Energy Economics

Fachbereich 2 Informatik und Ingenieurwissenschaften

Capacity market equations

- rational equilibrium price assuming truthful bidding

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

- 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 – 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 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

General idea of a capacity market

- transform volatile revenues into an annual payment

$\Rightarrow$ risk reduction for suppliers

$\Rightarrow$ decreasing risk premium

$\Rightarrow$ cost reduction

- solve the missing money problem

$\Rightarrow$ provide sufficient investment incentives

$\Rightarrow$ ensure sufficient generation capacity

- hedge load against high prices

$\Rightarrow$ reduction of spot market volatility

Revisiting the merit order effect of RES

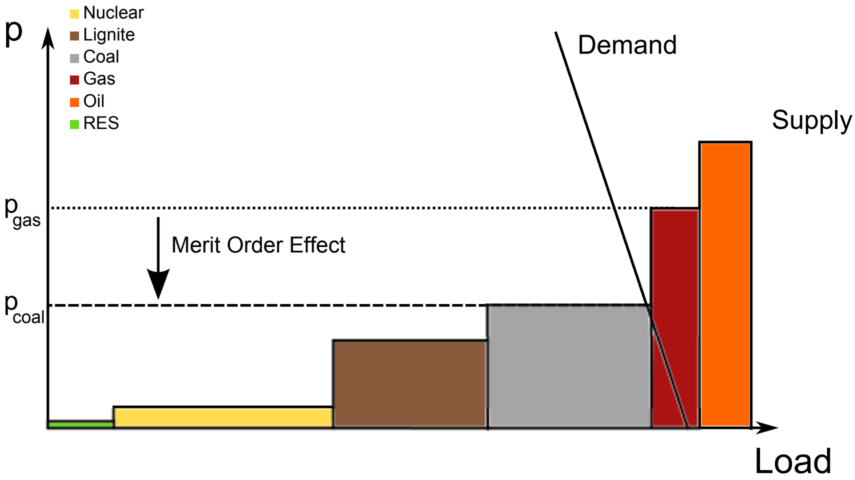

Figure: Schematic illustration of the merit order effect of RES as described by De Miera *et al.* (2008); Sensfuß *et al.* (2008); own illustration.

Merit order effect and capacity market

- for the following analysis we assume a representative base-load and a representative peak-load power plant
- assume φ_t corresponds to the share of RES in electricity generation in year t
- the merit order effect can be described by

$$\frac{\partial \bar{p}_{spot,t}}{\partial \varphi_t} < 0$$

- and

$$\frac{\partial d_{t,base}}{\partial \varphi_t} < 0, \qquad \frac{\partial d_{t,spike}}{\partial \varphi_t} < 0.$$

The power plant operator's view

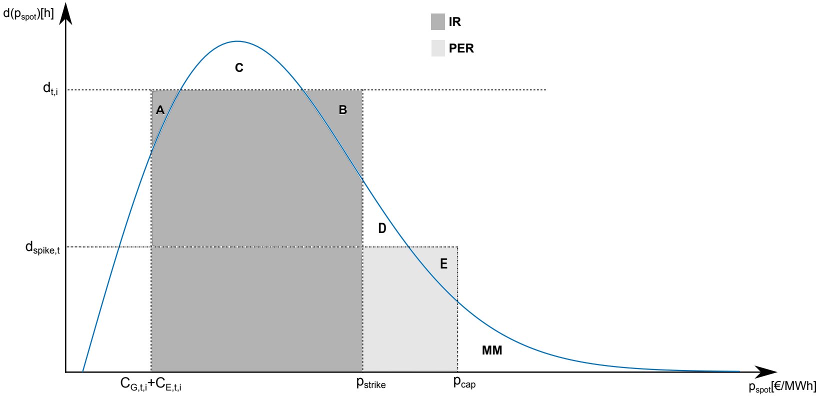

Figure: Schematic illustration of the distribution of electricity spot market prices for one year in €/MWh. The duration of power plant i's production in hours is a function of the spot price; source: Schäfer and Altvater (2019).

Merit order effect and capacity market

- the impact of a change of the share for RES on the price difference between base-load and peak-load power plants can be described by

$$
\begin{aligned}
\frac{\partial \Delta p_{t,base-peak}}{\partial \varphi_t} = & \overbrace{(p_{cap} - p_{strike}) \frac{\partial d^e_{spike,t}}{\partial \varphi_t}}^{\frac{\partial PER^e_t}{\partial \varphi_t}} \Delta X^e_{PER,t} + \frac{\partial MM^e_t}{\partial \varphi_t} \Delta X^e_{PER,t} \\
& - \Delta C^e_t (1 - X^e_{IR,t,base}) \frac{\partial d^e_{t,base}}{\partial \varphi_t} \\
& \overset{?}{\gtrless} 0.
\end{aligned} \tag{1}
$$

Merit order effect and capacity market

- since peak-load power plants are more flexible than base-load power plants, their failure rate should be lower than the failure rate of base-load power plants yielding

$$\Delta X^{e}_{PER,t} \geq 0$$

$\Rightarrow$ the first summand of Eq. 1 is negative for an increasing φ_t

Merit order effect and capacity market

- if PER decreases, MM increases to the same extent
- if IR decreases, MM increases to the same extent, too

$\Rightarrow$ if φ_t increases, MM increases more than PER decreases

$\Rightarrow$ for increasing φ_t the sum of the first two terms of Eq. 1 is positive

Merit order effect and capacity market

- since the third term of Eq. 1 is clearly positive, we find for an increasing share of RES in electricity generation

$$
\begin{aligned}
\frac{\partial \Delta p_{t,base-peak}}{\partial \varphi_t} &= \overbrace{(p_{cap} - p_{strike})\frac{\partial d^e_{spike,t}}{\partial \varphi_t}}^{\frac{\partial PER^e_t}{\partial \varphi_t}} \Delta X^e_{PER,t} + \frac{\partial MM^e_t}{\partial \varphi_t} \Delta X^e_{PER,t} \\
&\quad - \Delta C^e_t (1 - X^e_{IR,t,base}) \frac{\partial d^e_{t,base}}{\partial \varphi_t} \\
&> 0.
\end{aligned}
$$

$\Rightarrow$ for an increasing share of RES we find a **comparative advantage for peak-load power plants** at the capacity market.

$\Rightarrow$ the capacity market **opposes the disadvantage for peak-load power plants** at the energy-only market

Impact of RES – 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
$\mathrm{IR}^e_{t,base}$	$(p_{strike} - C_{G,t,base} - C_{E,t,base})d_{t,base}$	250,000 €/MW
PER^e_t	$(p_{cap} - p_{strike})d^e_{spike,t}$	400,000 €/MW

The expected potential PER decreases less than the expected potential IR in this example as empirical data suggest (Nicolosi and Fürsch, 2009).

- Calculate the price bids of the two power plants at the capacity market.

Exercise – solution

- price bids at the capacity market yield

$$p_{t,base} = 641{,}750 \text{ €}/\mathrm{MW} + \varrho^e_{base},$$
$$p_{t,peak} = 498{,}000 \text{ €}/\mathrm{MW} + \varrho^e_{peak}.$$

- $\mathrm{MM}^e_{t,base} = p_{t,base}$ - $\mathrm{PER}^e_t = 241{,}750$ €/MW
- $\mathrm{MM}^e_{peak} = p_{t,peak}$ - $\mathrm{PER}^e_t = 98{,}000$ €/MW

$\Rightarrow$ individual values for MM consider the availability factors!

Exercise – solution

- using

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

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

- potential missing money of the example can be calculated

$$MM^e_t = \frac{(871\ €/\mathrm{MW} - 250\ €/\mathrm{MW}(1 - 0.035) - 400\ €/\mathrm{MW}(1 - 0.03))1{,}000}{1 - 0.03}$$

$$= 249{,}226.8\ €/\mathrm{MW},$$

$$MM^e_t = \frac{490{,}000\ €/\mathrm{MW} - 400{,}000\ €/\mathrm{MW}(1 - 0.02)}{1 - 0.02} = 100{,}000\ €/\mathrm{MW}$$

$\Rightarrow$ the assumptions about MM are different although **MM is equal** for all power plants **in the equilibrium**

Exercise – solution

- Now the penalty can be calculated

$$\varrho^e_{t,base} = 241{,}750 \text{ €}/\mathrm{MW} \cdot 0.03/(1-0.03) = 7{,}476.8 \text{ €}/\mathrm{MW},$$
$$\varrho^e_{t,peak} = 98{,}000 \text{ €}/\mathrm{MW} \cdot 0.02/(1-0.02) = 2{,}000 \text{ €}/\mathrm{MW}$$

- price bids at the capacity market are

$$p_{t,base} = 649,226.8 \text{ €}/\mathrm{MW},$$
$$p_{t,peak} = 500,000 \text{ €}/\mathrm{MW}.$$

$\Rightarrow$ comparative advantage for the peak-load power plant!

Power plant maturity

- assuming two, except for their age, identical power plants yields

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

- using t for power plant i and $t + \Delta t$ for power plant j together with $i = j$ and

$$k_{t,i} = K_{0,i} \left((1 - \delta_i)^t \frac{\delta_i}{1 - \delta_i} + \tilde{\delta}_i \right)$$

yields

$$\Delta p_{t,j-i} = \underbrace{K_{0,i=j} (1 - \delta_{i=j})^t \frac{\delta_{i=j}}{1 - \delta_{i=j}}}_{\geq 0} \left[(1 - \delta_{i=j})^{\Delta t} - 1 \right].$$

$\Rightarrow$ comparative advantage for the older power plant

Sunk cost

- after an investment has been made, bidders have an incentive to bid PER per capacity unit instead of PER + MM because

$\rightarrow$ it increases the probability of being awarded

$\rightarrow$ it keeps the chance to receive a payment above PER

$\rightarrow$ a bid below PER per capacity unit is not rational since it means a loss

$\Rightarrow$ overcapacity (of existing power plants) lead to an equilibrium price equal to PER per capacity unit

$\Rightarrow$ no extra cost for consumers

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Path dependency of the optimal power plant mix

thought experiment with two scenarios

- the share of RES-based electricity generation **increases over time** to the share φ

$\Rightarrow$ certain age distribution of residual fossil power plants

- the share of RES-based electricity generation **directly increases** to the share φ (static one-shot framework)

$\Rightarrow$ residual fossil power plants are all of the same age

$\Rightarrow$ in scenario 2 the capacity mix is a best response to the share φ of RES-based electricity generation

$\Rightarrow$ in scenario 1 the age distribution with comparative advantages for older power plants prevents an optimal capacity mix

$\Rightarrow$ In a transition process (to RES-based electricity generation), the advantage of already existing old power plants produces a **“delayed” transformation** of the capacity mix!

Back to our example...

- We calculated the following (theoretical) bids

$$p_{t,base} = 649{,}226.8 \text{ €/MW},$$
$$p_{t,peak} = 500{,}000 \text{ €/MW}.$$

- an increasing share of RES-based electricity generation at first creates overcapacity

$\Rightarrow$ P^*=PER $= 400{,}000$ €/MW

$\Rightarrow$ no additional cost for consumers but risk reduction for power plant operators

Provision of new capacity

- we assume that new power plants face higher capital cost than old power plants leading to $\tilde{k}_{t,peak} = k_{t,peak} + X > k_{t,peak}$
- since new capacity is needed in this scenario, a new peak-load power plant will determine the clearing price

$$p_t^* = \left(500{,}000 + \frac{X}{1 - X^e_{PER,t,peak}}\right) \text{€}/\mathrm{MW}$$

- using

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

New capacity – exercise

Recall for the following tasks that only new peak-load power plants can compete with the old power plants if new capacity is necessary.

- Calculate the penalty factor ξ
- Calculate the penalties for a base-load and a peak-load power plant

References

Cramton, P., Ockenfels, A. and Stoft, S. (2013). Capacity market fundamentals. *Economics of Energy & Environmental Policy*, **2**, 27–46.

De Miera, G. S., del Rio Gonzalez, P. and Vizcaino, I. (2008). Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. *Energy Policy*, **36** (9), 3345–3359.

Hobbs, B. F., Iñón, J. and Stoft, S. E. (2001). Installed capacity requirements and price caps: Oil on the water, or fuel on the fire? *The Electricity Journal*, **14**, 23–34.

Information Platform of the German Transmission System Operators (Informationsplattform der deutschen Übertragungsnetzbetreiber – netztransparenz.de) (2018). EEG-Jahresabrechnungen. Available at: `https://www.netztransparenz.de/EEG/Jahresabrechnungen`, accessed April 1, 2018.

Nicolosi, M. and Fürsch, M. (2009). The impact of an increasing share of RES-E on the conventional power market–the example of Germany. *Zeitschrift für Energiewirtschaft*, **3**.

Schäfer, S. and Altvater, L. (2019). On the functioning of a capacity market with an increasing share of renewable energy. *Journal of Regulatory Economics*, **56**, 59–84.

Sensfuss, F., Ragwitz, M. and Genoese, M. (2008). The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany. *Energy Policy*, **36** (8).

Vázquez, C., Rivier, M. and Pérez-Arriaga, I. J. (2002). A market approach to long-term security of supply. *IEEE Transactions on Power Systems*, **17** (2), 349–357.

Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen e.V) (2018). Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern. Available at: `https://ag-energiebilanzen.de/index.php?article_id=29&fileName=20171221_brd_stromerzeugung1990-2017.xlsx`, accessed September 4, 2018.