Energy Economics

Fachbereich 2 Informatik und Ingenieurwissenschaften

Capacity market fundamentals

- regulator determines the total capacity necessary $\underline{C}$
- regulator defines a strike price p_{strike}
- regulator buys call options amounting to the necessary capacity
- call option of the regulator set an incentive to deliver electricity in an scarcity event

$\rightarrow$ Reliability Option (RO)

The power plant operator's view

- We introduce the failure rate $X_{IR,t,i}$ and $X_{PER,t,i}$

$\rightarrow$ share of total time the power plant is not running although prices are above variable cost

$\rightarrow$ failure rates are individual for each power plant

$\rightarrow$ $X_{IR,t,i} \geq X_{PER,t,i}$ since incentives to keep the power plant running are higher

$\Rightarrow$ for a power plant operator who simply sells electricity at the **energy-only market** revenue R in year t equals

$$R_t = (1 - X_{IR,t,i})IR_{t,i} + (1 - X_{PER,t,i})PER_t$$

Investment decision and capital

- How does the capital stock of a power plant change over its lifetime?
- We assume that the change of capital K of power plant i with respect to time t in years can be described by the following equation

$$K_{t,i} = K_{0,i}(1-\delta_i)^t - K_{0,i}\tilde{\delta}_i t \qquad \forall 1 > \delta_i, \tilde{\delta}_i \geq 0$$

- δ_i corresponds to the depreciation rate, a risk premium and the interest rate (profit margin) of the power plant
- $\tilde{\delta}_i$ corresponds to a linear depreciation rate if necessary
- An incentive to invest in new power plants only exists if there is a realistic chance to get back the investment (with an appropriate profit) during the lifetime T of the power plant

Investment decision and capital

- We assume p_{strike} equal to variable (and emission) cost of the last power plant in the merit order

$\Rightarrow$ scarcity rent vanishes

- lifetime depreciation of the power plant yields

$$
\begin{aligned}
K_{0,i} - K_{T,i} &= K_{0,i}(1 - (1-\delta_i)^T + \tilde{\delta}_i T) \\
&= \sum_{t=1}^{T} (K_{t-1,i} - K_{t,i}) := \sum_{t=1}^{T} k_{t,i} \\
&= K_{0,i} \sum_{t=1}^{T} \left((1-\delta_i)^t \frac{\delta_i}{1-\delta_i} + \tilde{\delta}_i \right) \\
&= \sum_{t=1}^{T} \left((1 - X^e_{IR,t,i}) IR^e_{t,i} + (1 - X^e_{PER,t,i}) PER^e_t + (1 - X^e_{PER,t,i}) MM^e_t \right)
\end{aligned} \tag{1}
$$

Investment decision and capital

- Let us assume the capacity market covers a time period of one year
- According to Eq. 1 we can write

$$k_{t,i} := (1 - X^e_{IR,t,i}) IR^e_{t,i} + (1 - X^e_{PER,t,i}) PER^e_t + (1 - X^e_{PER,t,i}) MM^e_t \quad (2)$$

- What is a rational bid at the capacity market?

$$p^*_t = p_t(\sum_{i=1}^{m} C_{t,i}) = k_{t,m} + X^e_{PER,t,m} PER^e_t - (1 - X^e_{IR,t,m}) IR^e_{t,m} \quad (3)$$

Incentive regulation

- Inserting Eq. 2 into Eq. 3 yields

$$p_t^* = PER_t^e + (1 - X_{PER,t,m}^e) MM_t^e \tag{4}$$

- a bidder without capacity (*deceiver* with $X_{PER,t,i}^e$=1) receives p_t^* while paying only PER_t^e

⇒ bidder can underbid all other participants

⇒ incentive to pretend higher capacity than available

- solution is the introduction of the penalty $\varrho_{t,i}^e$

Optimal penalty

- too low penalty $\rightarrow$ incentives to pretend higher capacity remain
- too high penalty $\rightarrow$ market may be distorted.

$\Rightarrow$ optimal penalty exactly eliminates incentives to deceive

$\Rightarrow$

$$\varrho^e_{t,i} = X^e_{PER,t,i} MM^e_t$$

- the penalty will be considered in the capacity bids turning Eq. 4 into

$$\begin{aligned} p^*_t &= PER^e_t + (1 - X^e_{PER,t,m}) MM^e_t + \varrho^e_{t,i} \\ &= PER^e_t + MM^e_t \end{aligned} \tag{5}$$

$\Rightarrow$ no advantage for deceivers anymore

Optimal penalty – practical implementation

- after the auction result is available the regulator can announce a penalty factor

$$\xi_t := \frac{p_t^*}{PER_t^e}$$

- all payments to the regulator are multiplied with the penalty factor if no electricity is delivered although the spot price exceeds the strike price

$\Rightarrow$ the payment increases from $X_{PER,t,m}^e PER_t^e$ to $X_{PER,t,m}^e p_t^* = X_{PER,t,m}^e (PER_t^e + MM_t^e)$

$\Rightarrow$ incentives to pretend higher capacity than available vanish

Capacity market equations

- rational equilibrium price assuming truthful bidding

$$p_t^* = p_t(\sum_{i=1}^{m} C_{t,i}) = k_{t,m} + X^e_{PER,t,m} PER^e_t - (1 - X^e_{IR,t,m}) IR^e_{t,m} + \varrho^e_{t,m}$$

- the annual capital decrease equals the revenue of the power plant including MM, if occurring

$$k_{t,i} = (1 - X^e_{IR,t,i}) IR^e_{t,i} + (1 - X^e_{PER,t,i}) PER^e_t + (1 - X^e_{PER,t,i}) MM^e_t$$

- as penalty and penalty factor we receive

$$\varrho^e_{t,i} = X^e_{PER,t,i} MM^e_t \Rightarrow \xi_t := \frac{p^*_t}{PER^e_t}$$

Capacity market equilibrium – step I

- we assume two power plants i and j
- the difference of their annual capital cost yields

$$\begin{aligned} k_{t,j} - k_{t,i} = {} & (1 - X^e_{IR,t,j}) IR^e_{t,j} - (1 - X^e_{IR,t,i}) IR^e_{t,i} \\ & - (X^e_{PER,t,j} - X^e_{PER,t,i}) PER^e_t \\ & - (X^e_{PER,t,j} - X^e_{PER,t,i}) MM^e_t . \end{aligned}$$

- or in short

$$\begin{aligned} \Delta k_{t,j-i} = {} & (1 - X^e_{IR,t,j}) IR^e_{t,j} - (1 - X^e_{IR,t,i}) IR^e_{t,i} - \Delta X^e_{PER,t} PER^e_t \\ & - \Delta X^e_{PER,t} MM^e_t . \end{aligned}$$

Capacity market equilibrium – step II

- difference between price bids of power plants i and j

$$
\begin{aligned}
\Delta p_{t,j-i} :&= p_{t,j} - p_{t,i} \\
&= \Delta k_{t,j-i} + \Delta X^e_{PER,t} PER^e_t + \Delta \varrho^e_t + (1 - X^e_{IR,t,i}) IR^e_{t,i} - (1 - X^e_{IR,t,j}) IR^e_{t,j} \\
&= \Delta \varrho^e_t - \Delta X^e_{PER,t} MM^e_t \\
&= 0.
\end{aligned}
$$

$\Rightarrow$ zero arbitrage principle

$\Rightarrow$ in the equilibrium all bids at the capacity market are identical!

Capacity market – exercise

capital costs peak-load	$k_{t,peak}$	490,000 €/MW
failure rate peak-load	$X^e_{PER,t,peak}$	0.02
capital costs base-load	k_{base}	871,000 €/MW
failure rate base-load	$X^e_{IR,t,base}$	0.035
	$X^e_{PER,t,base}$	0.03
$\mathrm{IR}^e_{t,base}$	$(p_{strike} - C_{G,t,base} - C_{E,t,base})d_{t,base}$	400,000 €/MW
PER^e_t	$(p_{cap} - p_{strike})d^e_{spike,t}$	500,000 €/MW

- Calculate the price bids of the two power plants at the capacity market.
- Calculate costs for electricity consumers with and without capacity market and compare the results.
- Assume revenues at the electricity market are a) 10 % higher b) 10 % lower than expected. Compare the effect with and without capacity market.

Capacity market – solution 1

- price bids at the capacity market yield

$$
\begin{aligned}
p_{base} &= 871{,}000 \text{ €/MW} + 0.03 \cdot 500{,}000 \text{ €/MW} + \varrho^{e}_{t,base} - 0.965 \cdot 400{,}000 \\
&= \mathbf{500{,}000\ €/MW} + \varrho^{e}_{base} \\
p_{peak} &= 490{,}000 \text{ €/MW} + 0.02 \cdot 500{,}000 \text{ €/MW} + \varrho^{e}_{t,peak} \\
&= \mathbf{500{,}000\ €/MW} + \varrho^{e}_{peak}
\end{aligned}
$$

$\Rightarrow$ capacity market is in its equilibrium

$\Rightarrow$ no MM

$\Rightarrow$ no penalty

Capacity market – solution 2

- price bids at the capacity market yield

$$\begin{aligned}
\xi^e_{c,t} &= \rho_{t,base}\underline{C}_t \cdot R^e_{t,base} + \rho_{t,peak}\underline{C}_t \cdot R^e_{t,peak} \\
&\quad + \rho_{t,base}\underline{C}_t(p^*_t - PER^e_t - \varrho^e_{t,base}) + \rho_{t,peak}\underline{C}_t(p^*_t - PER^e_t - \varrho^e_{t,peak}) \\
\xi^e_{eo,t} &= \rho_{t,base}\underline{C}_t \cdot R^e_{t,base} + \rho_{t,peak}\underline{C}_t \cdot R^e_{t,peak}
\end{aligned}$$

- with $\rho_{t,base}$ and $\rho_{t,peak}$ being the share of contracted base-load and peak-load capacity

$\Rightarrow$ since MM does not exist in this example (penalties are zero), costs are identical

Capacity market – solution 3a

- revenues at the energy only market

  $R_{t,peak} = 0.9 \cdot R^e_{t,peak} = 441{,}000$ €/MW

  $R_{t,base} = 0.9 \cdot R^e_{t,base} = 783{,}900$ €/MW
- capacity payments

  500,000 €/MW - 450,000 €/MW = 50,000 €/MW for both
- total revenue

  491,000 €/MW for the peak-load power plant

  833,900 €/MW for the base-load power plant

Capacity market – solution 3b

- revenues at the energy only market

  $R_{t,peak} = 1.1 \cdot R^{e}_{t,peak} = 539{,}000$ €/MW

  $R_{t,base} = 1.1 \cdot R^{e}_{t,base} = 958{,}100$ €/MW
- capacity payments

  500,000 €/MW - 550,000 €/MW = -50,000 €/MW for both
- total revenue

  489,000 €/MW for the peak-load power plant

  908,100 €/MW for the base-load power plant

$\Rightarrow$ significant attenuation of price fluctuations