Counterexamples to commonly held Assumptions on Unit Commitment and Market Power Assessment

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2 Topics

- Comparison of Theoretical Efficiency of Centralized and Decentralized Unit Commitment
(PoolCo vs. PX)
- Determination of Market Power revisiting the fundamental Economic Assumption of Marginal Costs being the baseline of competitive prices

Agenda 1: PoolCo vs PX

- Background Information
- The commonly used Argument
- Counterexample
- Conclusions

Background Information 1: PoolCo vs PX

- Unit Commitment: Technological constraints (minimum up-time, starting costs)
- ISO: Independent System Operator
- PoolCo vs. PX (Power Exchange)

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Conventional Centralized Unit Commitment

- Minimize the total generation cost

$$\min_{u_i, Q_i} \sum_{i=1}^{n} u_i C_i(Q_i)$$

- So that total generation equals total load

$$\sum_{i=1}^{n} Q_i = Q_D$$

- Lagrangian relaxation method

$$L(u, Q, l) = \sum_{i=1}^{n} u_i \left(C_i(Q_i) - l\, Q_i \right) + l\, Q_D$$

Conventional Centralized Unit Commitment

- Minimized over Q

$$\frac{dC_1}{dQ_1} = \ldots = \frac{dC_n}{dQ_n} = l$$

- Plug back

$$L(u, l) = \sum_{i=1}^{n} u_i \Big(C_i \big(Q_i(l) \big) - l\, Q_i(l) \Big) + l\, Q_D$$

- Minimized with respect to u_i -> Switching Law

$$u_i = \begin{cases} 0 & \text{if } C_i - l\,Q_i > 0 \\ 1 & \text{if } C_i - l\,Q_i < 0 \end{cases}$$

$$\boxed{\frac{C_i}{Q_i} < l}$$

Decentralized Unit Commitment

- Maximize the individual profit

$$\max_{Q_i} p_i(Q_i) \qquad p_i = PQ_i - C_i(Q_i)$$

- Decide in advance whether to turn on the unit

$$u_k \qquad \widehat{Q}_k \qquad \widehat{p}_k$$

- Expected Profit

$$\widehat{p}_{on} = \widehat{p} \cdot \widehat{Q_i} - C_i(\widehat{Q_i})$$

Decentralized Unit Commitment

- Decision

$$\hat{p}_{on} > 0$$

- Switching Law

$$\boxed{\frac{C_i(\widehat{Q_i})}{\widehat{Q_i}} < \hat{p}}$$

- Conclusion: a centralized system operator would schedule the same units as the individual power producers would in a decentralized way

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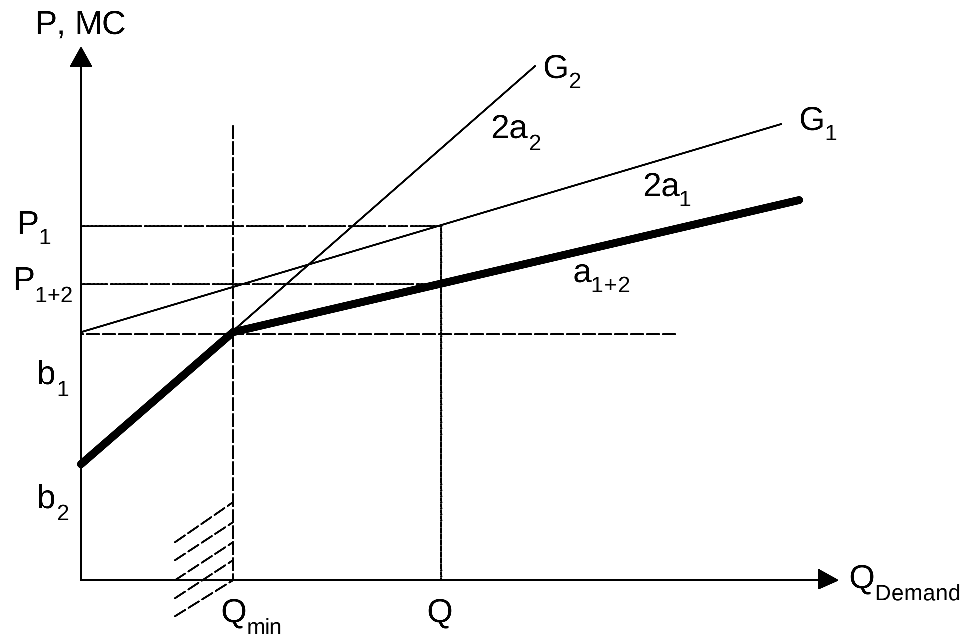
Counterexample: 2 Generators G_1, G_2

- Quadratic Cost Function: $C_i(Q_i) = a_i Q_i^2 + b_i Q + c_i$
- Linear increasing MC: $MC_i(Q_i) = 2a_i Q_i + b_i$

- Supply Functions:



- $Q_i = \mathrm{f}(a, b, c, Q)$

Counterexample: Conditions

We search Parameters a, b, c, Q so as to:

- Generator 1 makes profits:

$$a_1 Q_1^2 + b_1 Q_1 + c_1 < P_{1+2} Q_1$$

- Generator 2 loses money if switched on:

$$a_2 Q_2^2 + b_2 Q_2 + c_2 > P_{1+2} Q_2$$

- Total costs are lower with both generators on:

$$a_1 Q^2 + b_1 Q + c_1 > a_1 Q_1^2 + b_1 Q_1 + c_1 + a_2 Q_2^2 + b_2 Q_2 + c_2$$

Counterexample: Numerical Values

- Typical Parameters:

	G_1	G_2
a	1	2
b	1	1.6
c	1.1	0.7
Q	2	

- Differences:

	G_1	G_1 and G_2		
P	5	3.87		
	G_1	$G_1 + G_2$	G_1	G_2
% *Q*	100%	100%	72%	28%
C	**7.1**	**6.84**	4.59	2.25
Rev	10	7.73	5.54	2.19
⚐	2.9	0.9	0.95	**-0.06**

Agenda 1: PoolCo vs PX

- Background Information
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Conclusion 1 (PoolCo vs PX)

- A centralized Unit Commitment can lead to higher efficiency
- Explanation: It is possible that several generators can supply the demand with lower costs than the sub-group of generators that would obtain a profit in a free competitive market
  - assuming bidding marginal costs (!)

Agenda 2: Market Power

- Background Information
- Illustrative Example
- Numerical Values
- Conclusions

Background Information 2 (Market Power)

- „Offering power at a price significantly above marginal production (or opportunity) cost, or failing to generate power that has a production cost below the market price, is an indication of the exercise of market power…“ [Borenstein00]

- “Market power exists when a supplier or consumer influences prices ... If suppliers exercise market power, prices could be higher than marginal costs.” [DOE97]

Background Information 2 (Market Power)

- „Economic withholding occurs when a supplier offers output to the market at a price that is above both its full incremental costs and the market price (and thus, the output is not sold)" [FERC01]

[Borenstein00]: Borenstein S., Bushnell J., Wolak F.; Diagnosing Market Power in California's Restructured Wholesale Electricity Market; NBER Working Paper 7868

[DOE97]: Department of Energy; Electricity Prices in a Competitive Environment: Marginal Cost Pricing of Generation Services and Financial Status of Electric Utilities.

[FERC01]: Federal Energy Regulatory Commission; Investigation of Terms and Conditions of Public Utility Market-Based Rate Authorizations; Order E-47,

Agenda 3: Market power

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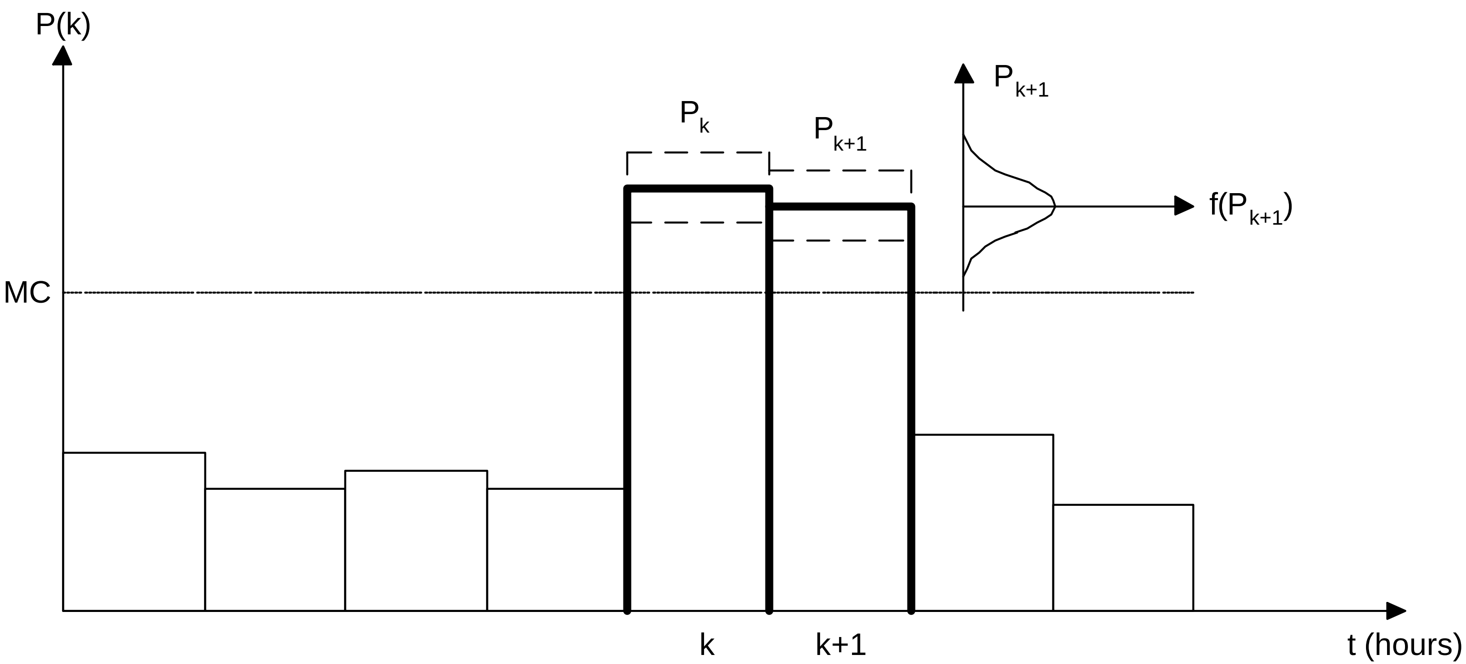
Illustrative Example

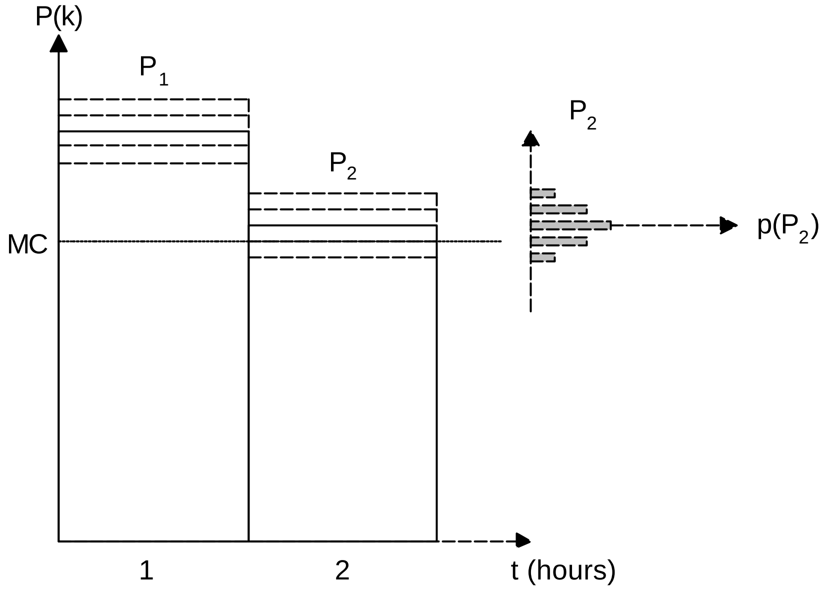
- MC=const, $t_{up,min}$=2, SU+SD=FOC
- Price taker



Illustrative Example

- Discrete Prices: $P_1 \in \{P_{11}, \ldots, P_{1i}, \ldots, P_{15}\}$

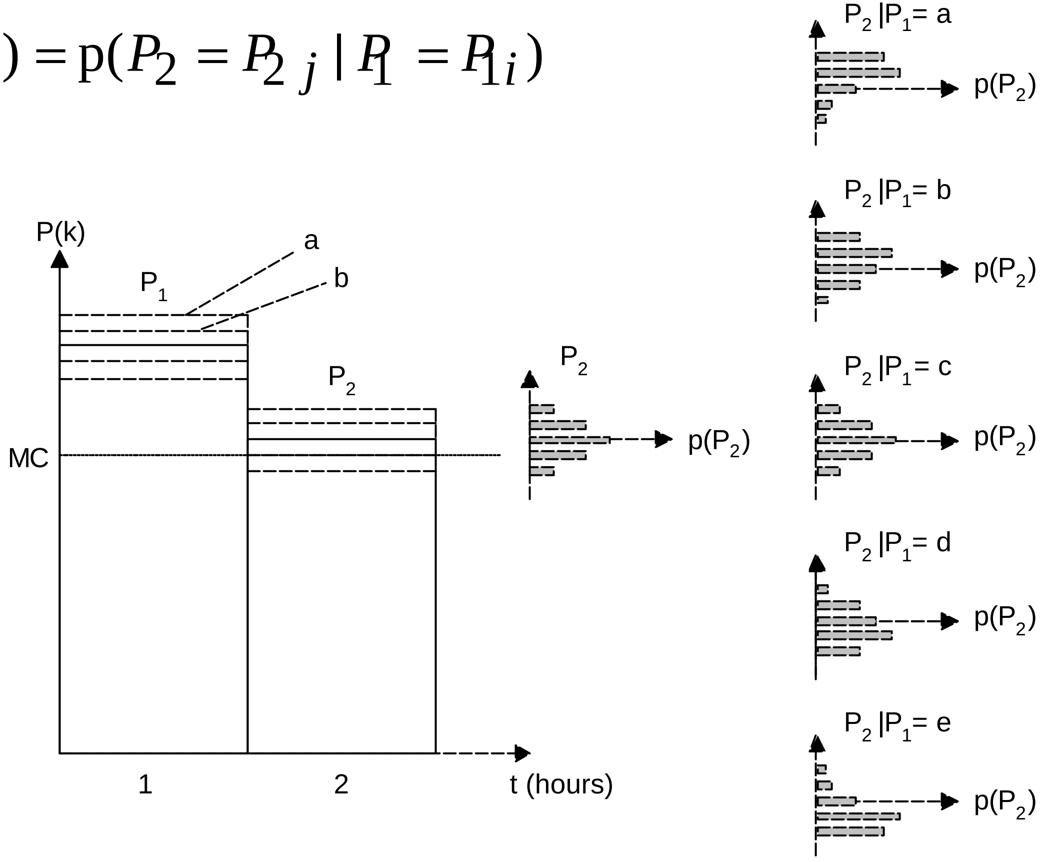
$$P_2 \in \{P_{21}, \ldots, P_{2j}, \ldots, P_{25}\}$$



Illustrative Example

- Correlation between Hours possible

$$p(P_2 = P_{2j}) = p(P_2 = P_{2j} \mid P_1 = P_{1i})$$



Agenda 3: Market Power

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Numerical Values – Example

- MC=50, Q=1, FOC=10

	Bid Sequence	Exp.Profit
Prices independent	(58,52), (60,54)	**1.1720**
	(58,54)	**1.1538**
	(50,50) (56,50),(56,52), (60,56),(62,56)	**1.0798**
	(60,52)	**0.9266**
Prices correlated	(60,52)	**1.7650**
	(58,52)	**1.6838**
	(60,54)	**1.6834**
	(50,50)	**1.0798**

Agenda 3: Market Power

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Conclusion 2 (Market Power)

- Market Prices above MC of the last unit do not prove the exercise of Market Power (!)
- In order to determine the optimal bidding sequence, the price correlations between hours have to be included in the algorithms

Summary

- A decentralized Unit Commitment is not always as efficient as the centralized one – even in the theoretical case.
- Marginal Costs cannot be used as the baseline from which Market Power is measured.

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Backup – 3 – Formula

- Expected Profit of Bidding (b_1,b_2):

$$J(b_1, b_2) = \sum_{P_i | P_i \ge b_1} \sum_{P_j | P_j \ge b_2} \mathrm{p}(P_1 = P_i) \cdot \mathrm{p}(P_2 = P_j) \cdot \begin{pmatrix} \left(P_i + P_j - 2MC\right) Q \\ -FOC \end{pmatrix}$$

$$+ \sum_{P_i | P_i \ge b_1} \sum_{P_j | P_j < b_2} \mathrm{p}(P_1 = P_i) \cdot \mathrm{p}(P_2 = P_j) \cdot \left(\left(P_i - MC\right) Q - FOC\right)$$

$$+ \sum_{P_i | P_i < b_1} \sum_{P_j | P_j \ge b_2} \mathrm{p}(P_1 = P_i) \cdot \mathrm{p}(P_2 = P_j) \cdot \left(\left(P_j - MC\right) Q - FOC\right)$$

Backup – 3 – Numerical Values

MC=50; $P_1 \in \{56,58,60,62,64,66\}$

Q=1; $P_2 \in \{46,48,50,52,54,56\}$

FC=10;

With $p_i=p(P_1=P_{1i}) = p(P_2=P_{2i})$ and $p_{i|j}=p(P_2=P_{2j} | P_1=P_{1i})$:

$p_1=0.1888$	$p_{1\|1}=0.45$	$p_{1\|2}=0.20$	$p_{j\|3}= p_j$
$p_2=0.1624$	$p_{2\|1}=0.20$	$p_{2\|2}=0.32$	
$p_3=0.2978$	$p_{3\|1}=0.27$	$p_{3\|2}=0.33$	$p_{j\|4}= p_{5-j\|2}$
$p_4=0.1624$	$p_{4\|1}=0.06$	$p_{4\|2}=0.08$	
$p_5=0.1888$	$p_{5\|1}=0.02$	$p_{5\|2}=0.08$	$p_{j\|3}= p_{5-j\|1}$