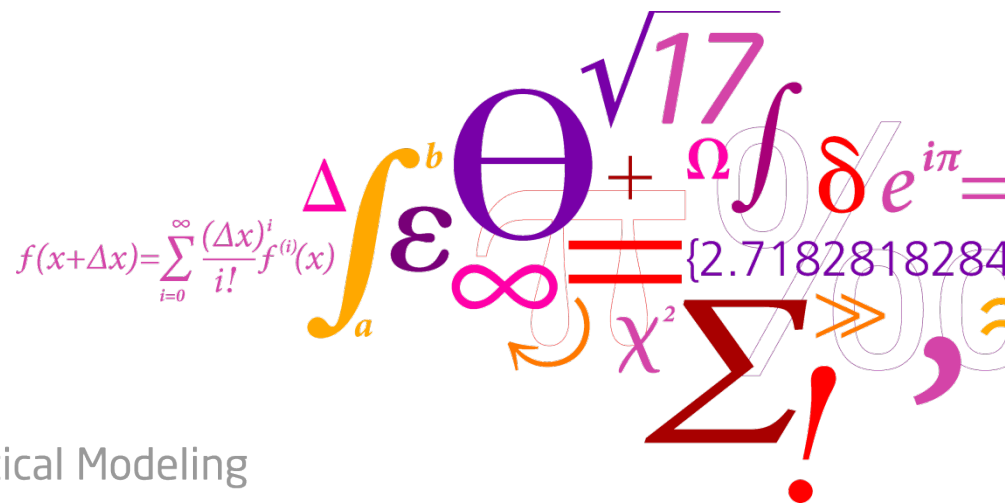


Tools for decision making under uncertainty in
electricity markets

Lecture 5: “Short-Term Trading for A Wind Power Producer”

Juan Miguel Morales

Salvador Pineda



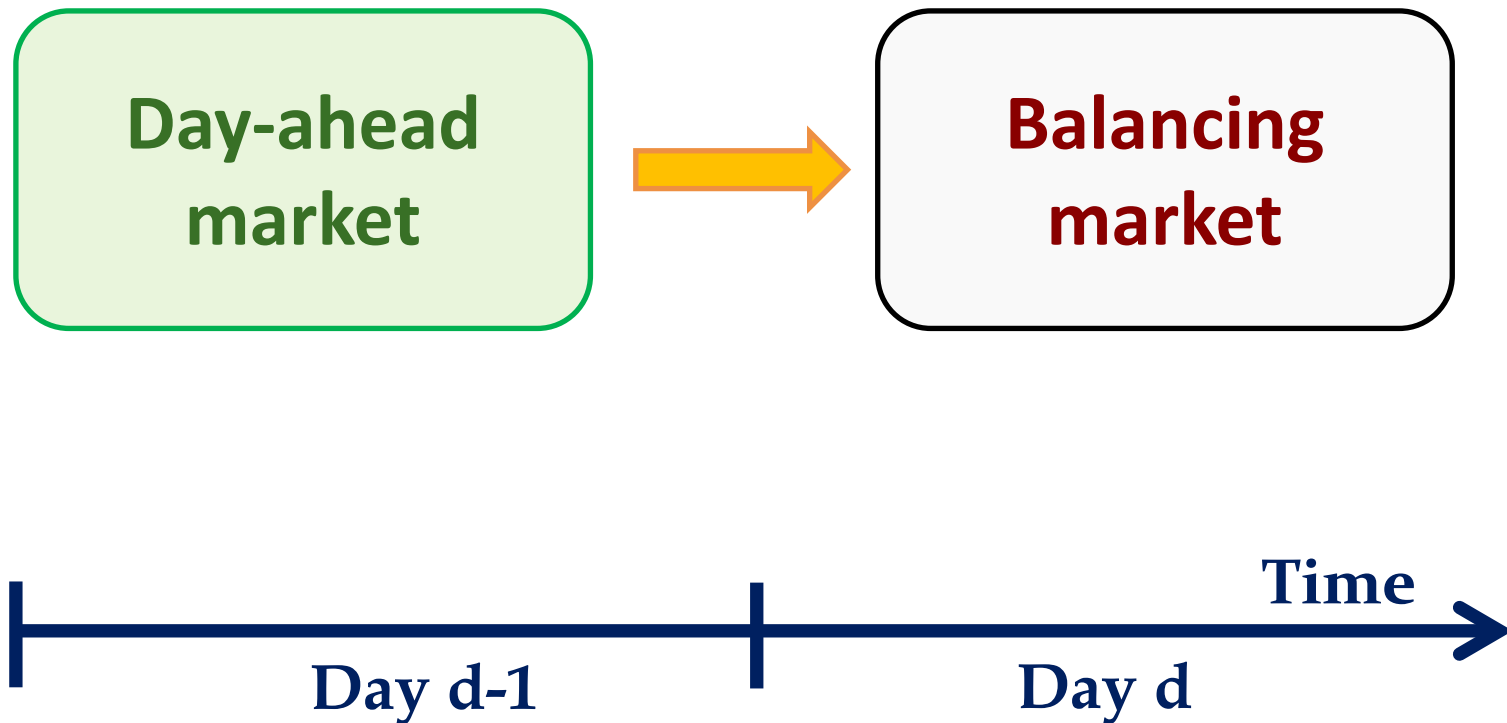
DTU Informatics

Department of Informatics and Mathematical Modeling

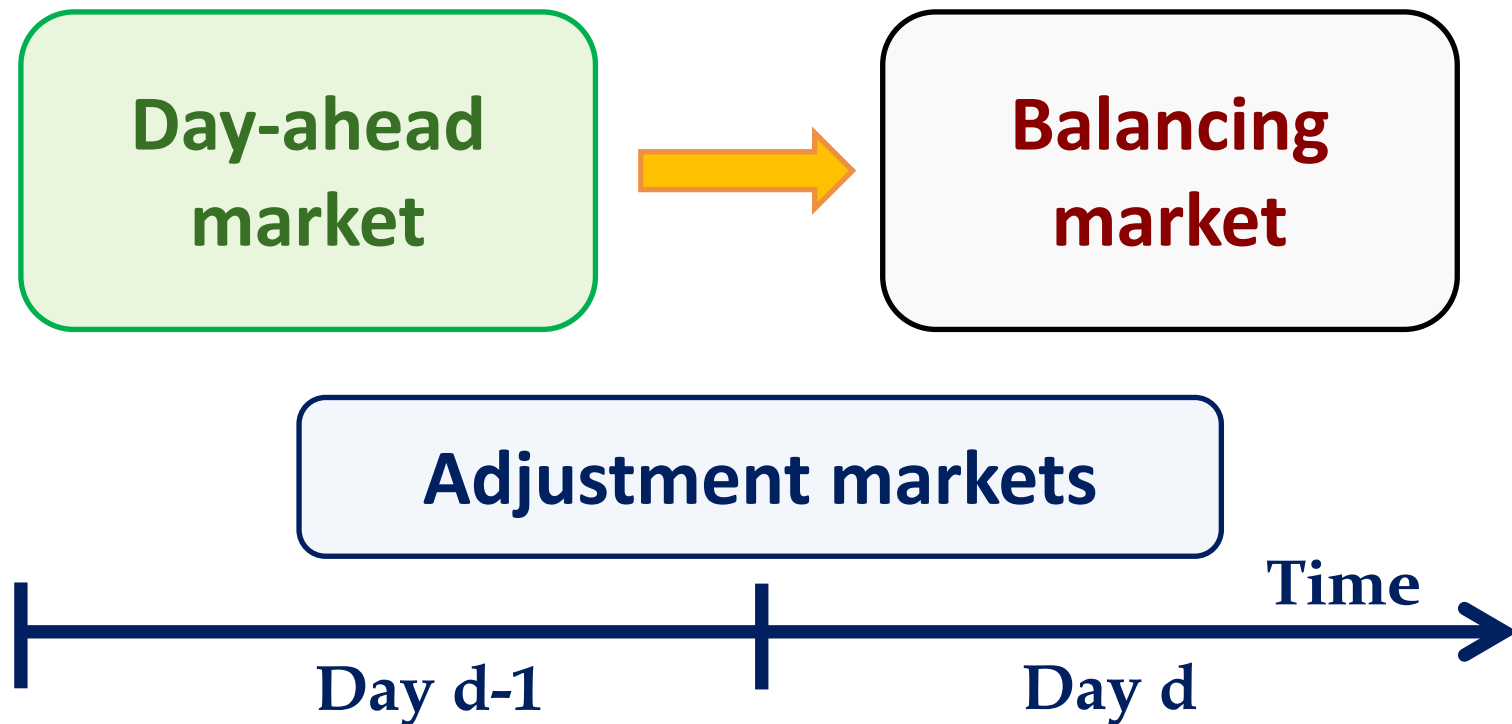
Outline

- 1) Motivation
- 2) Imbalance cost
- 3) Certainty gain process
- 4) Mathematical formulation
- 5) Example
- 6) Case study

Wind Producer Problem (Motivation)

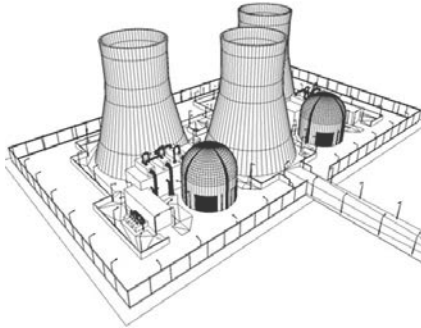


Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)

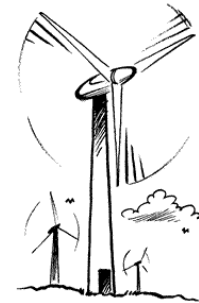
**Day-ahead
market**



**Inflexible units
(need advance planning)**



**Balancing
market**

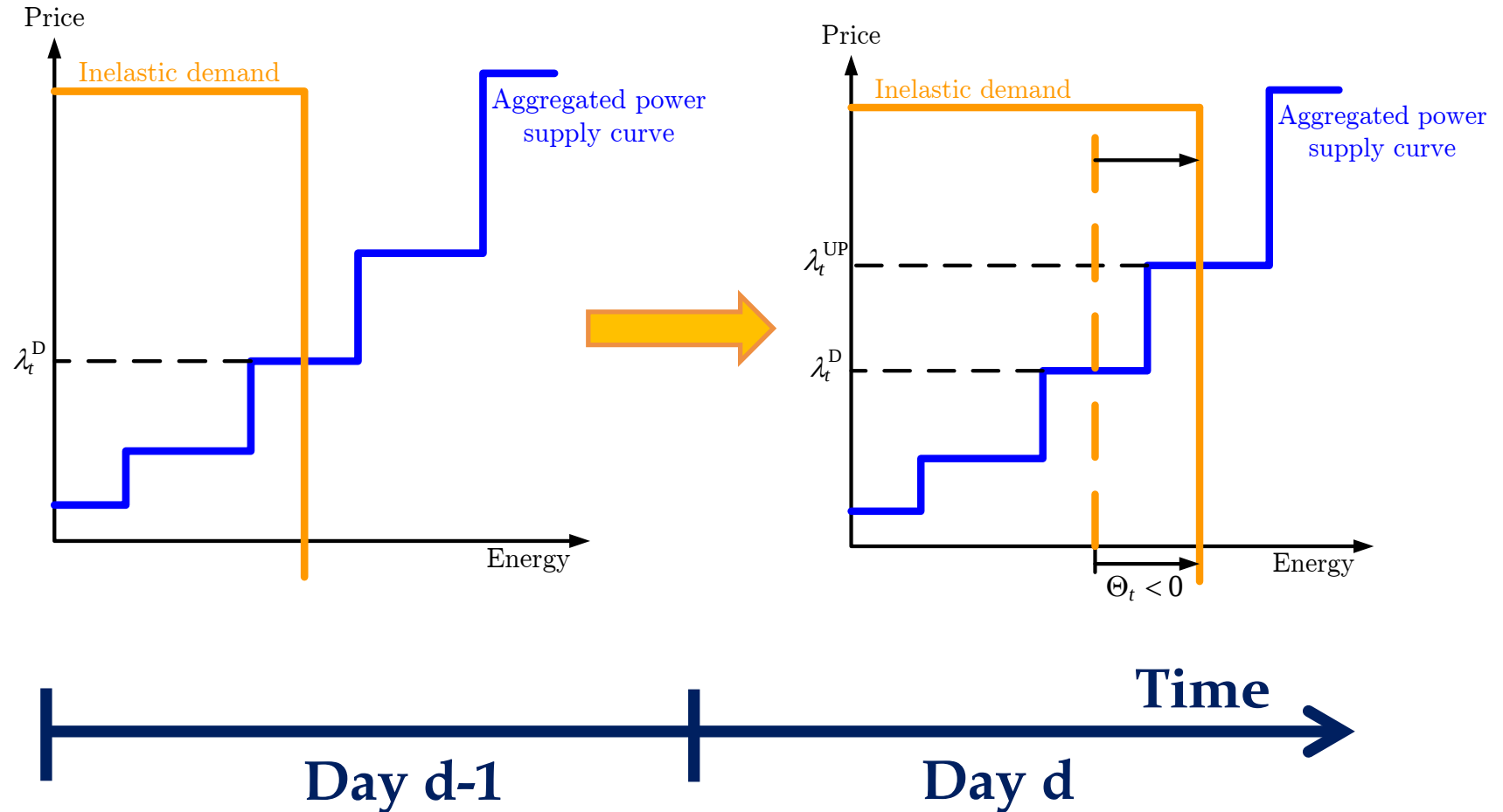


**Wind producers/consumers
(need balancing energy)**

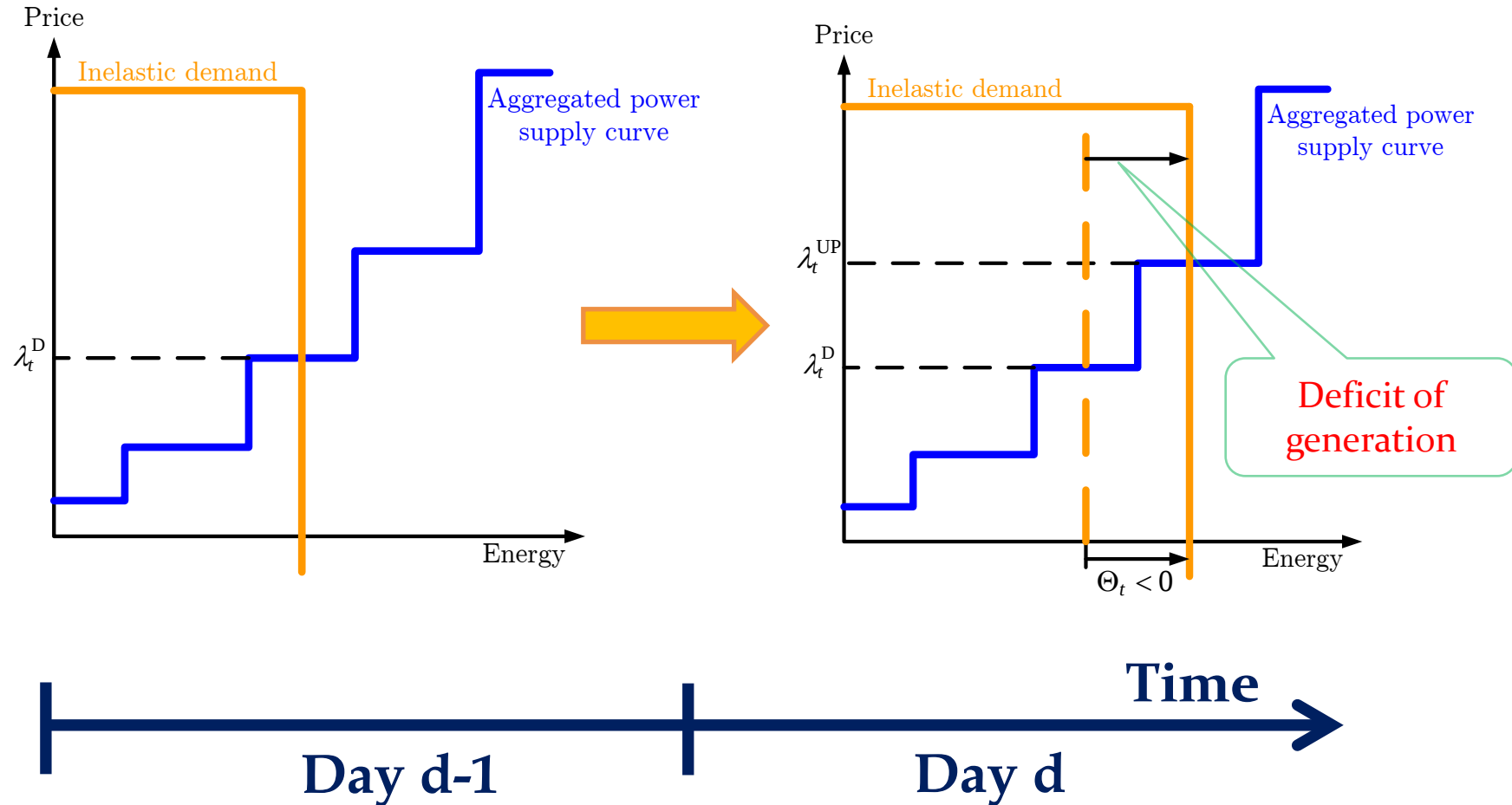
Wind Producer Problem (Motivation)

- ✓ A balancing mechanism is required to cope with unexpected energy deviations
- ✓ Positive (negative) deviation: higher (lower) production or lower (higher) consumption than scheduled in forward markets

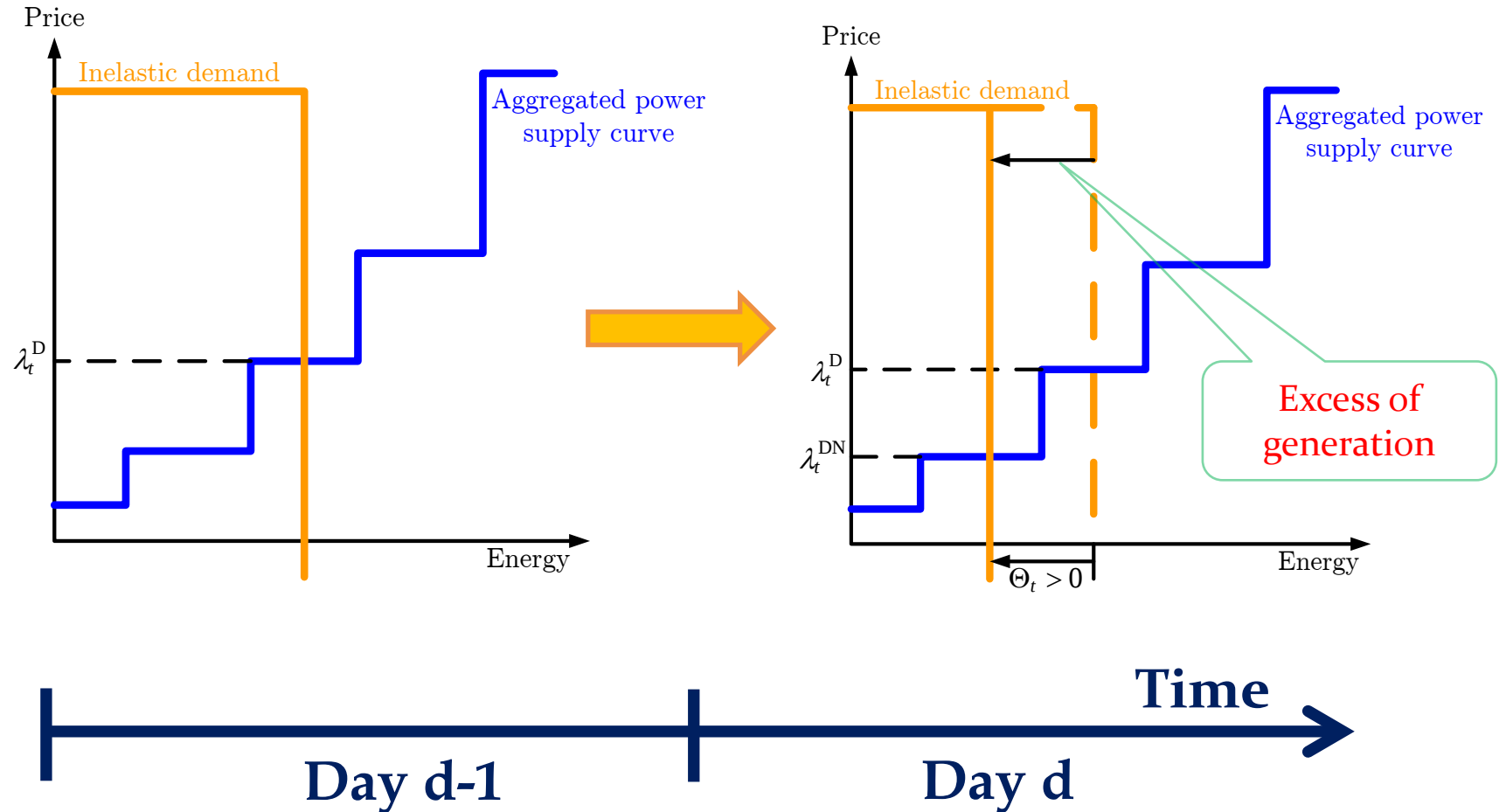
Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)



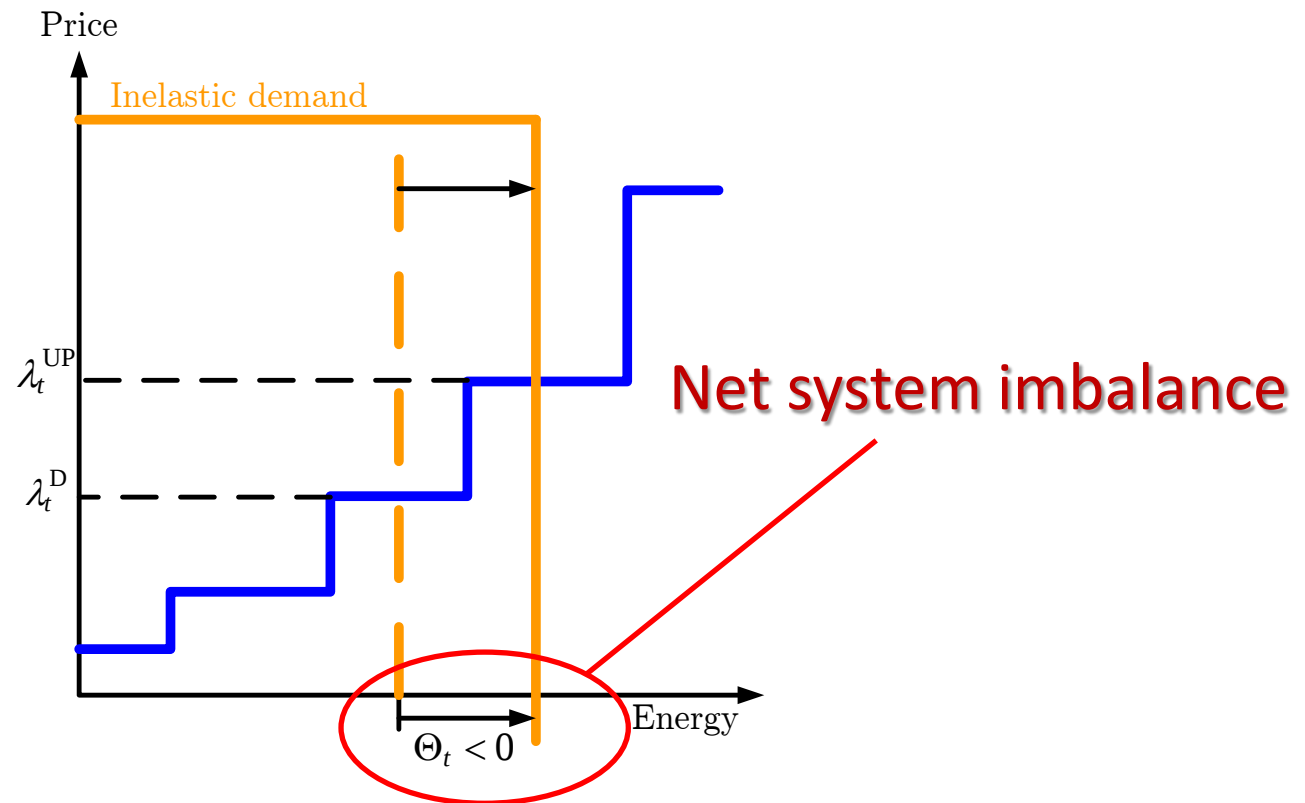
Wind Producer Problem (Motivation)



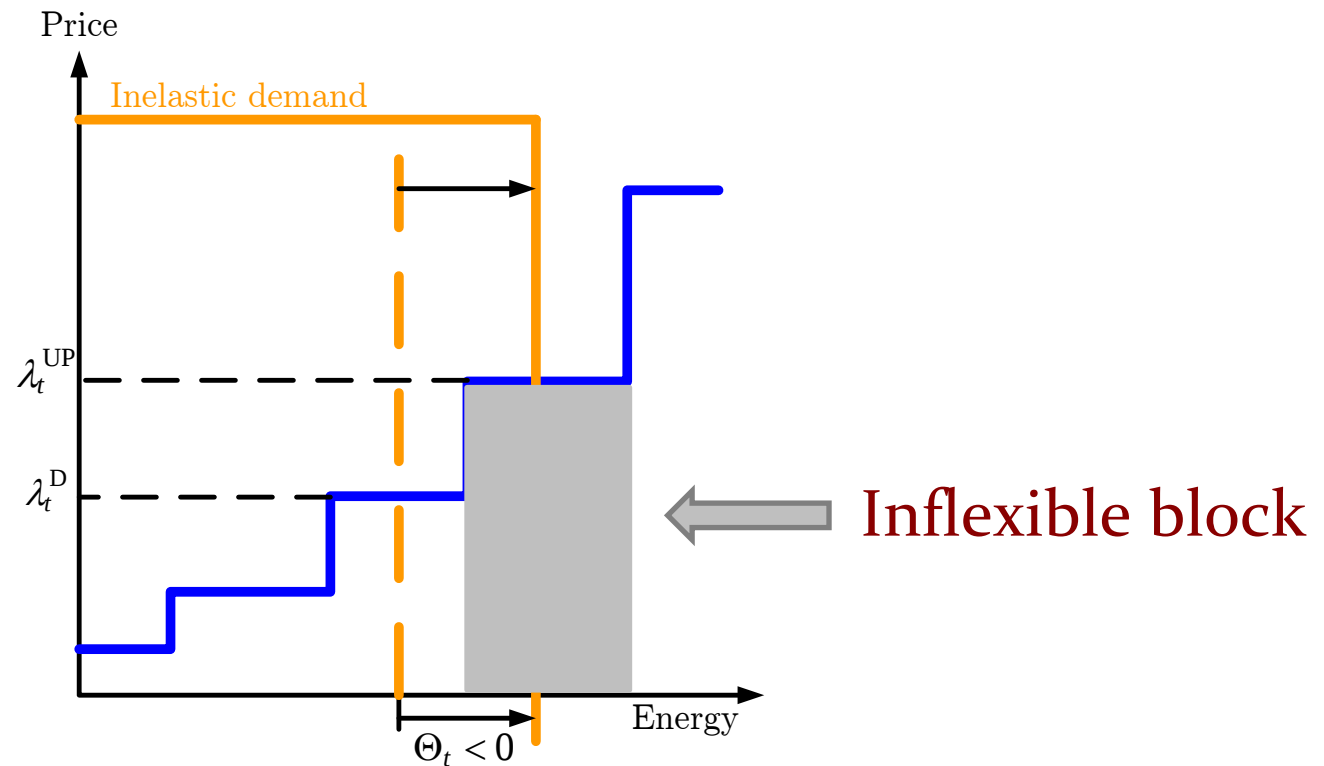
Wind Producer Problem (Motivation)

- ✓ Competitiveness damaged by uncertain wind availability for two primary reasons:
 - 1) Imbalances covered by *flexible*, but *expensive* energy sources through the balancing mechanism

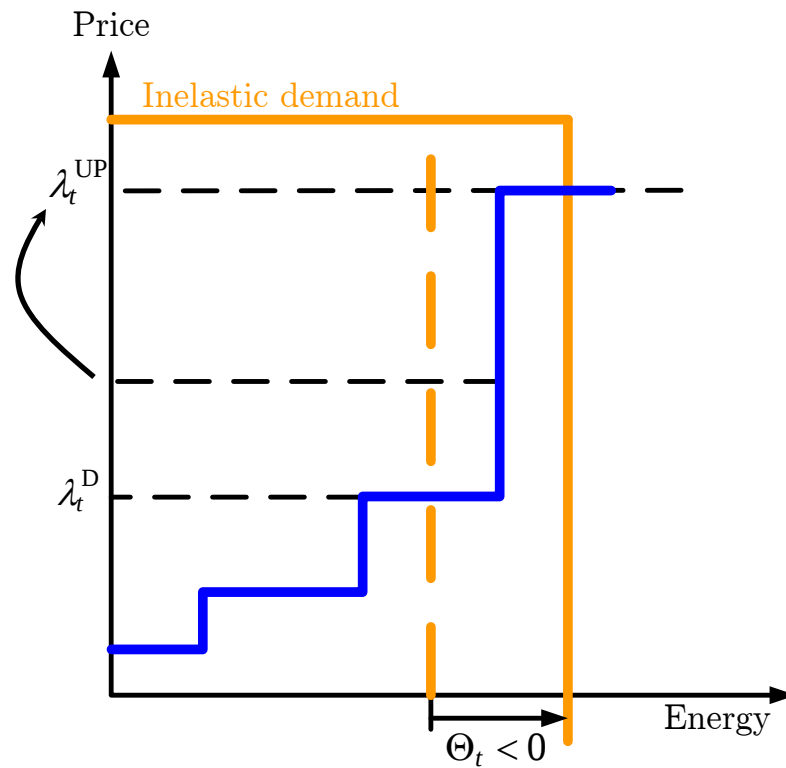
Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)

- ✓ Competitiveness damaged by uncertain wind availability for two primary reasons:
 - 1) Imbalances covered by *flexible*, but *expensive* energy sources through the balancing mechanism
 - The volatility of balancing prices is higher



Trading balancing energy is riskier!

Wind Producer Problem (Motivation)

- ✓ Competitiveness damaged by uncertain wind availability for two primary reasons:
 - 2) Some market designs “penalize” deviators (**dual-price balancing settlements**)
 - Price for positive deviations: λ_t^+
 - Price for negative deviations: λ_t^-
 - Cost of the energy required to counteract the net system imbalance.

Remark: In a single-price balancing settlement $\lambda_t^+ = \lambda_t^-$

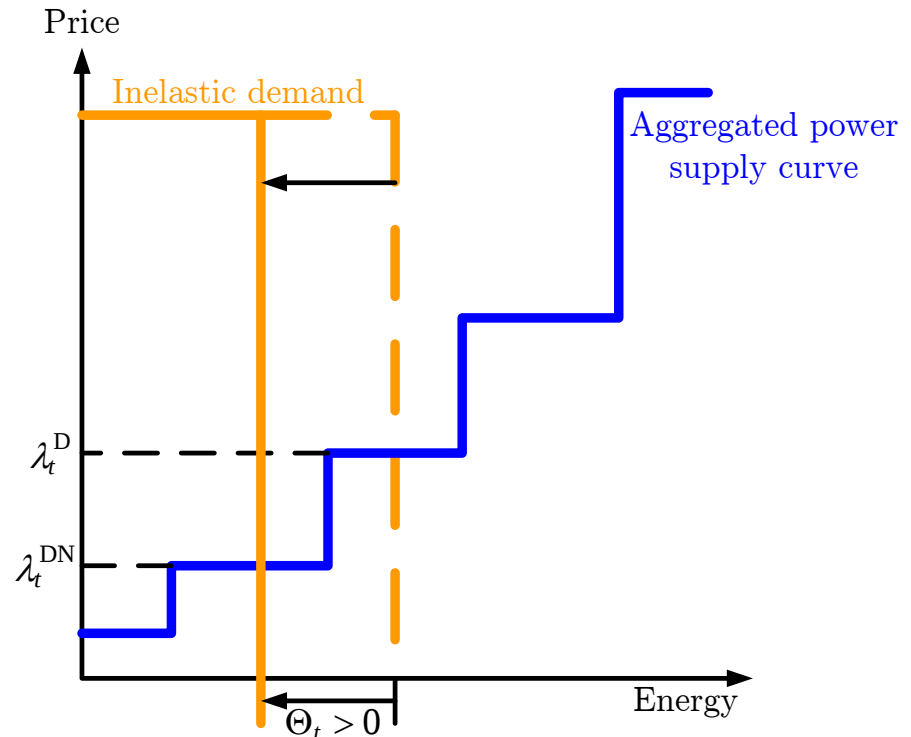
Wind Producer Problem

("One-sided penalty")

If the system imbalance > 0 (excess of generation):

$$\lambda_t^+ = \min(\lambda_t^D, \lambda_t^{DN})$$

$$\lambda_t^- = \lambda_t^D$$



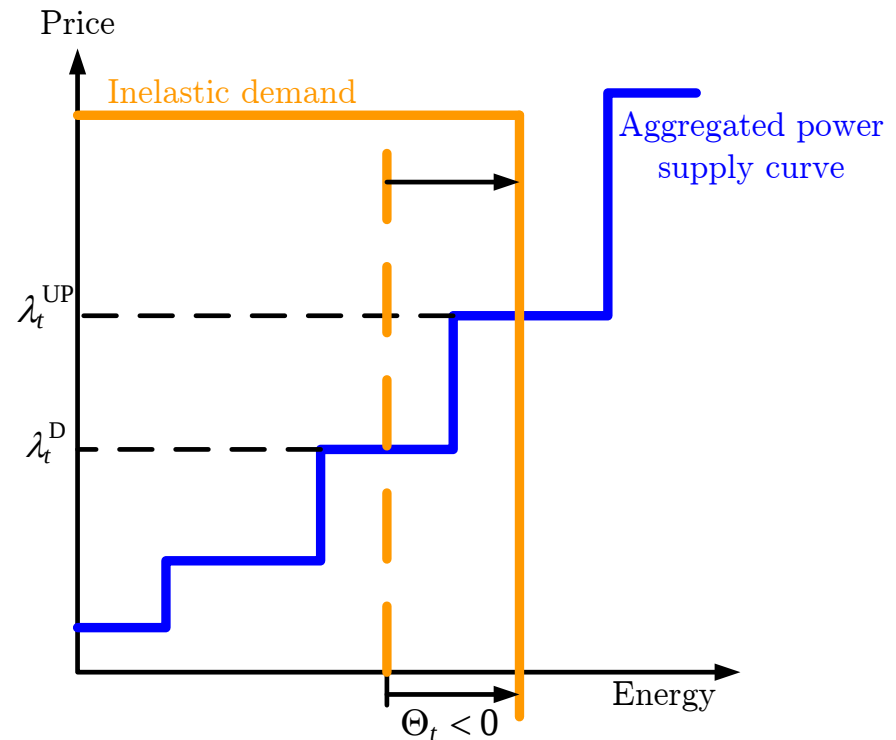
Wind Producer Problem

("One-sided penalty")

If the system imbalance < 0 (deficit of generation):

$$\lambda_t^+ = \lambda_t^D$$

$$\lambda_t^- = \max(\lambda_t^D, \lambda_t^{UP})$$



Wind Producer Problem

(“Two-sided penalty”)

Both positive and negative deviations are “penalized”,
i.e. λ^+ may be $< \lambda^D$ and λ^- may be $> \lambda^D$ at the same
trading period

Wind Producer Problem (Motivation)

- ✓ Competitiveness damaged by uncertain wind availability for two primary reasons:
 - 2) Some market designs “penalize” deviators (**dual-price balancing settlements**)
 - It holds that $\lambda_t^+ \leq \lambda_t^D$ and $\lambda_t^- \geq \lambda_t^D$



Imbalance cost!

By construction, trading in the balancing market is less beneficial than trading in the day-ahead market

Wind Producer Problem

(Imbalance cost)

An opportunity cost

- ✓ Loss of profit resulting from not having traded the energy deviation in the day-ahead market

If we define:

$$r_t^+ = \frac{\lambda_t^+}{\lambda_t^D}, \quad r_t^+ \leq 1$$
$$r_t^- = \frac{\lambda_t^-}{\lambda_t^D}, \quad r_t^- \geq 1$$

Wind Producer Problem

(Imbalance cost)

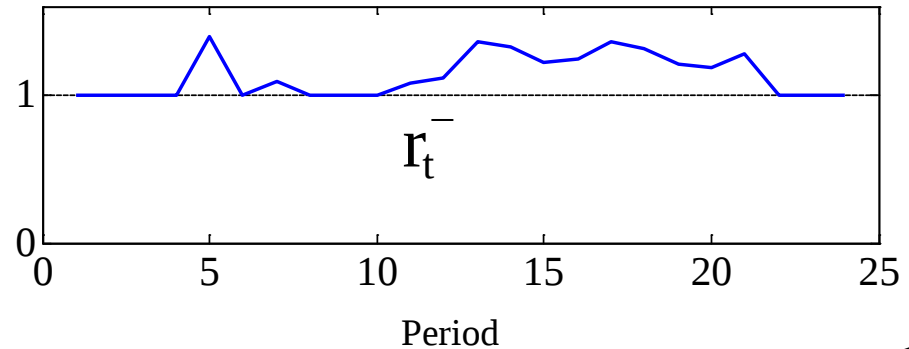
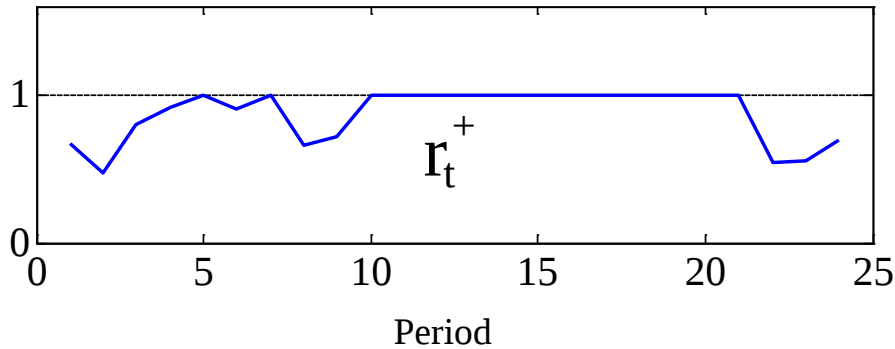
Then, the imbalance cost is given by:

$$I_t = \begin{cases} \lambda_t^D (1 - r_t^+) \Delta_t, & \Delta_t \geq 0 \\ -\lambda_t^D (r_t^- - 1) \Delta_t, & \Delta_t < 0 \end{cases}$$

Total energy deviation
incurred by the wind
producer

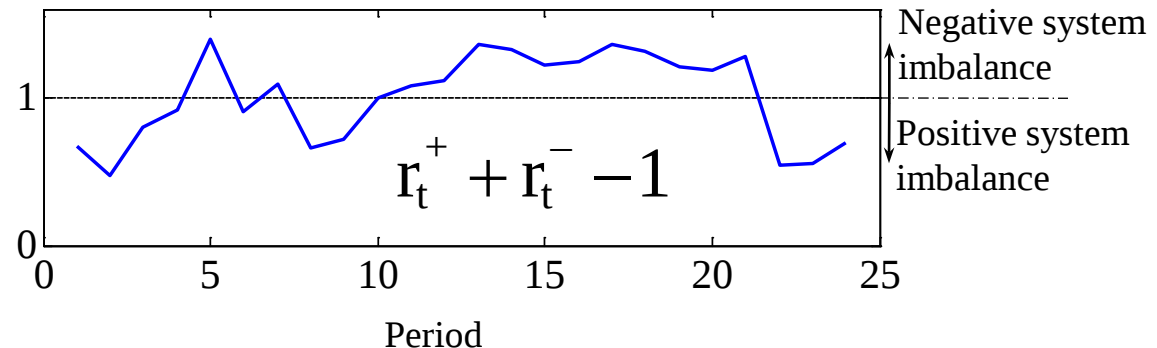
Wind Producer Problem

(Imbalance cost)



One-sided penalty!

Superimposing



Wind Producer Problem

(Aim)

Designing a stochastic programming model to build offers for wind producers to trade in different short-term markets (pool) within a fully-fledged electricity market.



Wind Producer Problem

(Aim)

- ✓ The wind producer offer strategy should:
 - Be profit effective.
 - Limit profit variability.
 - Minimize the need for balancing energy.

Wind Producer Problem (Market framework)

✓ Three independent and successive markets:

- Day-ahead market
- Adjustment market
- Balancing market



✓ No market power capability by the wind producer in any of these markets

Wind Producer Problem

(Uncertainty sources)

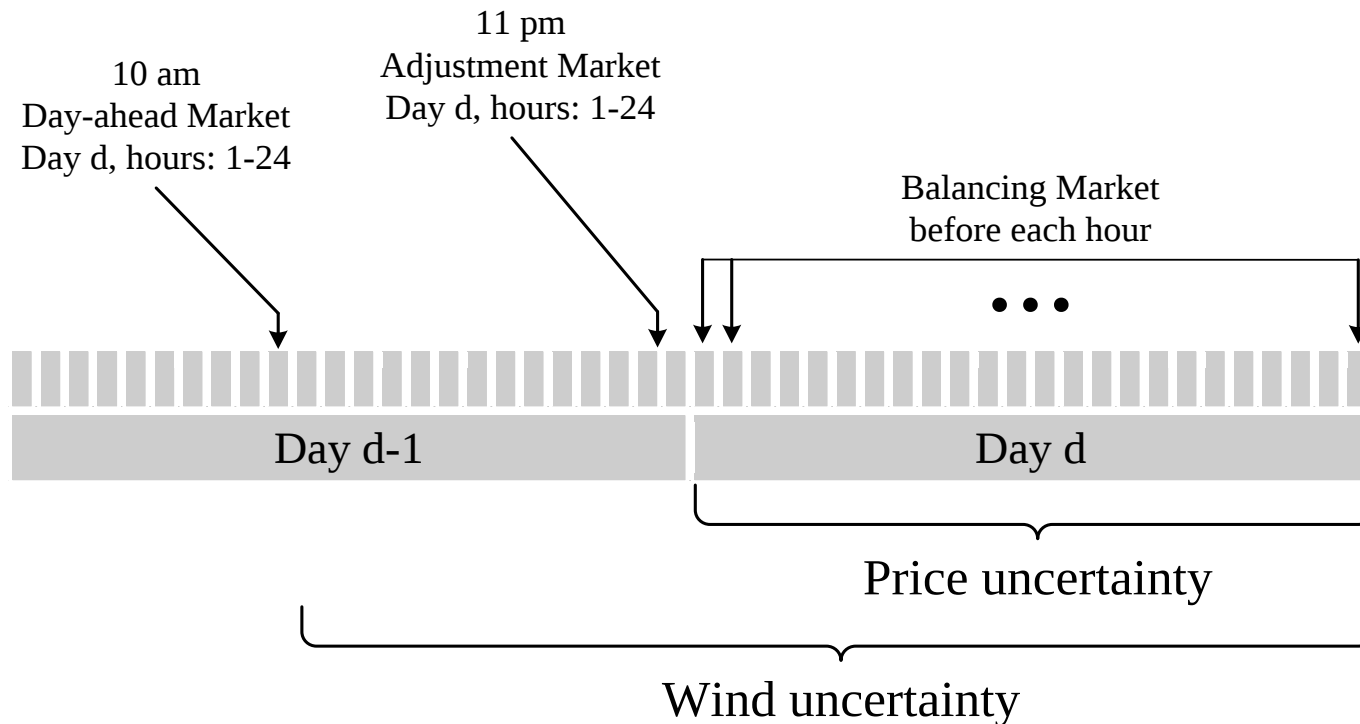
- ✓ Wind generation availability
- ✓ Day-ahead market prices
- ✓ Adjustment market prices: $\lambda_t^A - \lambda_t^D$
- ✓ Imbalance price ratios

$$r_t^+ = \frac{\lambda_t^+}{\lambda_t^D}, \quad r_t^+ \leq 1$$

$$r_t^- = \frac{\lambda_t^-}{\lambda_t^D}, \quad r_t^- \geq 1$$

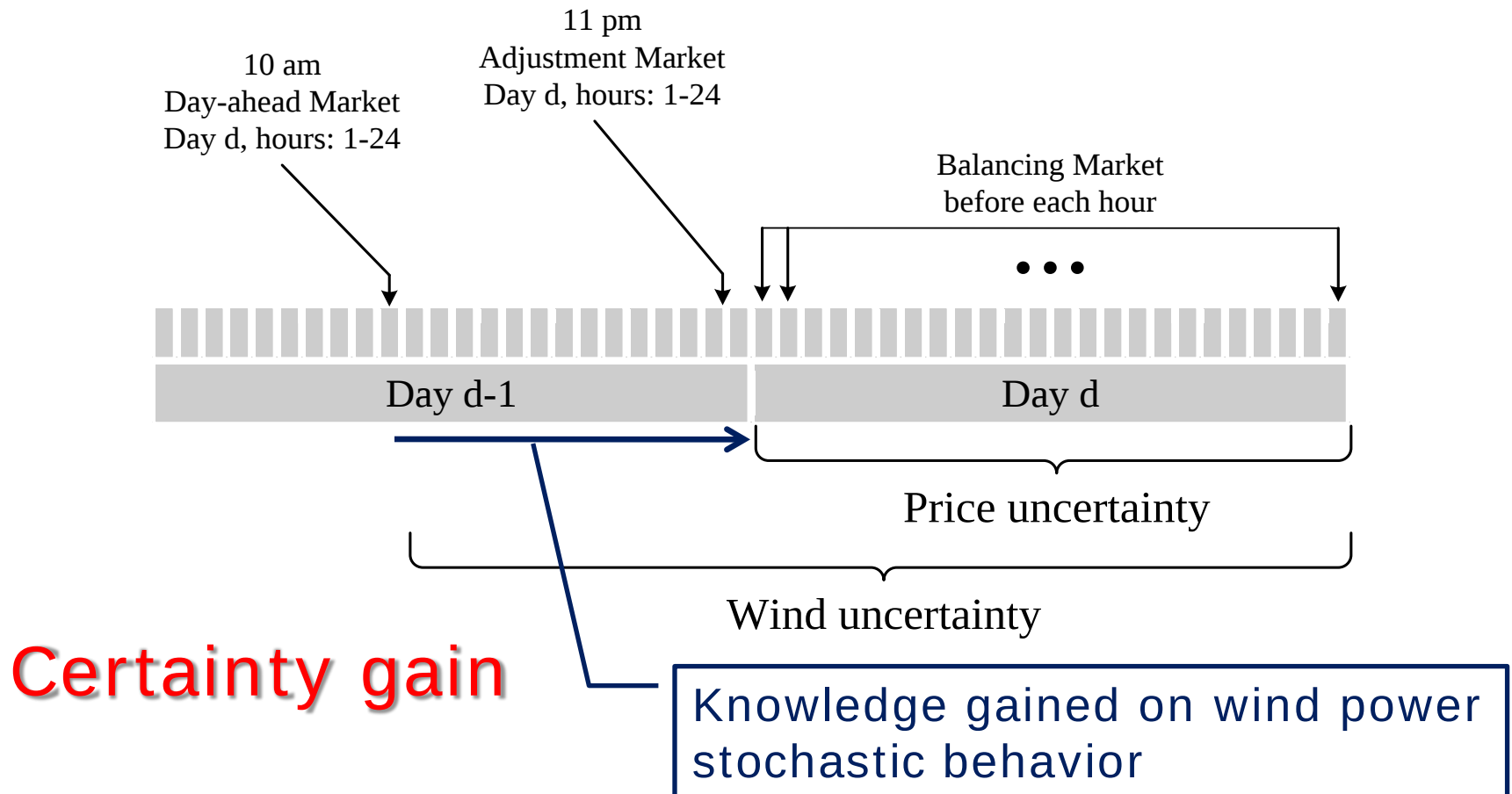
Wind Producer Problem

(Certainty gain process)



Wind Producer Problem

(Certainty gain process)



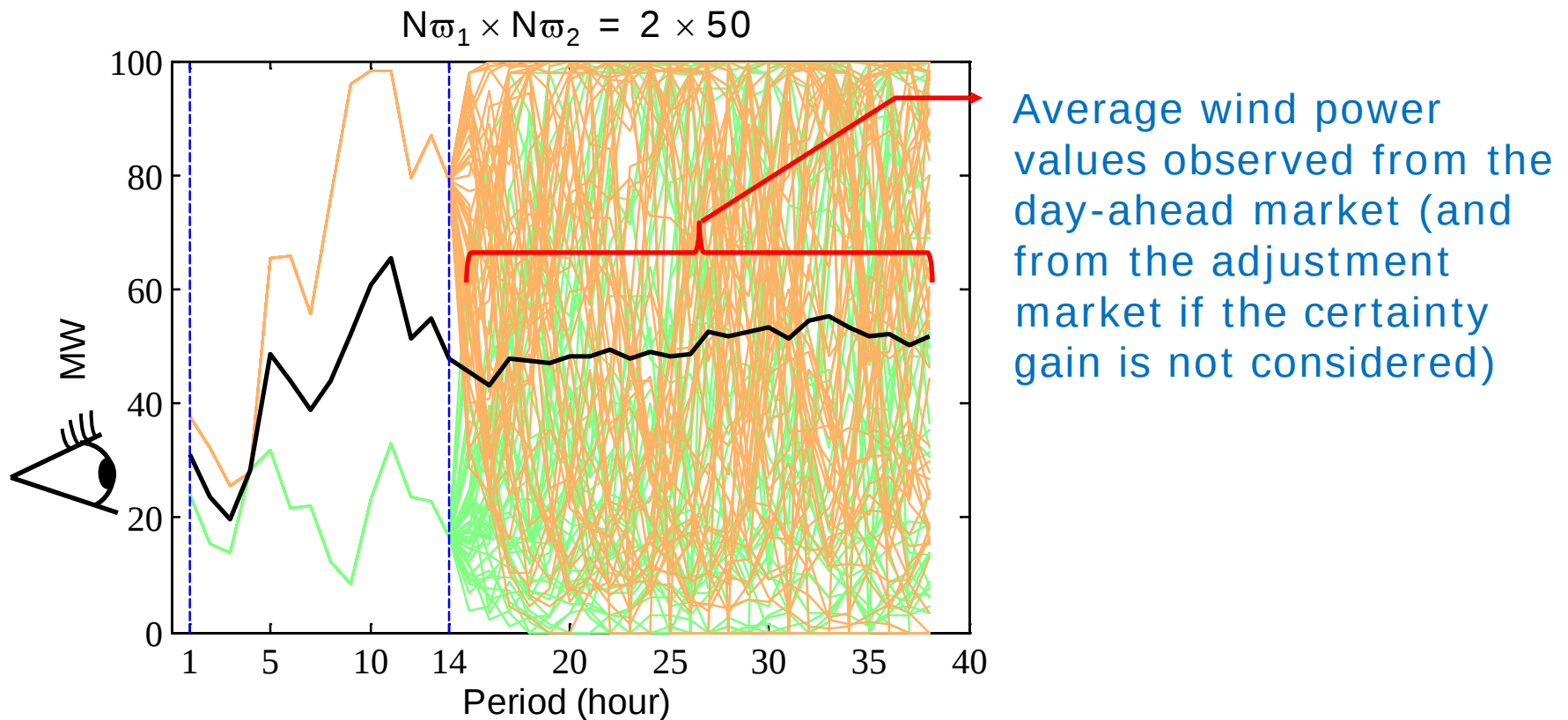
Wind Producer Problem

(Certainty gain process)

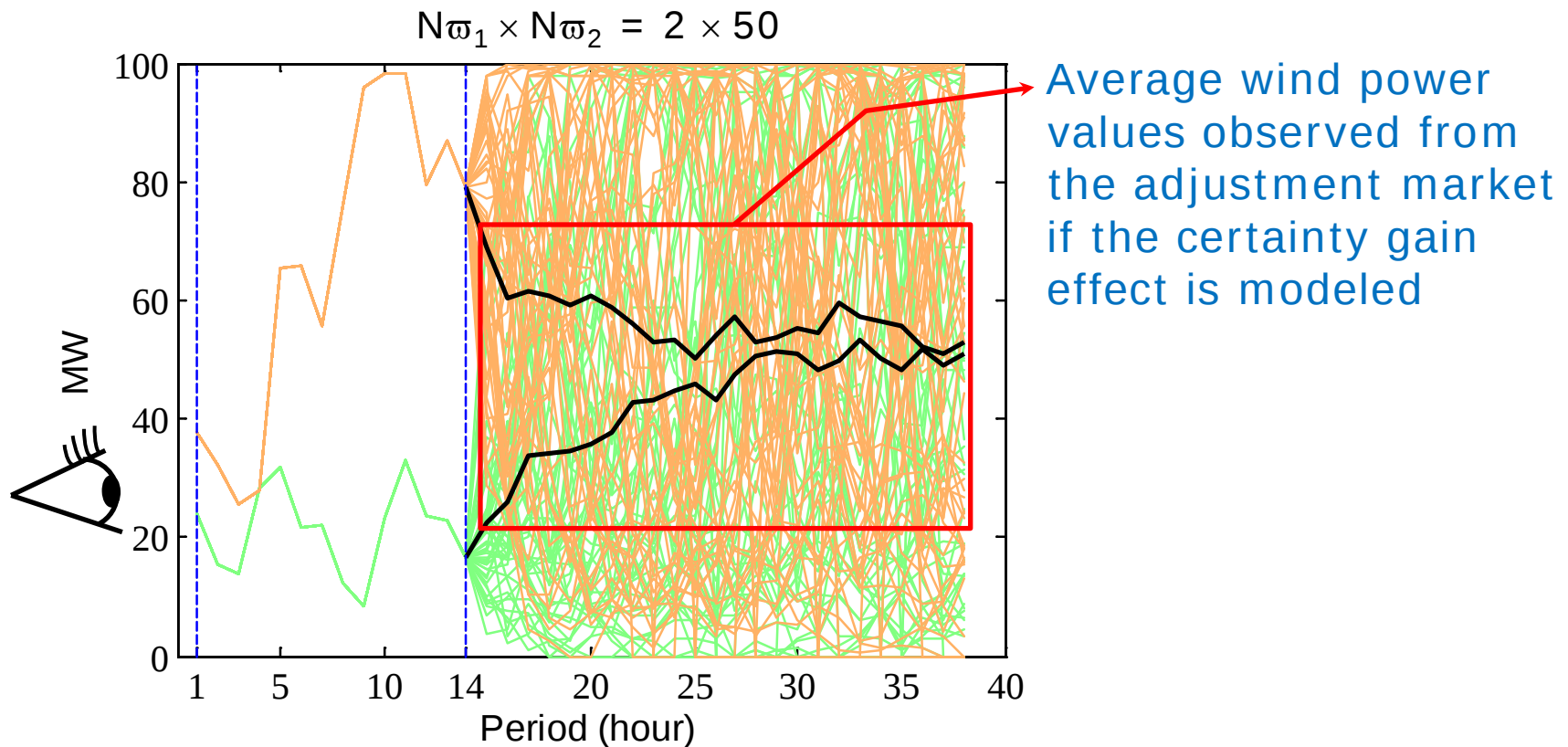
- ✓ The generation of wind power scenarios should account for the certainty gain phenomenon.
 1. N_{ϖ_1} scenarios between day-ahead and adjustment market.
 2. N_{ϖ_2} scenarios after the adjustment market.

Wind Producer Problem

(Certainty gain process)



Wind Producer Problem (Certainty gain process)

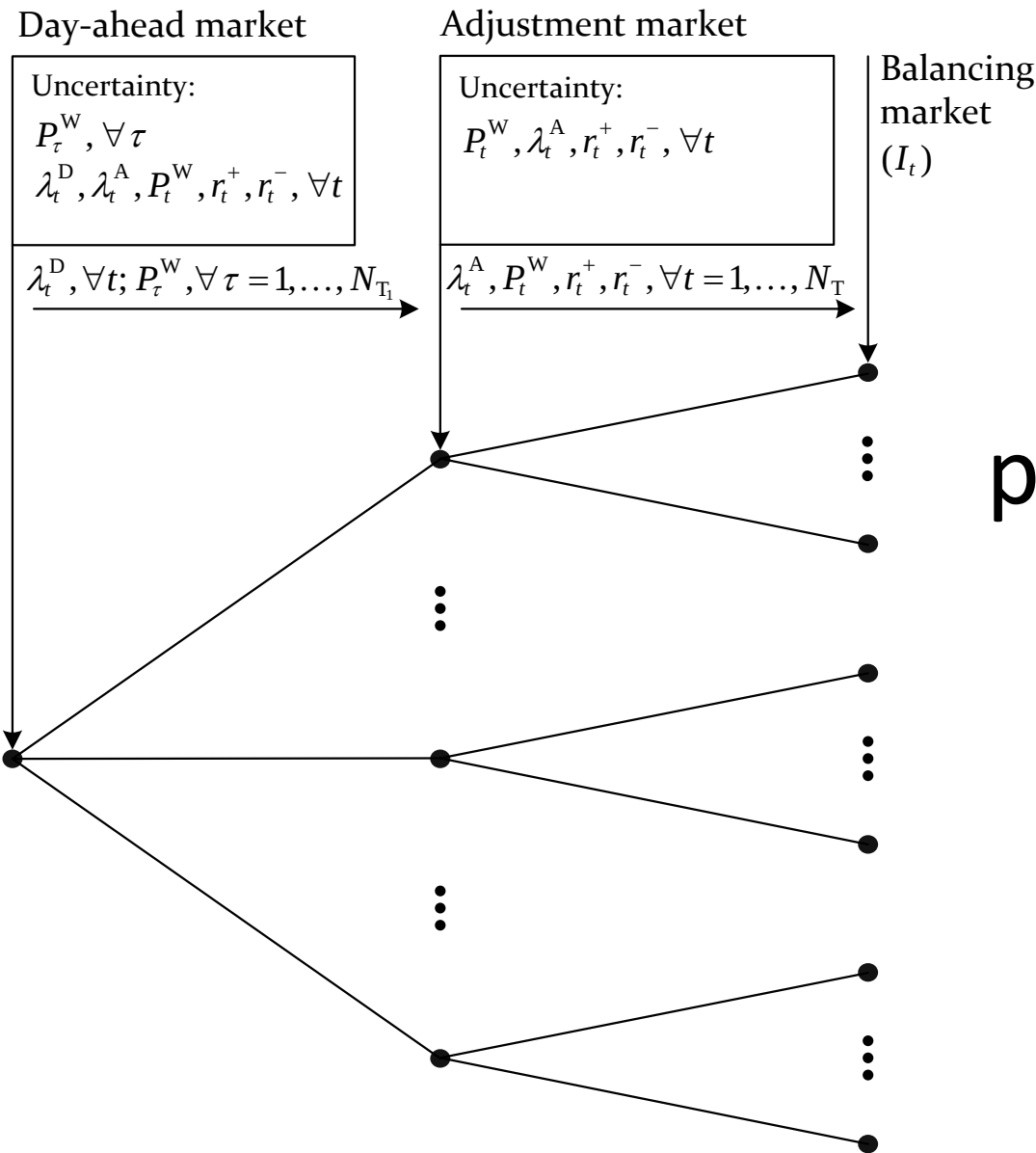


Wind Producer Problem

(Mathematical modeling)

Three-stage stochastic programming model:

- ✓ **First-stage variables:** Energy sold in the day-ahead market
- ✓ **Second-stage variables:** Energy traded in the adjustment market
- ✓ **Third-stage variables:** Deviations and their associated cost



Stochastic programming approach

Three stages, each one representing a market

Wind Producer Problem (Mathematical modeling)

- ✓ Maximize *Expected profit* + $\beta \times CVaR$
- ✓ Subject to constraints associated with:
 - Linearization of imbalance income
 - Non-anticipatory character of information
 - CVaR

Linear
programming
problem

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

Wind Producer Problem

(Mathematical modeling)

$$E\{\text{profit}\} = E\{$$

Revenue from trading in the day-ahead market

+ Revenue from trading in the adjustment market

+ Imbalance income } =

$$= \sum_{\omega=1}^{N_{\Omega}} \sum_{t=1}^{N_T} \pi_{\omega} \left[\lambda_{t\omega}^D P_{t\omega}^D d_t + \lambda_{t\omega}^A P_{t\omega}^A d_t + I_{t\omega}^I \right]$$

Wind Producer Problem

(Mathematical modeling)

$$E\{\text{profit}\} = E\{$$

Revenue from trading in the day-ahead market

+ Revenue from trading in the adjustment market

+ Imbalance income } =

$$= \sum_{\omega=1}^{N_{\Omega}} \sum_{t=1}^{N_T} \pi_{\omega} \left[\lambda_{t\omega}^D P_{t\omega}^D d_t + \lambda_{t\omega}^A P_{t\omega}^A d_t + I_{t\omega}^I \right]$$

Wind Producer Problem

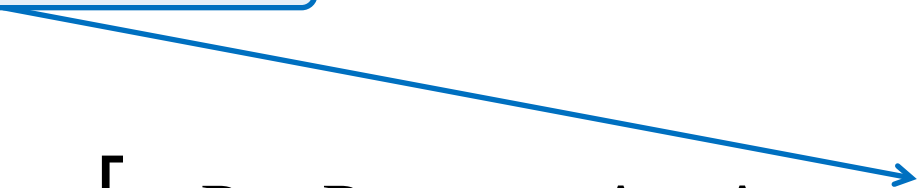
(Mathematical modeling)

$$E\{\text{profit}\} = E\{$$

Revenue from trading in the day-ahead market

+ Revenue from trading in the adjustment market

+ Imbalance income } =

$$= \sum_{\omega=1}^{N_{\Omega}} \sum_{t=1}^{N_T} \pi_{\omega} \left[\lambda_{t\omega}^D P_{t\omega}^D d_t + \lambda_{t\omega}^A P_{t\omega}^A d_t + I_{t\omega}^I \right]$$


Wind Producer Problem

(Linearization of the imbalance income)

$$I_{t\omega}^I = \begin{cases} \lambda_{t\omega}^D r_{t\omega}^+ \Delta_{t\omega}, & \Delta_{t\omega} \geq 0 \\ \lambda_{t\omega}^D r_{t\omega}^- \Delta_{t\omega}, & \Delta_{t\omega} < 0 \end{cases}$$

Linearization →

$$I_{t\omega}^I = \lambda_{t\omega}^D (r_{t\omega}^+ \Delta_{t\omega}^+ - r_{t\omega}^- \Delta_{t\omega}^-)$$

$$\Delta_{t\omega} = d_t (P_{t\omega} - P_{t\omega}^D - P_{t\omega}^A)$$

$$\Delta_{t\omega} = \Delta_{t\omega}^+ - \Delta_{t\omega}^-$$

$$0 \leq \Delta_{t\omega}^+ \leq P_{t\omega} d_t$$

$$0 \leq \Delta_{t\omega}^- \leq P^{\max} d_t$$

Total deviation decomposed into positive and negative deviations

Wind Producer Problem

(Non-anticipativity constraints)

$$P_{t\omega}^D = P_{t\omega'}^D, \quad \forall t, \forall \omega, \omega'$$

Wind Producer Problem

(Non-anticipativity constraints)

Relaxed to obtain offer curves!

$$P_{t\omega}^D = P_{t\omega'}^D, \quad \forall t, \forall \omega, \omega': \lambda_{t\omega}^D = \lambda_{t\omega'}^D$$

Power traded in day-ahead market can be different
for different price realizations!



Pairs $(P_{t\omega}^D, \lambda_{t\omega}^D)$ making up an offer curve

Wind Producer Problem

(Non-anticipativity constraints)

$$P_{t\omega}^A = P_{t\omega'}^A, \quad \forall t, \forall \omega, \omega': (\lambda_{t\omega}^D = \lambda_{t\omega'}^D, \forall t)$$

and $(P_{t\omega} = P_{t\omega'}, \forall t = 1, 2, \dots, N_{T_1})$

To model the certainty gain effect!

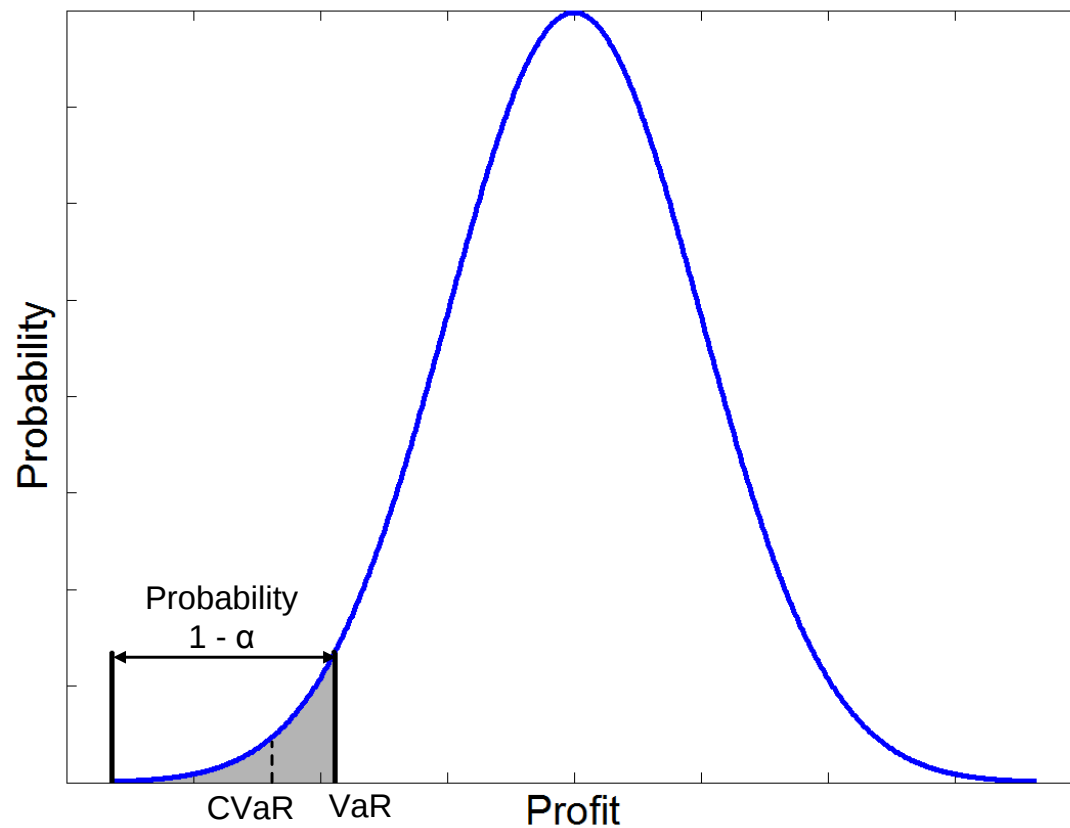
The power traded in the adjustment market can be different depending on the wind realization between the closure of the day-ahead and adjustment markets!

Wind Producer Problem

(Risk management)

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

Wind Producer Problem (CVaR modeling)



Wind Producer Problem (CVaR modeling)

$$\begin{aligned}
 \text{CVaR} &= \xi - \frac{1}{1-\alpha} \sum_{\omega \in \Omega} \pi_{\omega} \eta_{\omega} \\
 &- \sum_{t=1}^{N_T} [\lambda_{t\omega}^D P_{t\omega}^D d_t + \lambda_{t\omega}^A P_{t\omega}^A d_t + \lambda_{t\omega}^D (r_{t\omega}^+ \Delta_{t\omega}^+ - r_{t\omega}^- \Delta_{t\omega}^-)] \\
 &+ \xi - \eta_{\omega} \leq 0 \quad \forall \omega \\
 \eta_{\omega} &\geq 0 \quad \forall \omega
 \end{aligned}$$

Wind Producer Problem

(CVaR modeling)

Non-decreasing condition

$$P_{t\omega}^D - P_{t\omega'}^D \leq 0, \quad \forall t, \forall \omega, \omega': O(\lambda_{t\omega}^D) + 1 = O(\lambda_{t\omega'}^D)$$

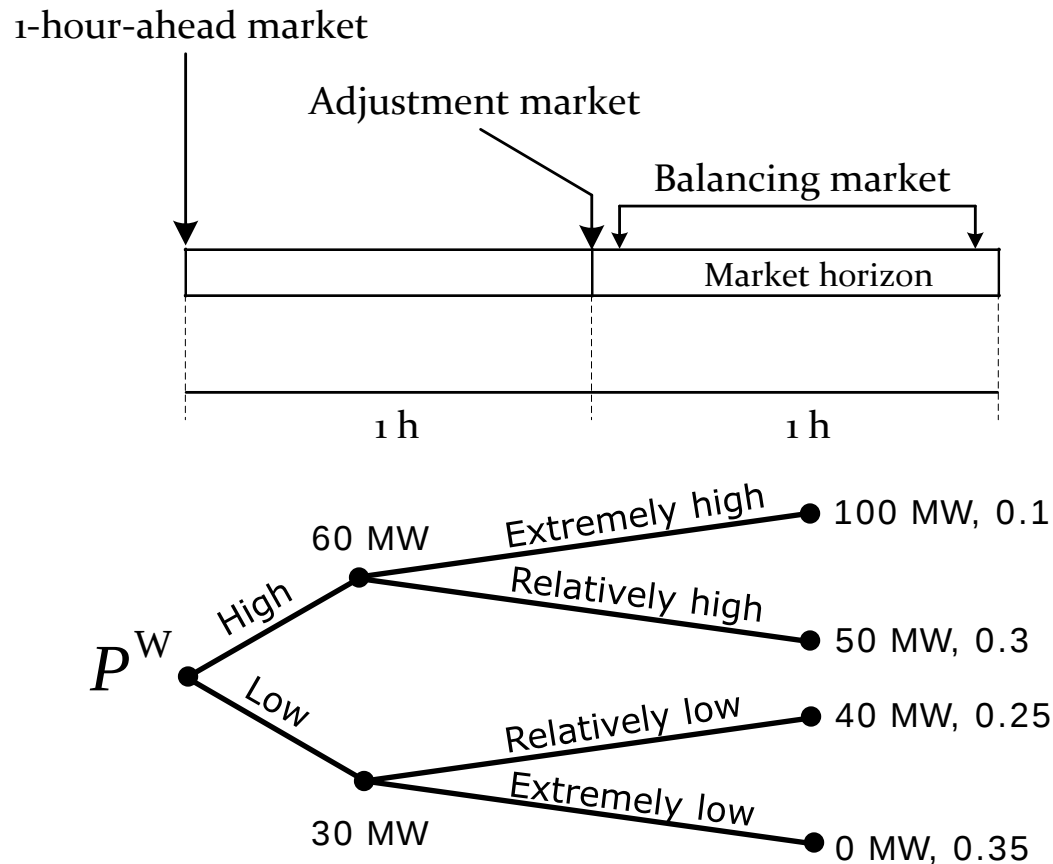
Bounds

$$0 \leq P_{t\omega}^D \leq P^{\max}, \quad \forall t, \forall \omega$$

$$0 \leq P_{t\omega}^D + P_{t\omega}^A \leq P^{\max}, \quad \forall t, \forall \omega$$

Wind Producer Problem

(Example: Wind production data)



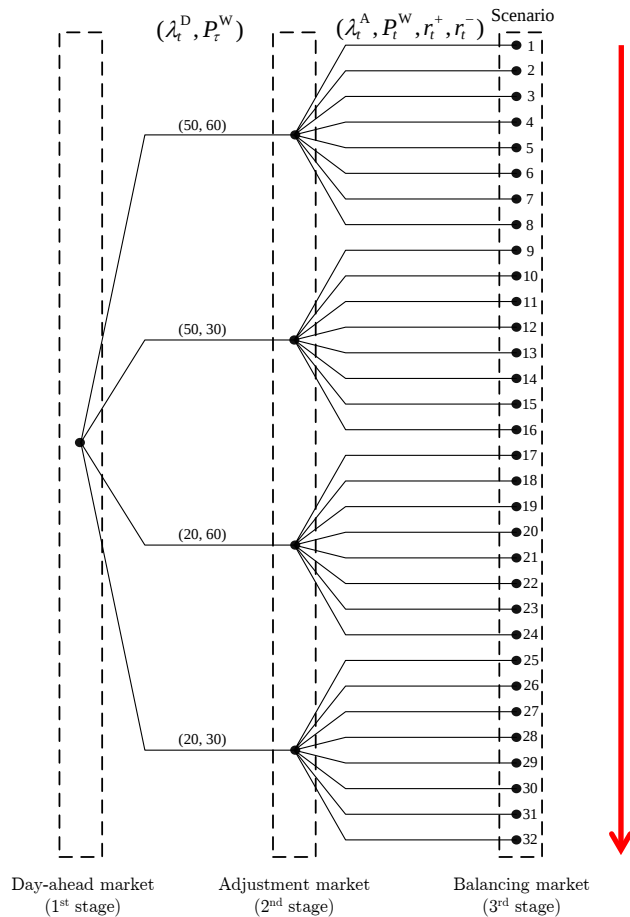
Wind Producer Problem

(Example: Price data)

	λ^D (\$/MWh)		$\Delta\lambda$ (\$/MWh)		(r^+, r^-)	
Value	50	20	-10	3	(1, 1.5)	(0.9, 1)
Prob.	0.40	0.60	0.35	0.65	0.7	0.3

Wind Producer Problem

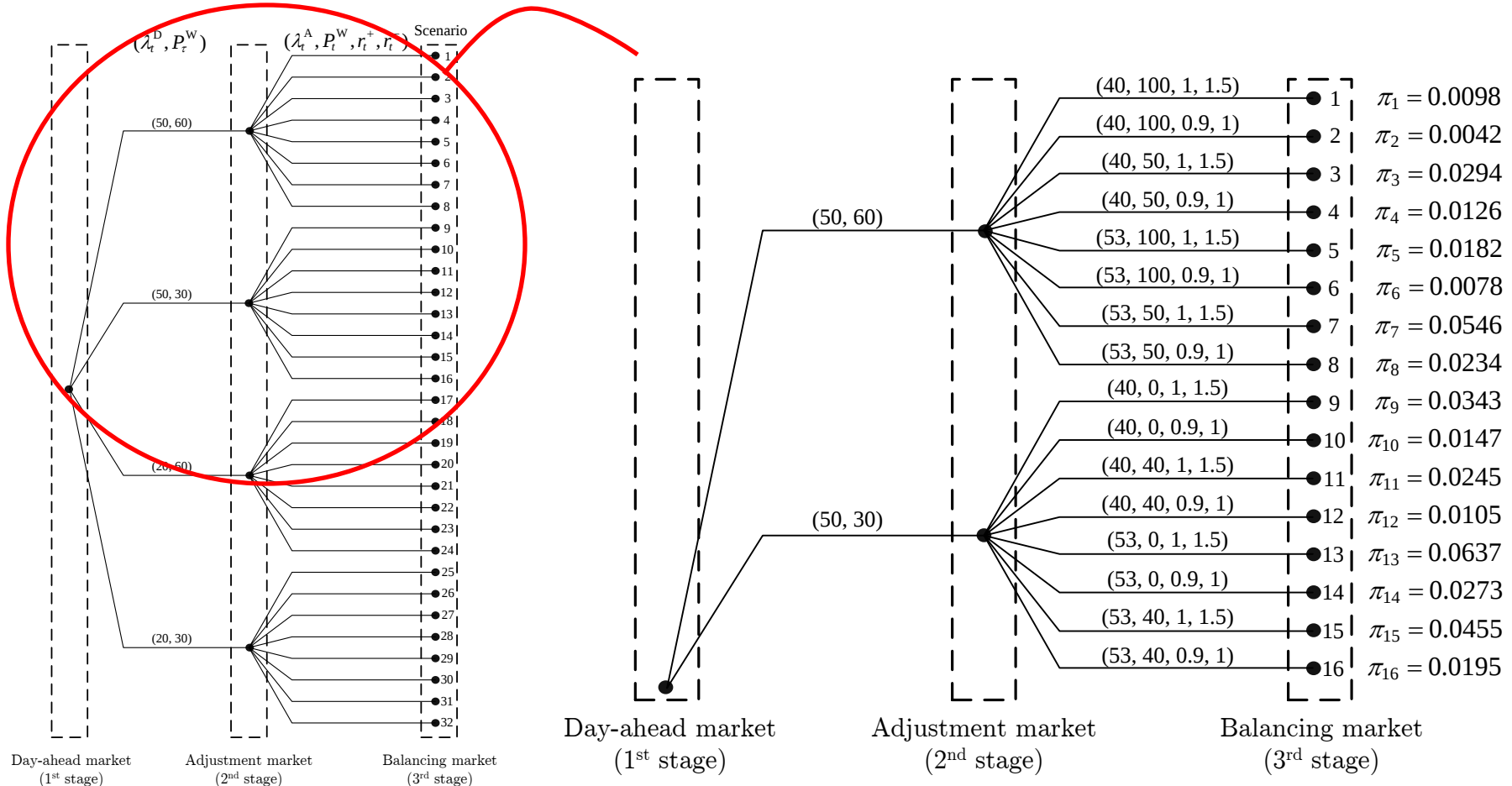
(Example: Scenario tree)



32
scenarios

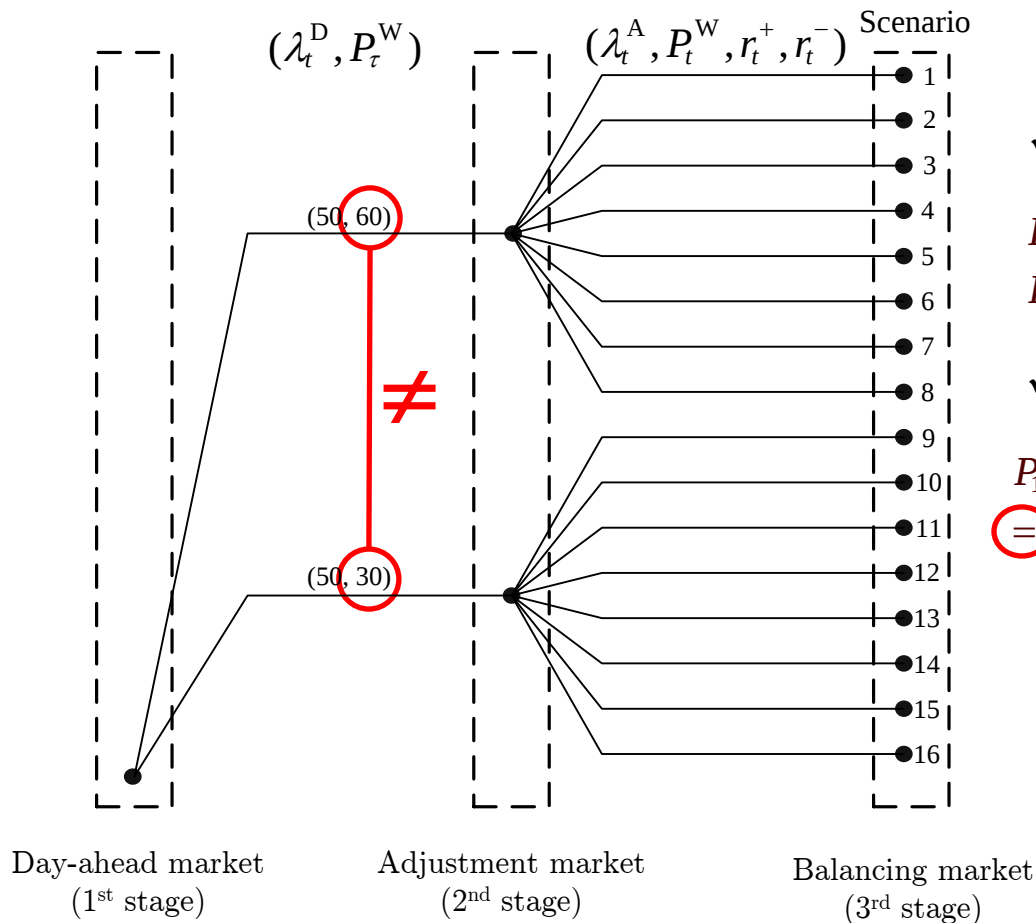
Wind Producer Problem

(Example: Scenario tree)



Wind Producer Problem

(Example: Certainty gain modeling)



✓ Modeling the certainty gain

$$P_1^A = P_2^A = P_3^A = P_4^A = P_5^A = P_6^A = P_7^A = P_8^A, \\ P_9^A = P_{10}^A = P_{11}^A = P_{12}^A = P_{13}^A = P_{14}^A = P_{15}^A = P_{16}^A$$

✓ Not modeling the certainty gain

$$P_1^A = P_2^A = P_3^A = P_4^A = P_5^A = P_6^A = P_7^A = P_8^A = \\ = P_9^A = P_{10}^A = P_{11}^A = P_{12}^A = P_{13}^A = P_{14}^A = P_{15}^A = P_{16}^A$$

More constrained!

Wind Producer Problem

(Example: Certainty gain effect)

✓ If

	(r^+, r^-)	
Value	(1, 1.5)	(0.9, 1)
Prob.	0.7	0.3



Expected profit: $\uparrow 0\%$

✓ If

	(r^+, r^-)	
Value	(1, 1.5)	(0.1, 1)
Prob.	0.7	0.3



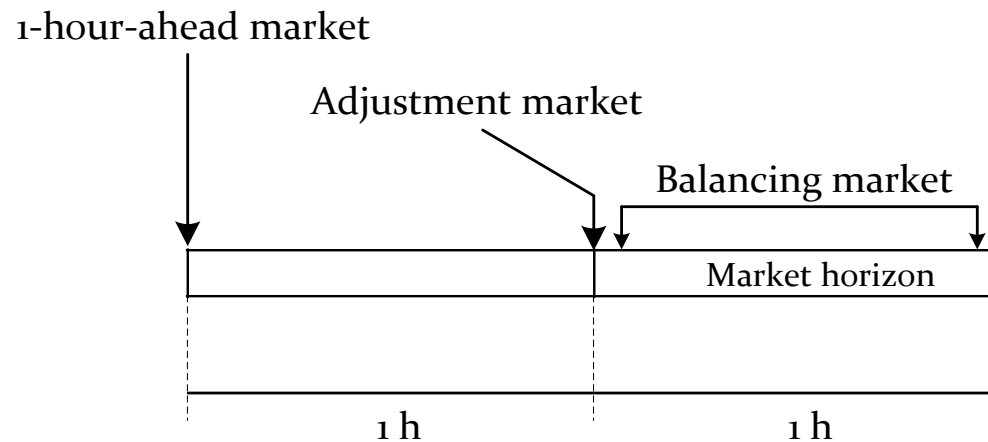
Expected profit: $\uparrow 14.03\%$



Very unfavorable imbalance prices!

Wind Producer Problem (Exercise)

Market framework:



Wind Producer Problem

(Exercise)

It is known that:

1. The price in the 1-h ahead market is equal to 50 €/MWh with a probability of 0.40 and equal to 20 €/MWh with a probability of 0.60
2. The price in the adjustment market is identical to the 1-h ahead market price
3. The quantity of power produced by a certain 100-MW wind farm during the hour between the closures of the 1-h ahead and adjustment markets may be *high* (60 MW) with a probability of 0.4 or *low* (30 MW) with a probability of 0.6

Wind Producer Problem

(Exercise)

It is known that:

4. If the wind power production is *high* (60 MW), the amount of power produced during the 1-h market horizon may be *extremely high* (100 MW) with a probability of 0.75 or *relatively high* (50 MW) with a probability of 0.25
5. If the wind power production is *low* (30 MW), the amount of power produced during the 1-h market horizon may be *extremely low* (0 MW) or *relatively low* (40 MW), both with a probability of 0.5

Wind Producer Problem

(Exercise)

It is known that:

6. Dual-price balancing settlement, two-sided penalty:
 - a) The price of the energy required to cover generation shortages is 20% higher than the 1-h ahead market price
 - b) Generation surpluses can be sold in the balancing market at a price 50% smaller than the 1-h ahead market price

Wind Producer Problem (Exercise)

Things to do:

1. Build the corresponding scenario tree (graphically)
2. Ignore the adjustment market. Compute:
 - a) Optimal bid in the 1-h ahead market
 - b) VSS and EVPI (please, provide absolute figures and percentages)
 - c) Power sold in the 1-h ahead market as a function of the risk aversion of the wind producer (graphically)

Wind Producer Problem (Exercise)

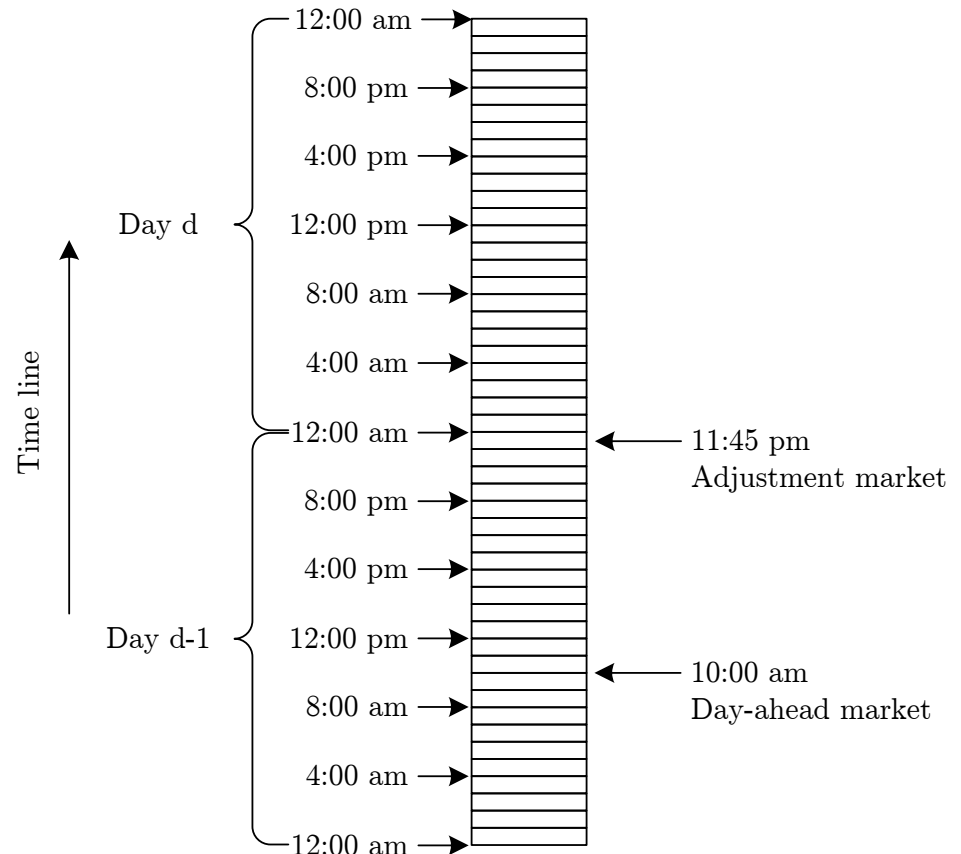
Things to do:

3. Consider the adjustment market. Compute:
 - a) Optimal bid in both the 1-h ahead and adjustment markets
 - b) Economic improvement due to the certainty gain effect

Wind Producer Problem

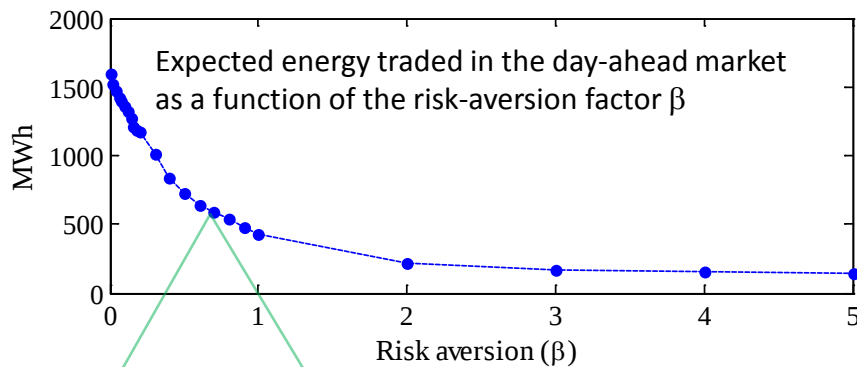
(Case study)

- ✓ Price data from Iberian Peninsula market.
- ✓ Wind speed data from a location in Kansas (US).
- ✓ 1 day.



Wind Producer Problem

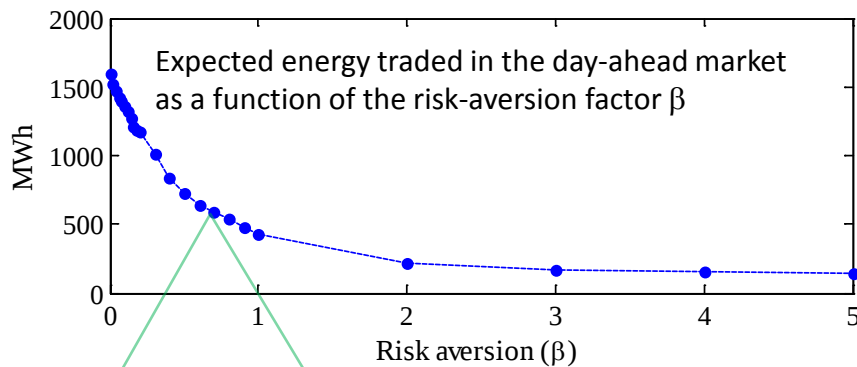
(Case study: No adjustment market)



Reducing the energy traded in the day-ahead market in the hope of selling in the balancing market at a competitive price

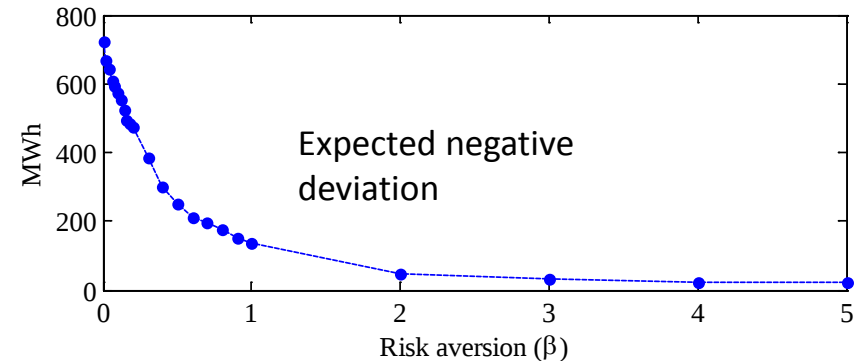
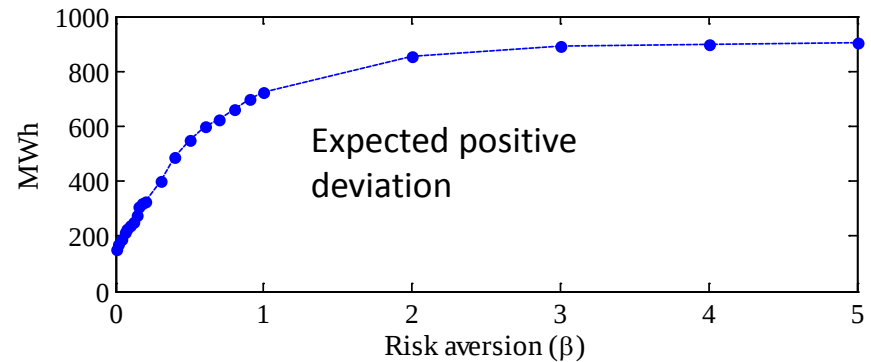
Wind Producer Problem

(Case study: No adjustment market)



Reducing the energy traded in the day-ahead market in the hope of selling in the balancing market at a competitive price

$$\beta \uparrow \Rightarrow E\{P^D\} \downarrow \Rightarrow \begin{cases} E\{\Delta^+\} \uparrow \\ E\{\Delta^-\} \downarrow \end{cases}$$

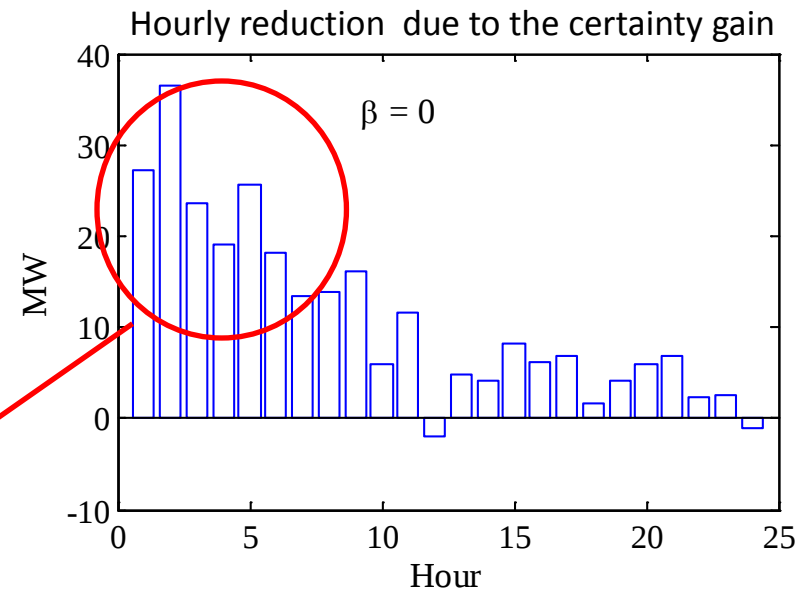
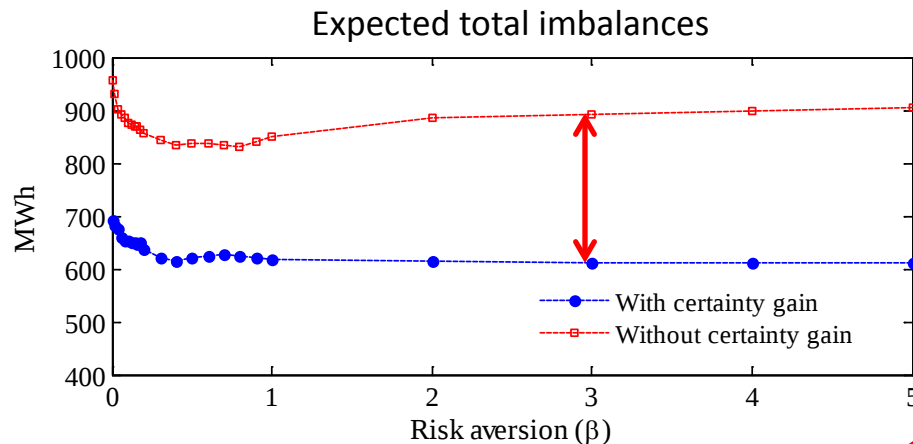


Negative deviations are more harmful to the wind producer than positive deviations (assuming that $r^+ \geq 0$)

Wind Producer Problem

(Case study: Adjustment market)

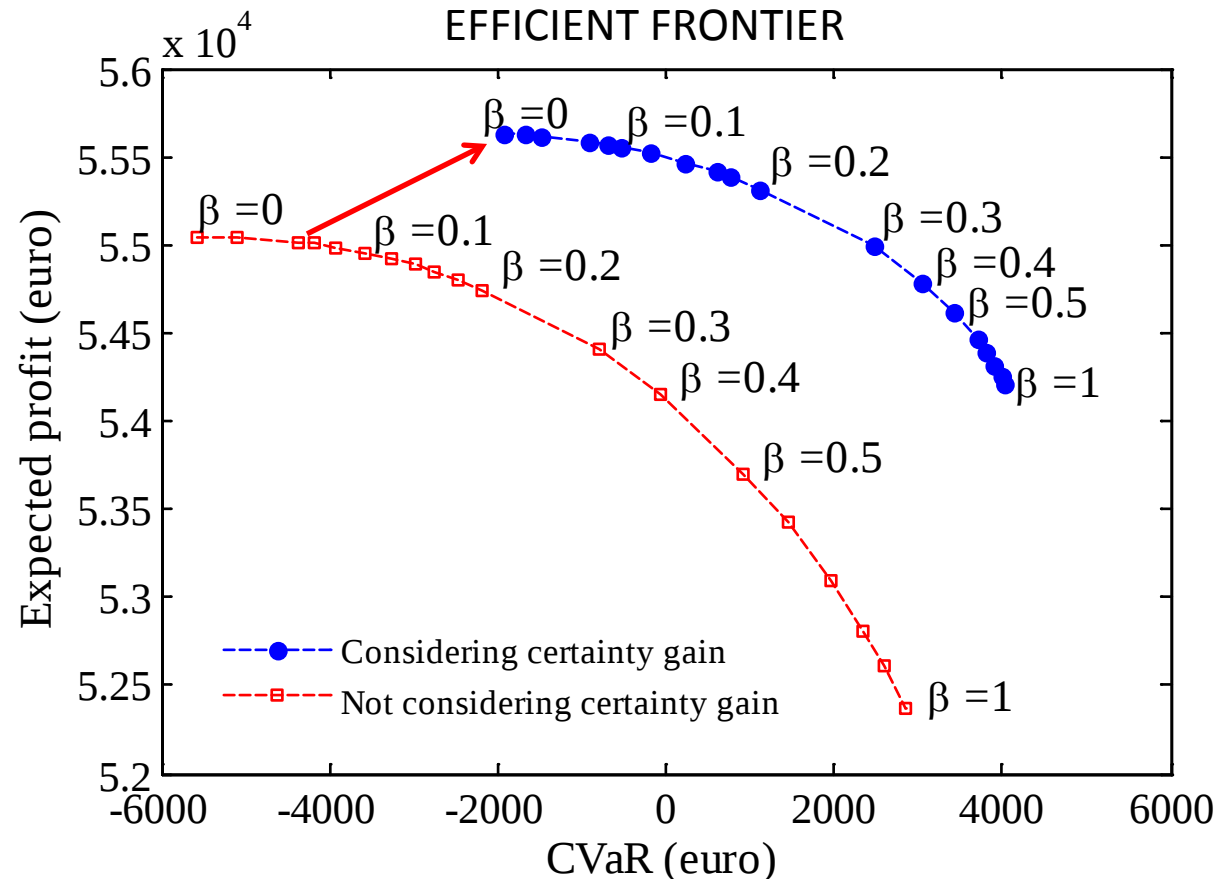
✓ Certainty gain effect!



A significant reduction for the first few hours

Wind Producer Problem

(Case study: Certainty gain effect)



Wind Producer Problem

(Case study: Certainty gain effect)

- ✓ No adjustment market

$$VSS = 1.87\%$$

Better not to offer forecasts!

- ✓ Adjustment market, no certainty gain effect

$$VSS = 2.58\% (\uparrow 0.71\%)$$

A new market $\Rightarrow$ new trading options

- ✓ Adjustment market, certainty gain effect

$$VSS = 3.61\% (\uparrow 1.03\%)$$

Good to have markets close to power delivery!



Thanks for your attention!