House of
Energy Markets
& Finance

Modelling German Electricity Wholesale Spot Prices with a Parsimonious Fundamental Model – Validation & Application

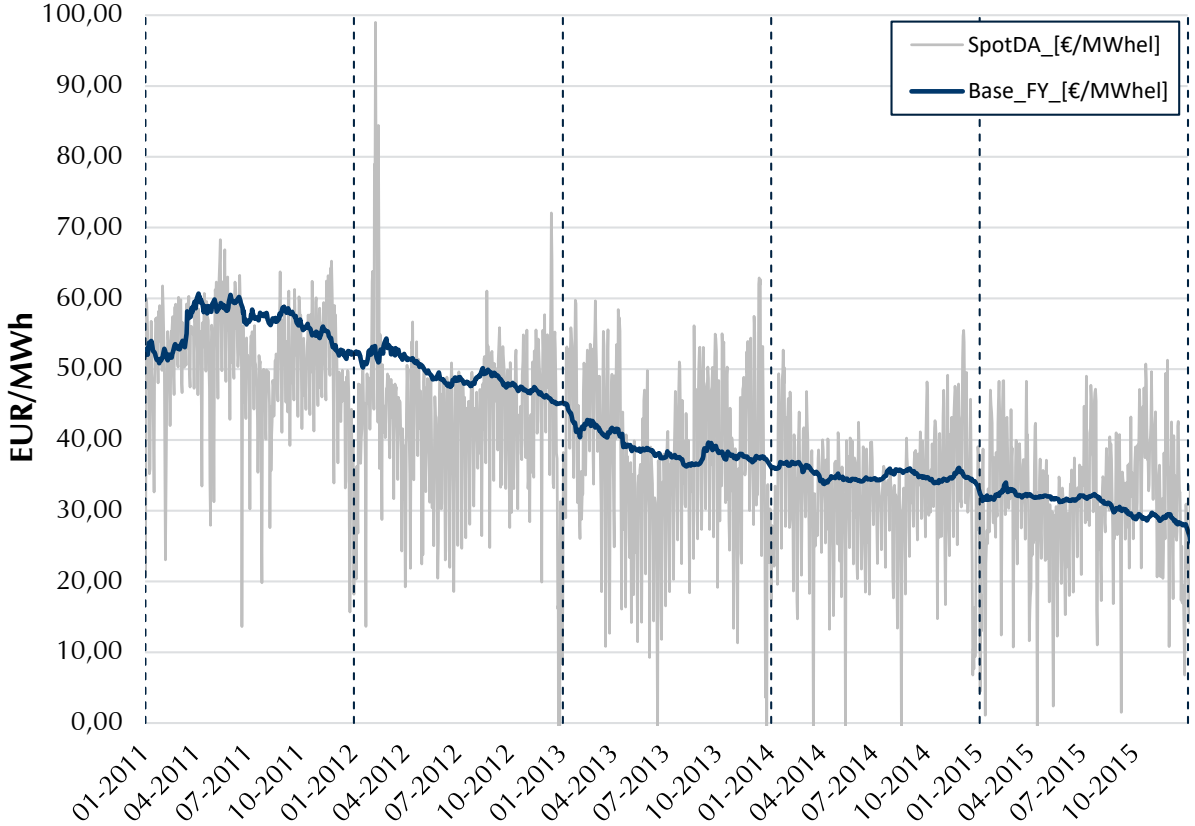
Philip Beran, Christian Pape, Christoph Weber

15th IAEE European Conference, Vienna, 06.09.2017

UNIVERSITÄT DUISBURG ESSEN

Open-Minded

Plunge in German electricity wholesale prices



- German electricity spot market price
  - 2011: 51.12 €/MWh
  - 2015: 31.63 €/MWh
  - Decrease of 38%
- Different effects
  - CO_2 price drop
  - Cheap fuel prices
  - Expansion of Renenwables
  - Nuclear phase out

➢ Use of a parsimonious model to reproduce the price drop?

Questions

1. Is it possible to reproduce the German day-ahead electricity price decline with a parsimonious fundamental model?

2. What would the German electricity price have looked like without the accelerated nuclear phase-out?

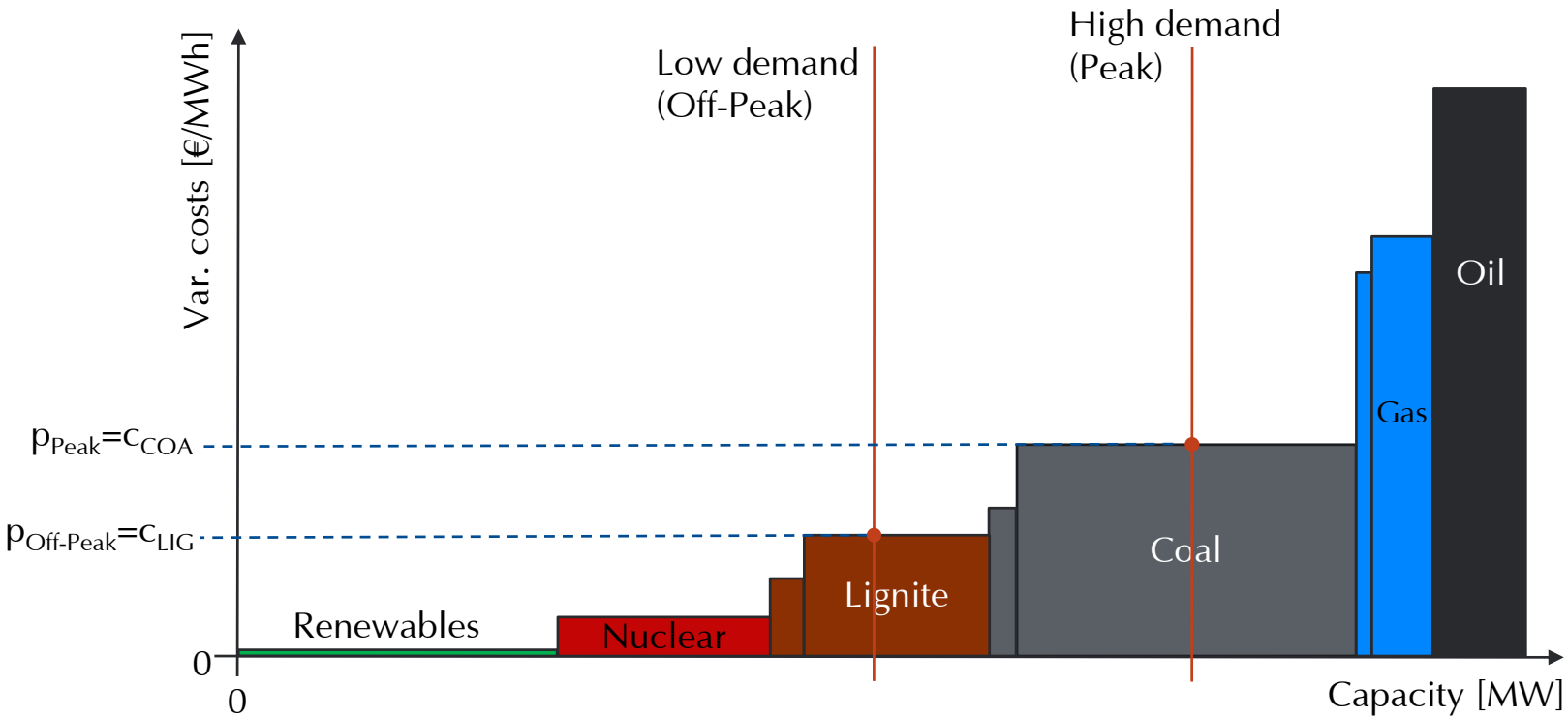
Agenda

UNIVERSITÄT DUISBURG ESSEN

Open-Minded

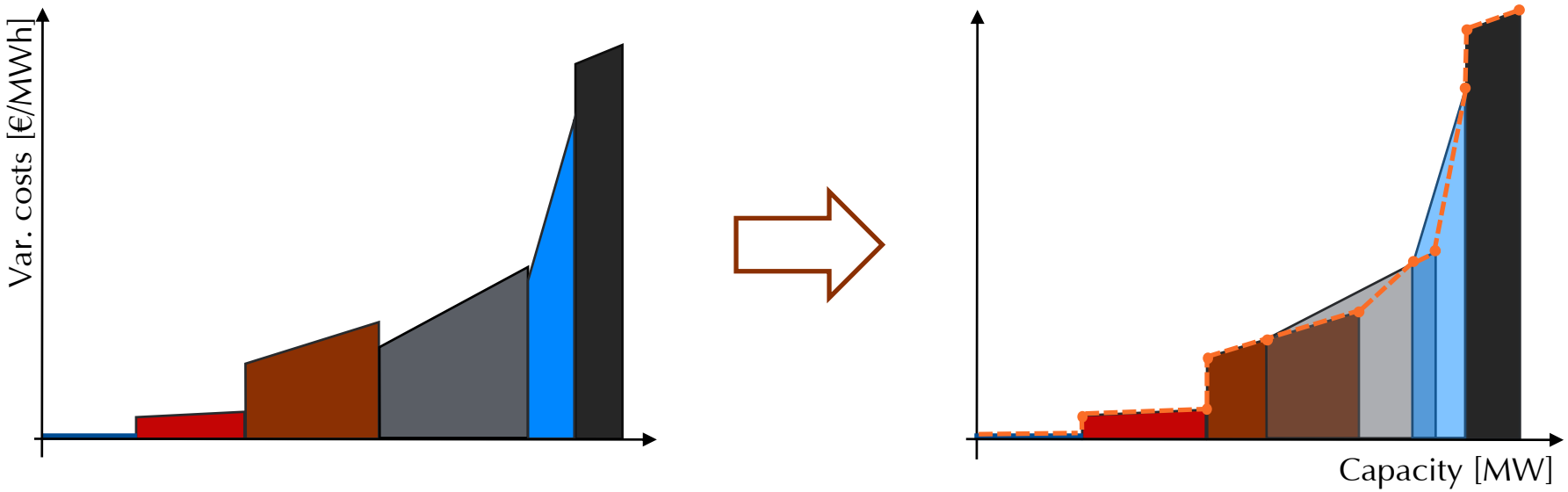
Motivation	1
Parsimonious model	2
Data & Model validation	3
Application: Counterfactual case study	4
Conclusions	5

Parsimonious fundamental model



- "Merit order" model
- Price results from the intersection of the supply and demand curve
- To reflect the actual situation better we adjust supply and demand side

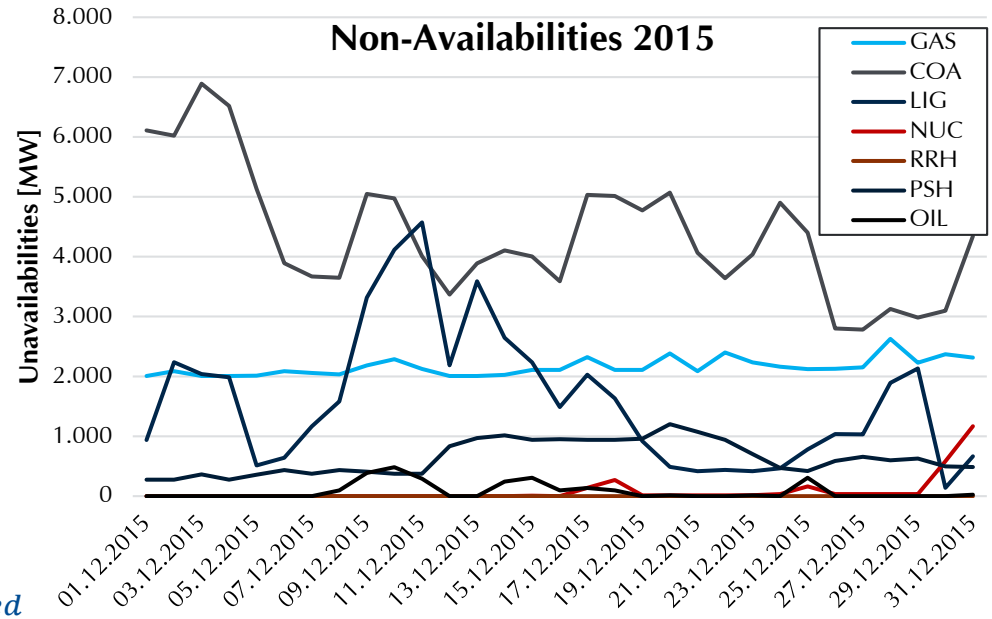
Supply side: piecewise linear supply stack



- We consider heterogeneity of technology classes by estimates on minimum and maximum efficiency resulting in intervals of ascending costs.
- Piecewise linear supply stack with mixed capacity intervals

Supply side: Power plant availabilities

- Power plant non-availabilities
  - Scheduled: $Unav_{pl,t}^{sched}$
  - Unscheduled: $Unav_{pl,t}^{unsched}$
  - Installed capacity: $Cap_{pl,t}$



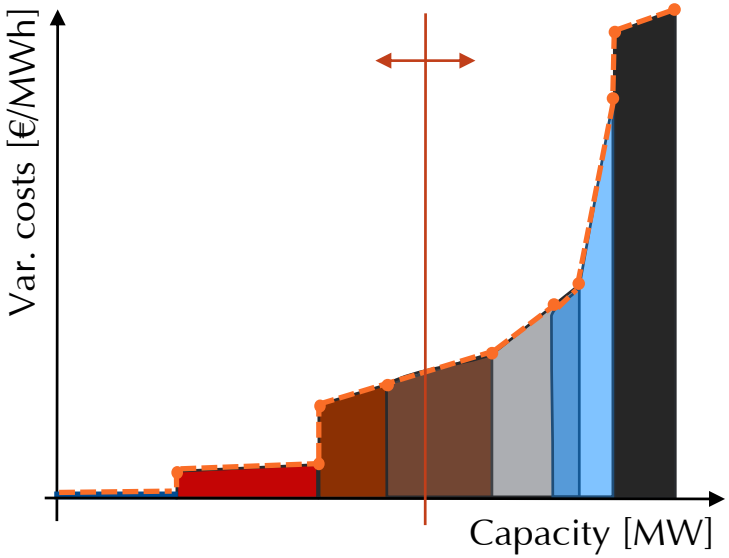
- Availability factor
  - $Av_{pl,t} = 1 - \frac{Unav_{pl,t}^{sched} + Unav_{pl,t}^{unsched}}{Cap_{pl,t}}$
  - $AvCap_{pl,t} = Av_{pl,t} \cdot Cap_{pl,t}$
  - $AvCap_{pl,t}^{CHP} = Av_{pl,t} \cdot Cap_{pl,t}^{CHP} - CHP_{pl,t}^{MustRun}$

Demand – Residual Load

- Residual load

$$D_t = L_t - W_t - S_t - CHP_t^{MustRun} - TB_t$$

  - $L_t = Demand$
  - $W_t = Wind\ feed - in$
  - $S_t = Solar\ feed - in$
  - $CHP_t^{MustRun} = Must - run\ CHP\ production$
  - $TB_t = Transmission\ balance$
    - Ex-post analysis: Available as data
    - Ex-ante analysis: Use of an auxiliary model



Demand – Transmission balance

UNIVERSITÄT DUISBURG ESSEN
Open-Minded

2 Parsimonious Model

- Explaining German transmission balance with a multiple regression model:

$$TB_t = \beta_0 + \beta_1 Wind_t + \beta_2 PV_t + \beta_3 Temp_t + \beta_4 FS_t + \beta_5 L_t + \beta_6 AvCap_{LIG,t} + \beta_7 AvCap_{NUC,t} + \beta_8 CO_2 Preis + \varepsilon_t$$

Regression result				
Variable	**Estimate**	**SA**	**tStat**	**pValue**
(constant) [MWh]	6124,1300	635,6297	9,6347	0,0000
Wind-infeed [MWh]* **	-0,3548	0,0086	-41,0770	0,0000
Solar-infeed [MWh]* **	-0,4652	0,0090	-51,9271	0,0000
Temperature [°C]* **	146,5702	7,5380	19,4443	0,0000
Filling level of Scand. reservoirs [GWh] **	-0,0044	0,0020	-2,2555	0,0241
Load [MW]* **	0,0862	0,0035	24,2831	0,0000
Available lignite capacity [MW]* **	-0,4337	0,0286	-15,1606	0,0000
Available nuclear capacity [MW]* **	-0,5448	0,0222	-24,5539	0,0000
CO_2-price [€/t]* **	183,5405	12,4692	14,7195	0,0000
# observations	26304	Mean dependent variable		-2313
adjusted R^2	0,650691	Akaike Info Criterion		18,24908
F-statistics	6126	Schwarz Criterion		18,25188

Agenda

UNIVERSITÄT DUISBURG ESSEN
Open-Minded

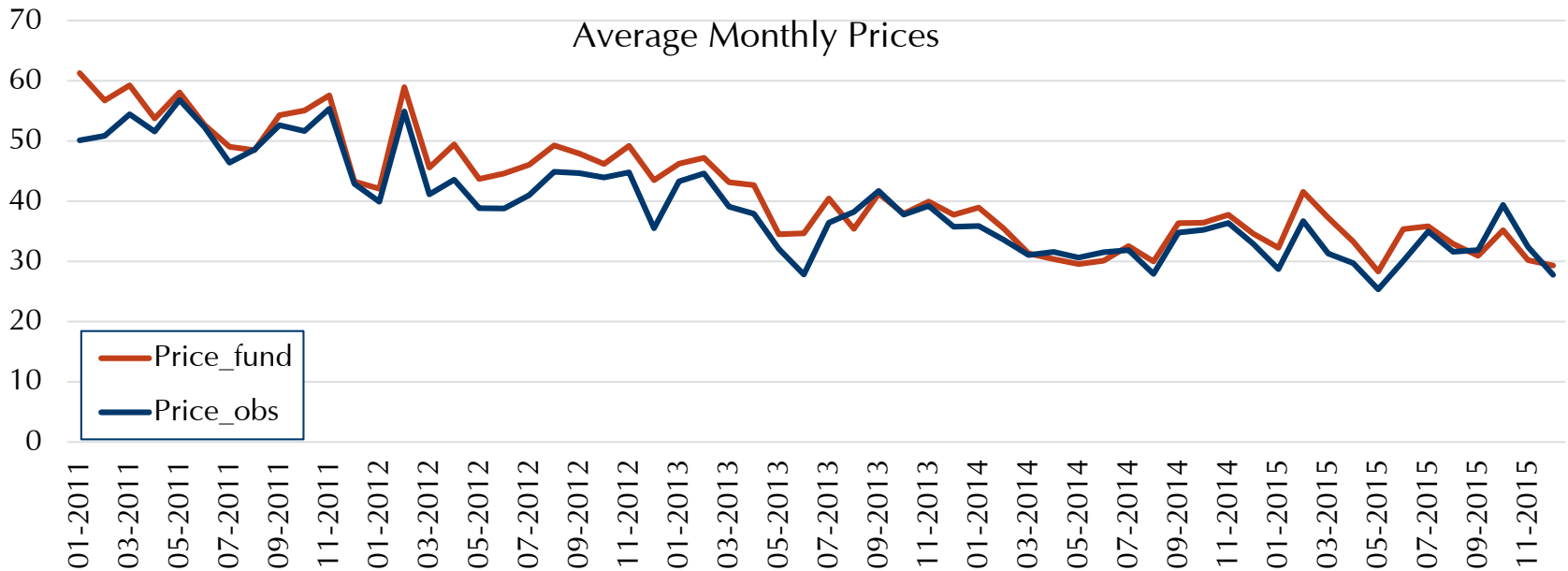
Motivation	1
Parsimonious model	2
Data & Model validation	3
Application: Counterfactual case study	4
Conclusions	5

Data

3 Data & Validation

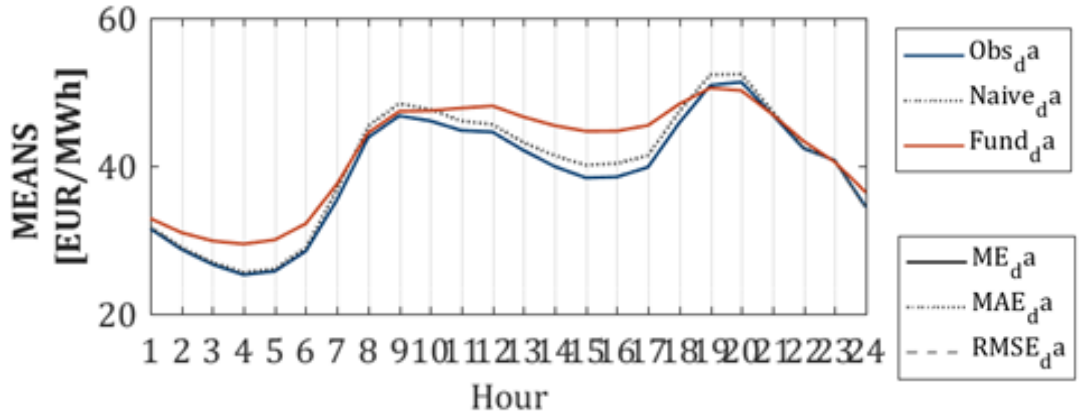
Type	Dataset	Source	Data manipulation & Remarks
Fuel prices	Coal price (API#2) Gas price (OTC TTF DA) Oil price (ICE Brent Index) CO2 price (EUA)	Energate.de	
Load	Hourly load values for a specific country and year Monthly electricity statistics	Entso-e transparency platform & entso-e.eu + IEA	Scaling of Entso-e hourly load data to IEA monthly electricity supplied
Renewable Infeed	Wind-feed-in (DA-Forecast) PV-feed-in (DA-Forecast)	German TSOs	
Transmission balance	Scheduled commercial exchanges	Entso-e transparency platform	
CHP factors	Share of must-run CHP production Temperature data	DeStatis + BMWi + DWD	Based on turbine types and power plant information
Capacities	Installed hourly capacity Installed CHP capacity	EEX Transparency platform +BnetzA	Hourly power plant capacities from EEX scaled to net installed capacity of BNetzA Kraftwerksliste
Availabilities	Scheduled and unscheduled unit unavailability	EEX Transparency	Hourly availability factor for each technology class (cf. above)

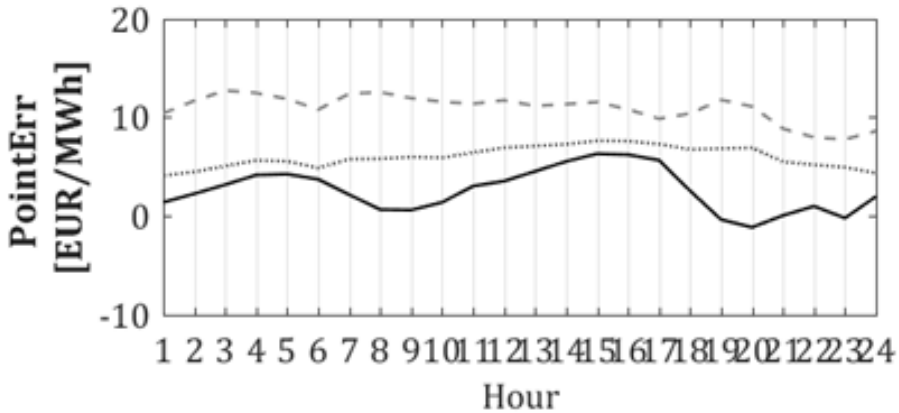
Price validation I



[€/MWh]	2011		2012		2013		2014		2015		Overall	
	Obs	Fund	Obs	Fund	Obs	Fund	Obs	Fund	Obs	Fund	Obs	Fund
Mean	51,12	54,10	42,60	47,14	37,79	40,04	32,76	33,61	31,63	33,96	39,18	41,77
S.D.	13,60	14,17	18,68	16,06	16,45	15,79	12,77	10,15	12,67	9,66	16,63	15,60
# neg.	15	0	56	12	63	0	64	0	126	0	324	12
Min	-36,82	20,75	-221,99	-10,00	-100,03	6,76	-65,03	6,70	-79,94	6,50	-221,99	-10,00
Max	117,49	162,15	210,00	210,90	130,27	94,43	87,97	70,59	99,77	68,01	210,00	210,90

Price validation II

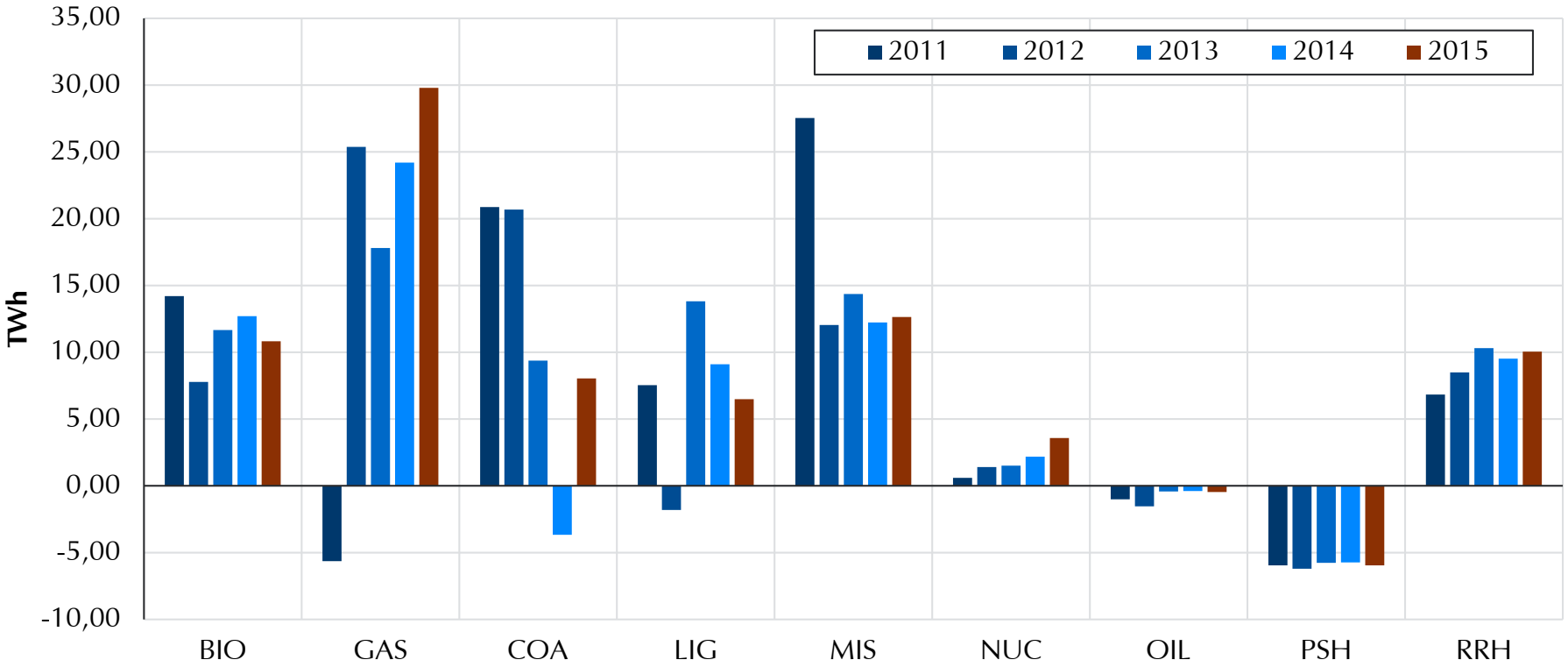




- Model prices are on average higher than observed prices.
- Problems with extreme prices
- Lower price volatility

Errors	ME	MAE	RMSE	R
2011	2.98	5.91	8.72	0.59
2012	4.54	7.00	12.3	0.57
2013	2.26	7.04	9.75	0.65
2014	0.84	4.55	6.7	0.72
2015	1.86	5.45	7.41	0.66
Overall	**2.50**	**5.99**	**9.19**	**0.69**

Production validation



- Good results for most combustible fuels (coal, lignite, nuclear and oil).
- Problems with modelling gas and Renewables

Agenda

UNIVERSITÄT DUISBURG ESSEN
Open-Minded

Motivation	1
Parsimonious model	2
Data & Model validation	3
Application: Counterfactual case study	4
Conclusions	5

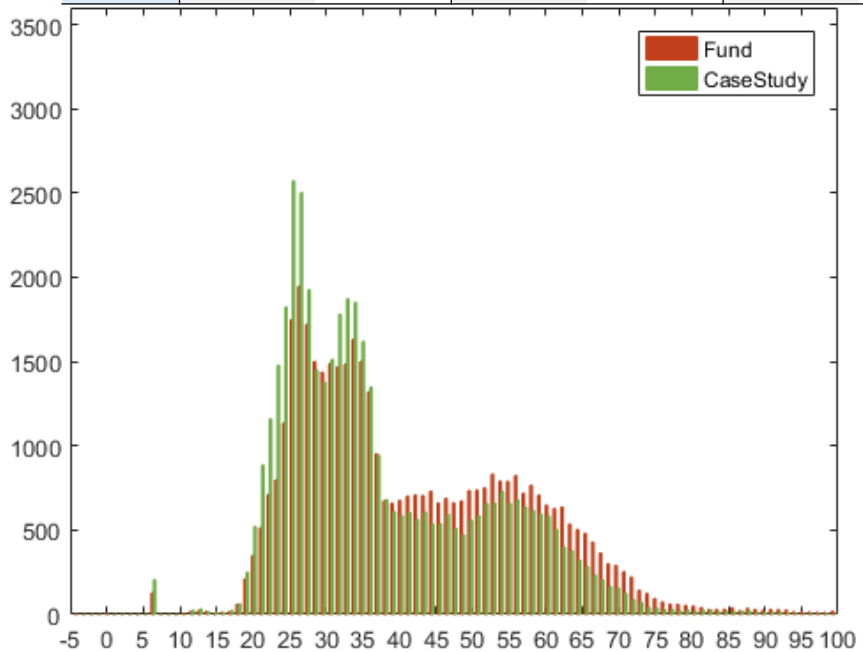
Case Study: No accelerated nuclear phase-out in Germany

- Accelerated nuclear phase out
  - Fukushima accident on 11.03.2011
  - German government decided to phase out nuclear power generation
  - As a result 12 GW nuclear capacity were shut down
  - ➢ How would the German electricity market look like without the accelerated nuclear phase-out?
- Counter factual scenario
  - For the counterfactual analysis a non-observable case is designed to compare with the actual situation.
- Construction of counterfactual situation
  - Direct influence: Installed nuclear capacity
  - Indirect influence: CO_2-price, electricity export balance

Case study: price results

4 Application: Counterfactual case study

[€/MWh]	Overall		2011		2012		2013		2014		2015	
	FundM	CaseS	FundM	CaseS	FundM	CaseS	FundM	CaseS	FundM	CaseS	FundM	CaseS
Min	-10,0	6,5	20,8	15,3	-10,0	6,5	6,8	6,8	6,7	6,7	6,5	6,7
Max	210,9	127,7	162,2	127,7	210,9	100,2	94,4	84,8	70,6	65,4	68,0	59,9
# neg.	12	0,0	0	0,0	12	0,0	0	0,0	0	0,0	0	0,0
Mean	41,7	37,7	54,1	51,1	47,1	42,7	40,0	35,2	33,6	30,1	33,5	29,7
S.D.	15,6	13,9	14,2	12,5	16,1	13,5	15,8	13,8	10,1	7,7	9,6	6,9

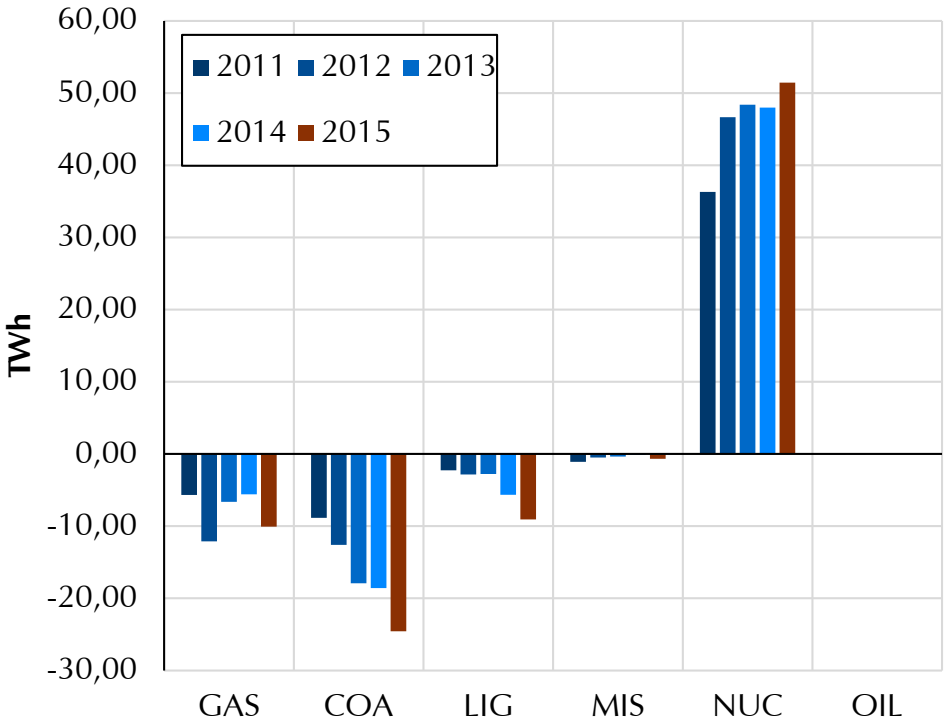


- Prices would have declined on average by 4.02 €/MWh.
- In 2015 price would have been on average below 30 €/MWh.
- Lower price volatility

Case study: production results

- Increased nuclear production in GER (+ 45 TWh/a)
- Lower production from other combustible fuels (-28 TWh/a)

  Of which..
  - Coal -16 TWh/a
  - Lignite -4.29 TWh/a
  - Gas -7.73 TWh/a
- Difference between additional nuclear and lower combustible production (17 TWh/a) is exported.
  - In 2015 Germany would have achieved an export surplus of 62 TWh.



[TWh]	2011	2012	2013	2014	2015
Actual Exchange	-4,1	-20,3	-34,3	-35,6	-55,5
Counterfact. Exchange	-22,4	-38,9	-54,9	-53,6	-62,5

Agenda

UNIVERSITÄT DUISBURG ESSEN

Open-Minded

Motivation	1
Parsimonious model	2
Data & Model validation	3
Application: Counterfactual case study	4
Conclusions	5

Conclusions

- Parsimonious fundamental model
  - The simplified model can reproduce hourly day-ahead prices with an average error of 2.50 €/MWh and a MAE of 5.99 €/MWh.
  - It replicates the German electricity price drop
  - Model shortcomings
    - Problems with extreme prices → No negative prices and overall too high prices
    - Lower volatility
    - Problems modelling renewables and gas production volumes
- Case study
  - Without accelerated nuclear phase-out German electricity prices would be on average 4.02 €/MWh lower.
  - The output of coal and gas-fired power plants would have dropped, but overall production would have risen and German net power exports would have increased drastically.

Thank you for your attention!

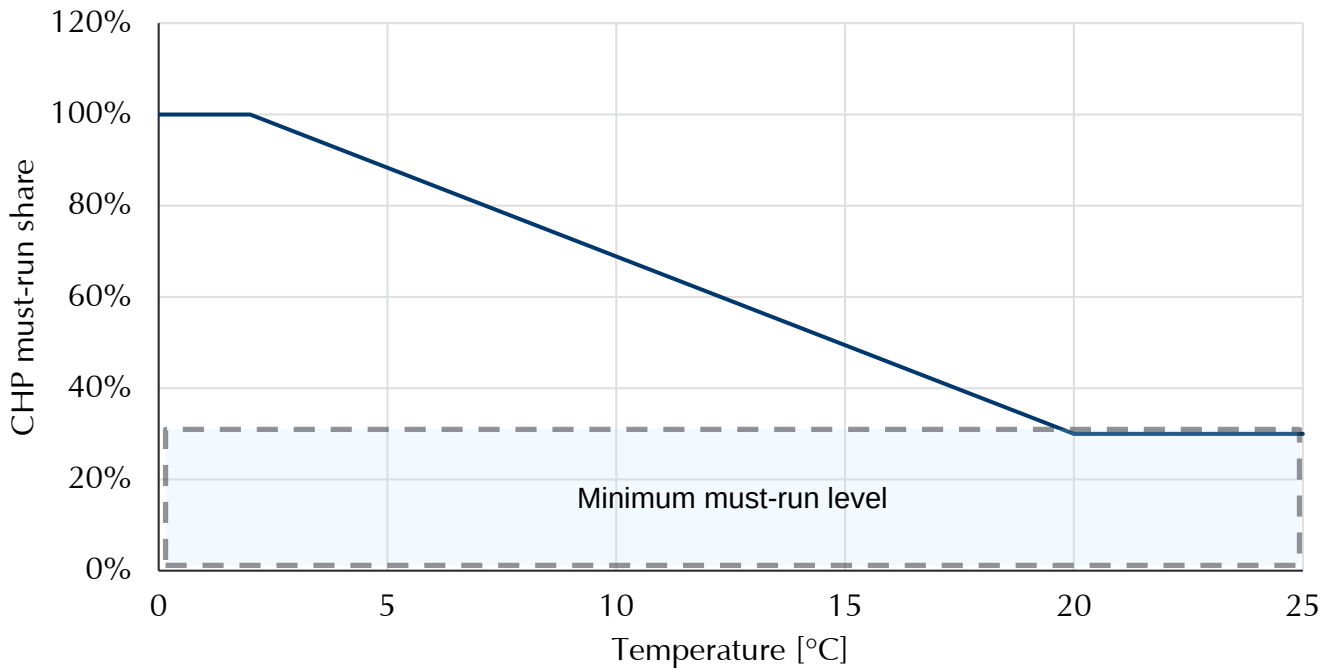
Philip Beran

House of Energy Markets & Finance
University of Duisburg-Essen, Campus Essen
Berliner Platz 6-8
45127 Essen
Germany

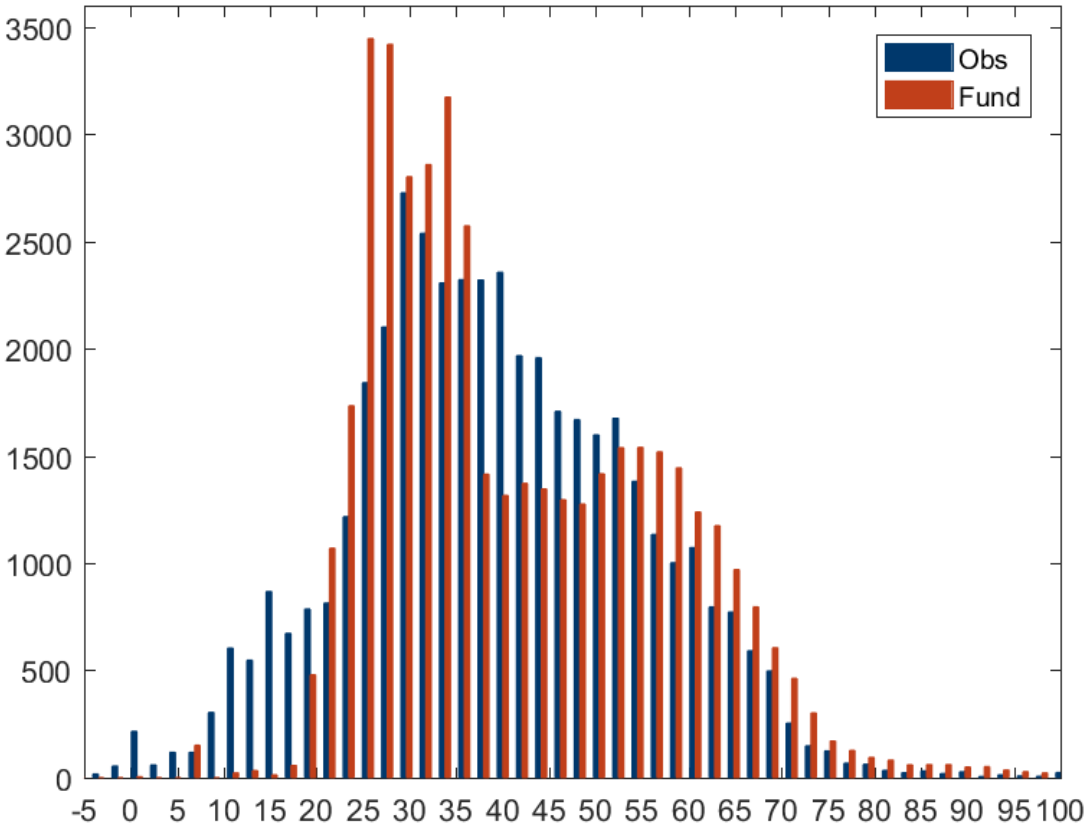
philip.beran@uni-due.de

Supply side: CHP must-run power plants

- Combined-Heat-and-Power (CHP) must-run power plants
  - Temperature driven CHP plants create a must-run production independent from power prices
  - Temperature-dependent must-run level



Price validation III



- Model prices are higher than observed prices
- High price concentration in price range 25-35 €/MWh.
- Rarely low model prices
- No negative model prices