Spot market price effects of reserve provision – analyses based on a parsimonious fundamental model

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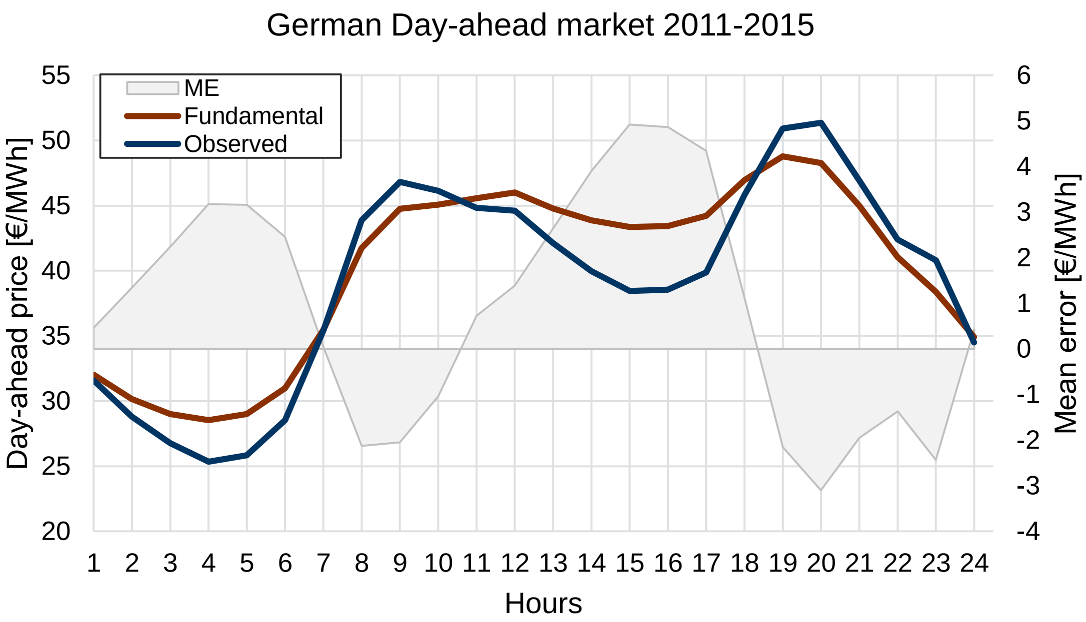
Motivation

- Various fundamental electricity market models have weaknesses in explaining price peaks and troughs.
  - One reason for this behaviour: No or insufficient consideration of provision of reserve.
- Reserve power is an important component of energy systems with a high proportion of renewable energies and thus plays a special role in the German energy transition.

1. What are the effects on the bidding curve from provision of reserve?
2. What are the effects on modelled fundamental electricity market prices from provision of reserve?



Cmp. Beran et al. (2019).

Agenda

Market for control reserve

2 Analytical model of reserve provision

	Frequency Containment Reserves (FCR)	Automatic Frequency Restoration Reserves (FRR-a)	Manual Frequency Restoration Reserves (FRR-m)
Characteristics	• Reserve for frequency adjustment • European setup (UCTE) • Common cross border auction	• Reserve for load flow regulation • Conducted via a balancing signal from grid coupling stations	• Reserve especially for compensation of power plant outages
Activation Time	30 Seconds	5 Minutes	Max. 15 Minutes
Tendering Procedure	Weekly	Weekly*	Daily
Tenders & Products	One tender for positive & negative control reserve	Separate tenders for positive & negative reserve for two distinct provision periods (peak/offpeak)*	Separate tenders for positive and negative control reserve for distinct 4-hour periods
Compensation	• Capacity (reservation) • Price (Pay-as-Bid Auction)	• Capacity (Reservation) and Energy (activation) • Price (Pay-as-Bid Auction)	

*) Since 12.07.2018: Daily tendering for FFR-a and block products instead of provision periods.

Analytics of efficient spot & reserve prices

- Which plants provide reserve capacity?
  Assumptions:
  - Conventional generation plants may only offer part of their capacity in reserve markets, reasons:
    - Limited plant load change rates
    - Minimum capacities due to must-run conditions
  - Capacity offered as positive reserve may not be simultaneously offered in the spot market

$$K^{Spot} + R^{+} \leq K^{max}$$

  - Energy demand and reserve provision are jointly provided by available „online" capacity
  - Reserve provision is limited by ramping capability of available (online) capacity α
- For economic reasons, it is best if the demanded reserve energy is provided by the marginal power plant K_m and adjacent units.
- First provider of reserve capacity

$$K_0 = D + \mathrm{R}^{+} - \frac{1}{\alpha}\mathrm{R}^{+}$$

- Must run capacity because of reserve provision

$$MR^{R^{+}} = \frac{\gamma}{\alpha} R^{+}$$

$\alpha = Max.reserve\ cap.\ factor$

$\gamma = Min.\ capacity$ factor

$D = Actual\ demand$

$K^{max} = Maximum\ capacity$

$K^{Spot} = Spot\ market\ capacity$

$R^{+} = Reserve\ demand$

Cmp. Baldursson et al. (2017).

Merit order effects of reserve provision

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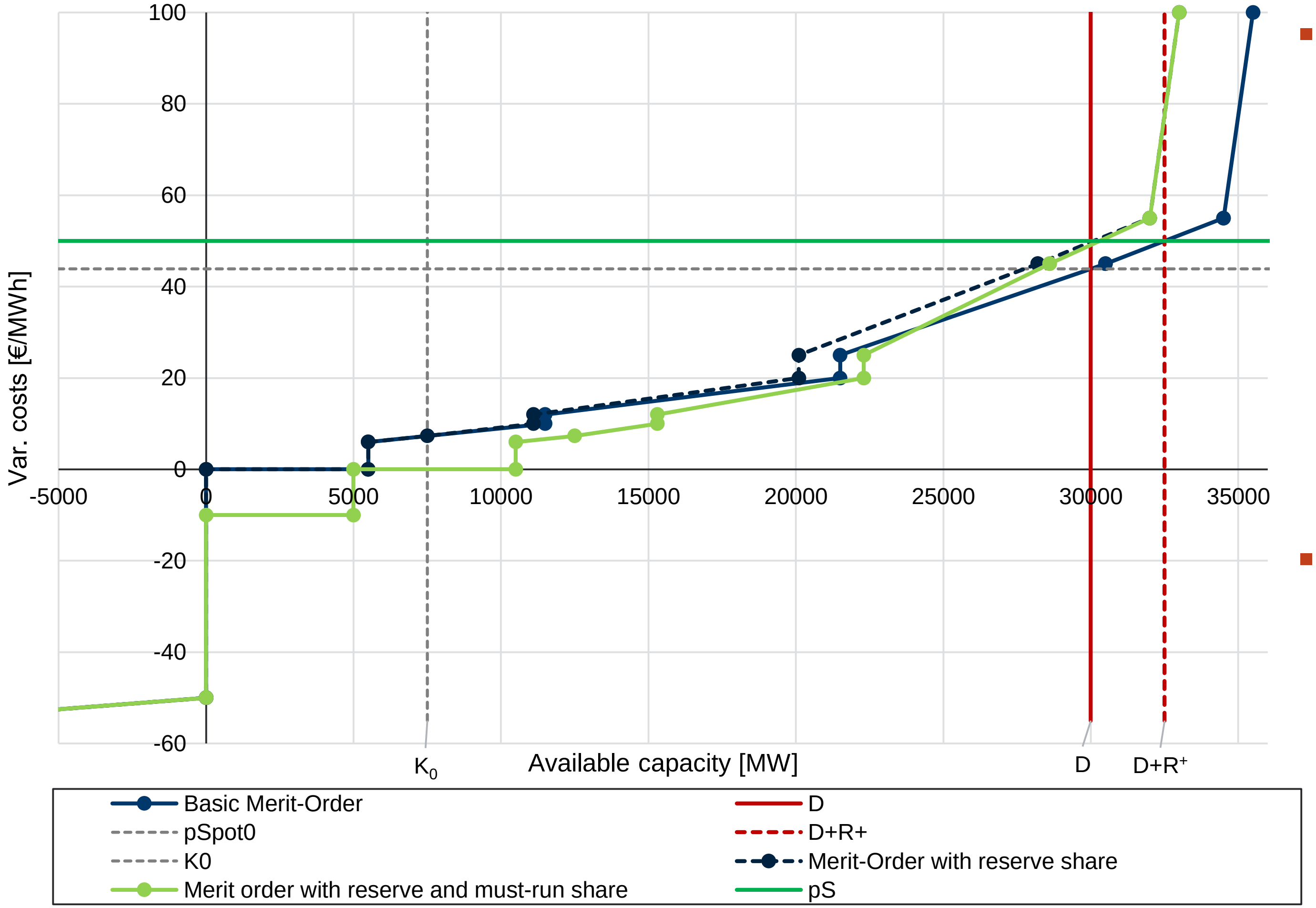
2 Analytical model of reserve provision



- Legend:

  $D = Actual\ demand$

  $R^{+} = Reserve\ demand$

  $\gamma = Min.\ capacity\ factor$

  $\alpha = Max. reserve\ cap.\ factor$

  $p_S = Spot\ market\ price$

- First reserve capacity

$$K_0 = D + R^{+} - \frac{1}{\alpha} R^{+}$$

$$MR^{R^{+}} = \frac{\gamma}{\alpha} R^{+}$$

What about prices?

- Relation between spot market and reserve prices
  - Indifference condition for the first provider of reserve K_0 (if K_0>0)

$$p_R = p_S - c_0$$

  - Zero profit condition (if $K_0 < 0$) of the marginal plant

$$\alpha_m p_R = (1-\alpha_m)(c_m - c_0)$$

- Spot market price

$$p_S = \begin{cases} c_m & K_0 \geq 0 \\ c_0 & K_0 < 0 \end{cases}$$

- Reserve market prices

$$p_R = \begin{cases} c_m - c_0 & K_0 \geq 0 \\ \frac{1-\alpha_m}{\alpha_m}(c_m - c_0) & K_0 < 0 \end{cases}$$

$p_R = \mathit{Reserve\ market\ price}$

$p_S = \mathit{Spot\ market\ price}$

$c_0 = \mathit{Marginal\ costs\ of\ first\ provider\ of\ reserve}$

$c_m = \mathit{Marginal\ costs\ of\ marginal\ plant}$

$\alpha = \mathit{Max.\ reserve\ cap.factor}$

Cmp. Baldursson et al. (2019).

Analytical results

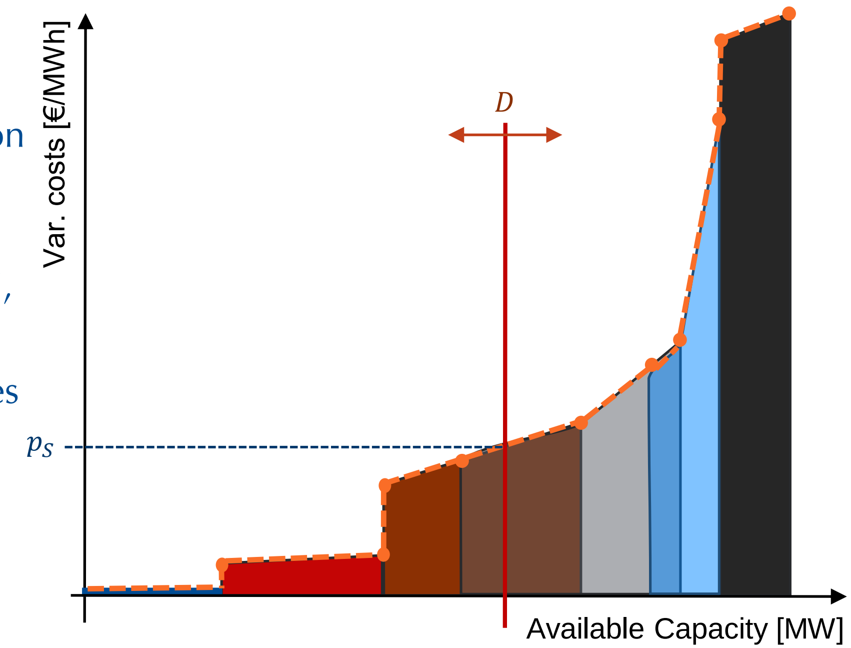
- Merit order effects of reserve provision
  - Available capacity in the spot market is reduced → **Steeper bidding curve** in the area of the marginal power plant
  - More capacity must be online: New must run block on the left side of the bidding curve → **Shift of the bidding curve**
  - New shape of the bidding curve $\tilde{b}$:

$$\tilde{b}(x) = \begin{cases} m\left(x, \frac{\gamma}{\alpha} R^+\right) & f\ddot{u}r\ x < \frac{\gamma}{\alpha} R^+ \\ b\left(x - \frac{\gamma}{\alpha} R^+\right) & f\ddot{u}r\ \frac{\gamma}{\alpha} R^+ \leq x \leq K_0 + \frac{\gamma}{\alpha} R^+ \\ b\left(K_0 + \frac{1}{1-\alpha-\gamma}\left(x - \left(K_0 + \frac{\gamma}{\alpha} R^+\right)\right)\right) & x > K_0 + \frac{\gamma}{\alpha} R^+ \end{cases}$$

- Expected spot market price effects:
  - High residual demand: Slope is steeper around marginal power plant → **Higher prices**
  - Low residual demand: Not enough online capacity for reserve procurement ($K_0 < 0$) → Additional online capacity needed → Spot market oversupply → negative spot market prices → **Lower prices**

Agenda

- Starting point:
  - “Merit order” (supply-stack) model
  - Heterogeneity of technology classes by estimates on minimum and maximum efficiency → Intervals of ascending costs
  - Considered technologies: Bio, Nuc, Lig, Coa, CCG, OCG, Oil, Rrh, Mis
  - Piecewise linear supply stack with mixed capacities
- Residual Load
  - $D_t = L_t - W_t - S_t - CHP_t^{MR} - TB_t$
- Detailed data on
  - Load
  - Renewable Infeed
  - Capacities
  - Imports & Exports
  - Availabilities
- Uncoupled time periods: No start-up costs or minimum operation times
- Spot market price results from the intersection of the supply and demand curve



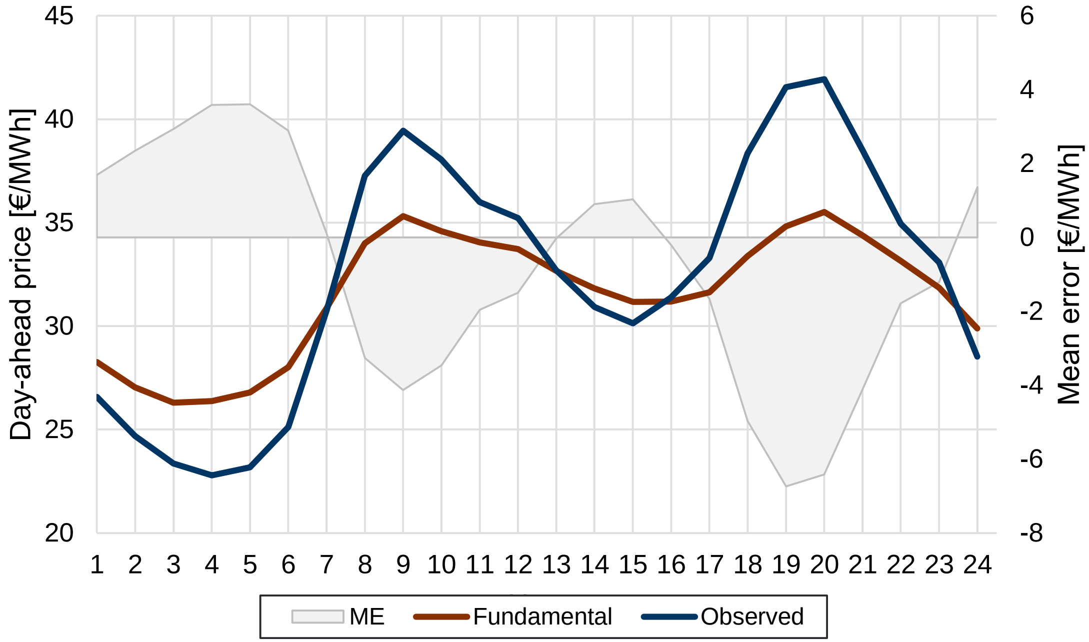
Cmp. Beran et al. (2019).
Cmp. Kallabis et al. (2016).

Fundamental electricity market model ParFuM – Base case (Fund0)

- Hourly data for Germany between 01.01.2016 – 30.06.2018
- Base case: No consideration of reserve provision

Stats	Obs	Fund0
Mean	32.41	31.53
Min	-130.09	0.00
Max	163.52	87.55
SD	15.53	7.86
#Neg	347.00	0.00

Errors	Fund0
ME	-0.87
MAE	6.44
RMSE	10.84
R^2	0.52



- Model shortcomings:
  - Problems with extreme prices (pos./neg.) → No fundamental negative prices
  - Price volatility is too low

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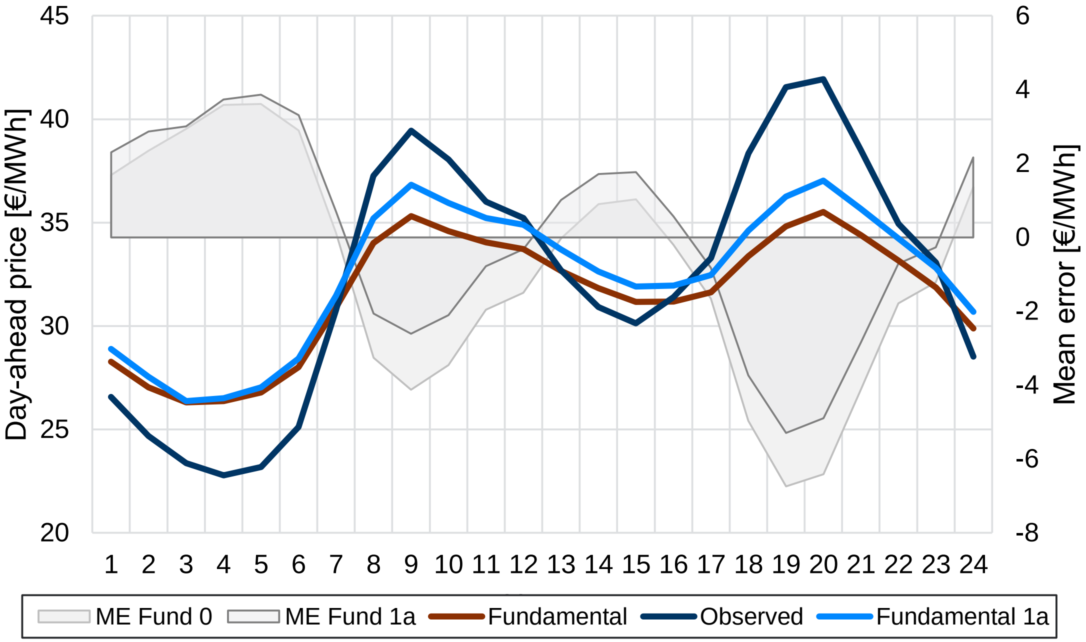
Fundamental electricity market model ParFuM – Reserve provision case (Fund1a)

- Extension of the base case with general consideration of positive reserve:
  - Reserve cap. share α=0.1 – Must-run-share γ=0.1 for all technologies

Stats	Obs	Fund0	Fund1a
Mean	32.41	31.53	32.43
Min	-130.09	0.00	-51.47
Max	163.52	87.55	96.38
SD	15.53	7.86	9.79
#Neg	347.00	0.00	89.00

Errors	Fund0	Fund1a
ME	-0.87	0.02
MAE	6.44	6.13
RMSE	10.84	10.26
R^2	0.52	0.56



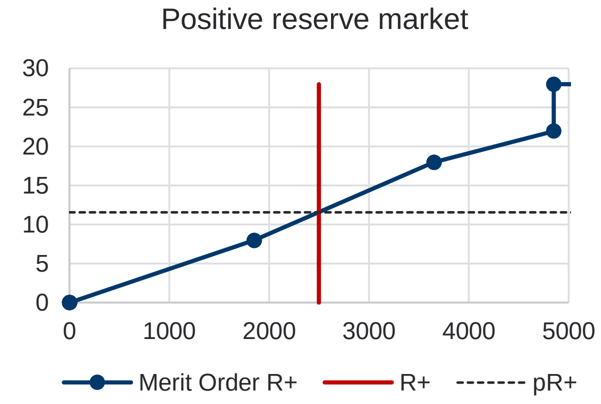
- Relative MAE change (%)

Hours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
rel. Δ MAE	1.60	-0.16	-1.35	2.80	5.27	1.82	-5.56	-9.52	-10.55	-8.97	-6.02	-5.07	-1.77	-3.08	-1.65	-4.15	-6.25	-8.65	-9.88	-10.54	-9.51	-4.75	-3.99	1.25

Agenda

Conclusion

- Results
  1. What are the effects on the bidding curve from provision of reserve?
     - Available capacity in the spot market is reduced → Steeper bidding curve
     - Must-run capacity increases → Shift of the bidding curve
  2. What are the effects on modelled fundamental electricity market prices from provision of reserve?
     - Improvement of spot market model quality with regard to overall prices: MAE s reduced and S.D. increased.
     - Counter-intuitive effects with low but not extreme residual load (e.g. at night)



- Next steps
  - Distinction between FCR and FRRa
  - Distinction between positive and negative reserve products
  - Technology specific reserve- and must run-factors
  - Evaluation of fundamental reserve market prices

Thank you for your attention!

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