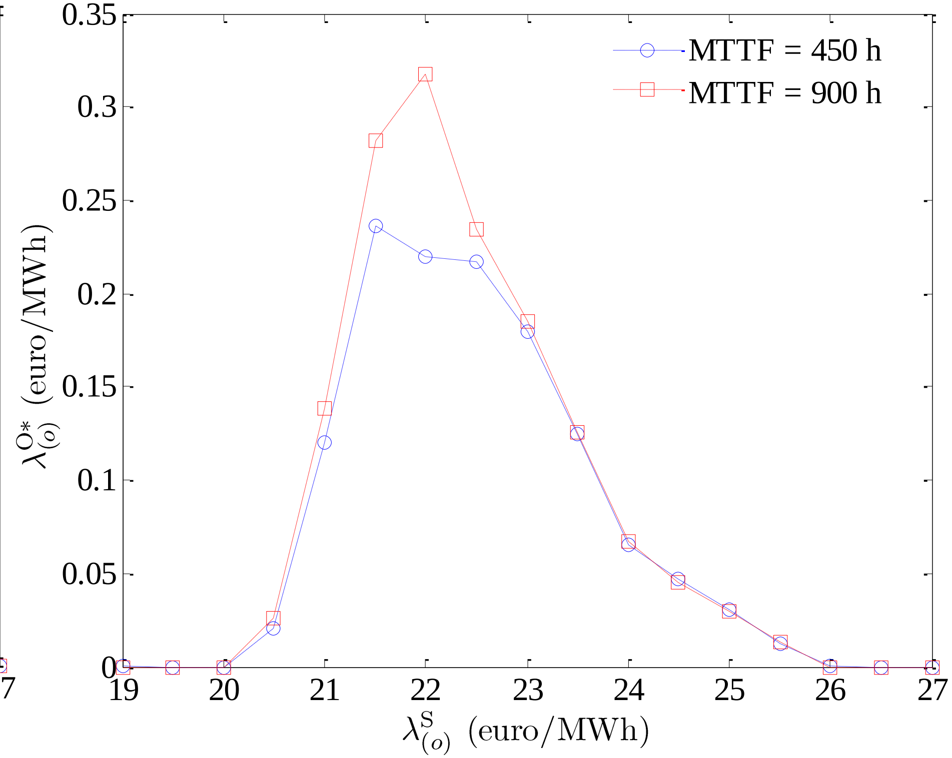
Case study

➢ **MAXIMUM OPTION PRICE (impact of MTTF)**

FOR = 5%



FOR = 10%



↑FOR→OPTION

↑MTTF→OPTION

Outline

- Introduction
- Model
- Case study
- Conclusions

Outline

- Introduction
- Model
- Case study
- Conclusions

Conclusions

Multi-stage stochastic programming

Conclusions

Options → ↓ Price and availability risk

Conclusions

Options → ↓ Price and availability risk

Options ↔ Forwards

Conclusions

Options $\Rightarrow$ $\downarrow$ Price and availability risk

Options $\Leftrightarrow$ Forwards

- Strike price $\approx$ Spot
- FOR with $\uparrow$MTTF
- Option price < Max. Option

Conclusions

Options → ↓ Price and availability risk

Options ↔ ~~Forwards~~

- Strike price ≈ Spot
- FOR with ↑MTTF
- Option price < Max. Option

Conclusions

Options → ↓ Price and availability risk

Options ↔ Forwards

- Forward price > Spot
- ↓FOR
- ↓MTTF

informs

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Conclusions

Options → ↓ Price and availability risk

~~Options~~ ↔ Forwards

- Forward price > Spot
- ↓FOR
- ↓MTTF

Conclusions

- How do electricity options work? ✓
- How can electricity options be modeled? ✓
- How do electricity options reduce price risk? ✓
- How do electricity options reduce availability risk? ✓
- When is an option contract more profitable than a forward contract? ✓

Thank you!

Questions?

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Model

Stochastic programming

Objective function

Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

Pool

$$\textbf{profit}_{\omega} = \sum_{t=1}^{N_T}\left(\boxed{\lambda_{t\omega}^{P} P_{t\omega}^{P} T_t} - C(P_{t\omega}^{G})\right) + \sum_{c_1=1}^{N_{C_1}} \lambda_{c_1}^{1} P_{c_1}^{1} T_{c_1} + \sum_{c_2=1}^{N_{C_2}} (\lambda_{c_2}^{1} P_{c_2}^{1} + \lambda_{c_2\omega}^{2} P_{c_2\omega}^{2}) T_{c2} + \sum_{o=1}^{N_O} v_o(-\lambda_o^{O} P_o + y_{o\omega}\lambda_o^{S} P_o) T_o$$

$\lambda_{t\omega}^{P} \rightarrow$ Pool price

$P_{t\omega}^{P} \rightarrow$ Power sold in the pool

$T_t \rightarrow$ Duration of time period

Constraints

Production unit bounds

Energy balances

Forward and option constraints

Nonanticipativity constraints

Model

Stochastic programming

Objective function

Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

$$\textbf{profit}_{\omega} = \sum_{t=1}^{N_T} \Big(\underbrace{\lambda_{t\omega}^{P} P_{t\omega}^{P} T_t}_{\text{Pool}} - \underbrace{C(P_{t\omega}^{G})}_{\text{Cost}} \Big) + \sum_{c_1=1}^{N_{C_1}} \lambda_{c_1}^{1} P_{c_1}^{1} T_{c_1} + \sum_{c_2=1}^{N_{C_2}} (\lambda_{c_2}^{1} P_{c_2}^{1} + \lambda_{c_2\omega}^{2} P_{c_2\omega}^{2}) T_{c2} +$$

$$+ \sum_{o=1}^{N_O} v_o(-\lambda_o^{O} P_o + y_{o\omega} \lambda_o^{S} P_o) T_o$$

$C(\cdot) \rightarrow$ Cost function

$P_{t\omega}^{G} \rightarrow$ Generated power

Constraints

Production unit bounds

Energy balances

Forward and option constraints

Nonanticipativity constraints

Model

Stochastic programming

Objective function

Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

Contracts spanning period 1

$\lambda^1_{c_1} \rightarrow$ Forward price

$P^1_{c_1} \rightarrow$ Sold power

$T_{c_1} \rightarrow$ Forward contract duration

Pool

Cost

Forward 1

$$\text{profit}_{\omega} = \sum_{t=1}^{N_T}\left(\lambda^P_{t\omega}P^P_{t\omega}T_t - C(P^G_{t\omega})\right) + \sum_{c_1=1}^{N_{C_1}}\lambda^1_{c_1}P^1_{c_1}T_{c_1} + \sum_{c_2=1}^{N_{C_2}}(\lambda^1_{c_2}P^1_{c_2} + \lambda^2_{c_2\omega}P^2_{c_2\omega})T_{c2} +$$

$$+\sum_{o=1}^{N_O} v_o(-\lambda^O_o P_o + y_{o\omega}\lambda^S_o P_o)T_o$$

Constraints

Production unit bounds

Energy balances

Forward and option constraints

Nonanticipativity constraints

Model

Stochastic programming

Objective function

Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

Contracts spanning period 2

$\lambda^1_{c_2}, \lambda^2_{c_2\omega} \rightarrow$ Forward price in stage 1/2

$P^1_{c_2}, P^2_{c_2\omega} \rightarrow$ Sold power in stage 1/2

$T_{c_2} \rightarrow$ Forward contract duration

Pool | Cost | Forward 1 | Forward 2

$$\text{profit}_{\omega} = \sum_{t=1}^{N_T}\left(\boxed{\lambda^P_{t\omega} P^P_{t\omega} T_t} - \boxed{C(P^G_{t\omega})}\right) + \boxed{\sum_{c_1=1}^{N_{C_1}} \lambda^1_{c_1} P^1_{c_1} T_{c_1}} + \boxed{\sum_{c_2=1}^{N_{C_2}} (\lambda^1_{c_2} P^1_{c_2} + \lambda^2_{c_2\omega} P^2_{c_2\omega}) T_{c2}} +$$

$$+ \sum_{o=1}^{N_O} v_o(-\lambda^O_o P_o + y_{o\omega}\lambda^S_o P_o) T_o$$

Constraints

Production unit bounds

Energy balances

Forward and option constraints

Nonanticipativity constraints

Model

Stochastic programming

Objective function

Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

Pool — Cost — Forward 1 — Forward 2 — Option

$$\text{profit}_{\omega} = \sum_{t=1}^{N_T} \left(\underbrace{\lambda_{t\omega}^{P} P_{t\omega}^{P} T_t}_{\text{Pool}} - \underbrace{C(P_{t\omega}^{G})}_{\text{Cost}} \right) + \underbrace{\sum_{c_1=1}^{N_{C_1}} \lambda_{c_1}^{1} P_{c_1}^{1} T_{c_1}}_{\text{Forward 1}} + \underbrace{\sum_{c_2=1}^{N_{C_2}} (\lambda_{c_2}^{1} P_{c_2}^{1} + \lambda_{c_2\omega}^{2} P_{c_2\omega}^{2}) T_{c2}}_{\text{Forward 2}} + \underbrace{\sum_{o=1}^{N_O} v_o(-\lambda_o^{O} P_o + y_{o\omega} \lambda_o^{S} P_o) T_o}_{\text{Option}}$$

$v_o \rightarrow$ **Option purchase (1/0)**

$\lambda_o^O, \lambda_o^S \rightarrow$ **Option and strike price**

$y_{o\omega} \rightarrow$ **Option exercise (1/0)**

$P_o \rightarrow$ **Sold power**

$T_o \rightarrow$ **Option duration**

Constraints

- Production unit bounds
- Energy balances
- Forward and option constraints
- Nonanticipativity constraints

Model

Stochastic programming

Objective function

Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

Constraints

Production unit bounds

$$u_{t\omega}k_{t\omega}P_{\max} \geq P^{G}_{t\omega} \geq u_{t\omega}k_{t\omega}P_{\min}$$

$k_{t\omega}$ → Constant (availability scenario)

$u_{t\omega}$ → Binary variable (on/off)

Energy balances

Forward and option constraints

Nonanticipativity constraints

Model

Stochastic programming

Objective function

Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

Constraints

Production unit bounds

Energy balances

$$P_{t\omega}^{G} = \sum_{c_1 \in F_t^1} P_{c_1}^{1} + \sum_{c_2 \in F_t^2} \left(P_{c_2}^{1} + P_{c_2\omega}^{2}\right) + \sum_{o \in O_t} v_o y_{o\omega} P_o + P_{t\omega}^{P}$$

$$P_{t\omega}^{P} \geq \mathbf{0},\ \forall k_{t\omega} = \mathbf{1}$$

Forward and option constraints

Nonanticipativity constraints

Model

Stochastic programming

Objective function

Maximize $CVaR_{\alpha}(\text{profit}_{\omega})$

Constraints

Production unit bounds

Energy balances

Forward and option constraints

$$P^{1}_{c_1} \geq 0$$

$$P^{1}_{c_2} + P^{2}_{c_2\omega} \geq 0$$

$$P_{o} \geq 0$$

Nonanticipativity constraints

Case study

- (a) sell 350MW during the second month at 21€/MWh. Re-trading in stage 2 at the following prices:

$\lambda^2_{c2\omega}$	20.69	22.42	24.15
Probability	0.25	0.5	0.25

- (b) buy a put option to sell 350MW during the second month at 21€/MWh. Option price = 0.1€/MWh

α	FOR = 0%		FOR = 5%		FOR = 10%	
	(a)	(b)	(a)	(b)	(a)	(b)
0	5.245	5.418	5.141	5.314	5.035	5.209
0.5	5.078	5.117	4.919	4.970	4.756	4.860
0.9	5.078	5.055	4.599	4.649	4.429	4.499