House of Energy Markets & Finance

UNIVERSITÄT DUISBURG ESSEN

Offen im Denken

Short- to Mid-term Day-Ahead Electricity Price Forecasting Using Futures

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Cracow, Poland

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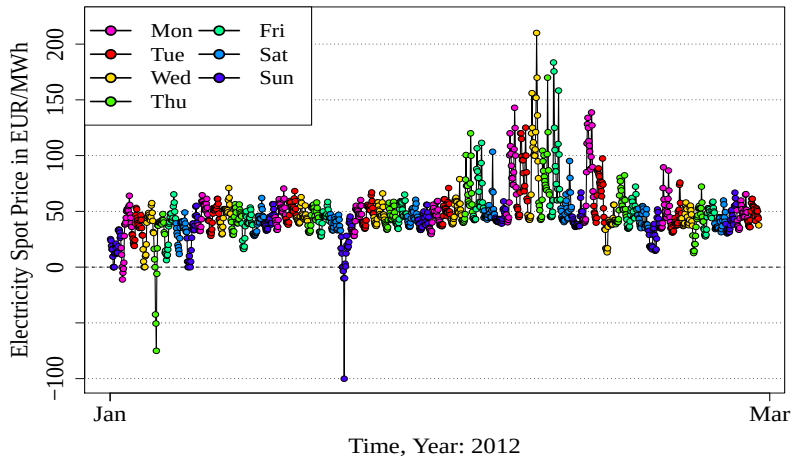
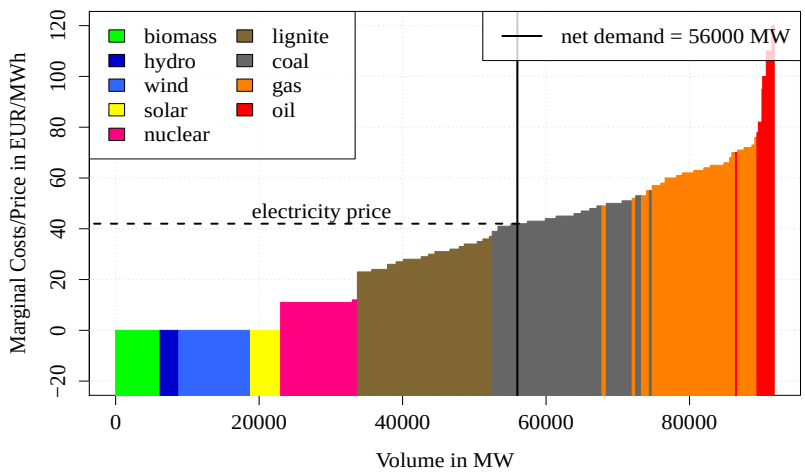
Two classes on electricity price forecasting

1. historical data based models
   - electricity price is modeled dependent on its own past
   - econometric/statistical/data mining approaches
   - e.g. time series, ANN, etc
   - sometimes fundamental related regressors, like load, wind power production are used
   - most popular approach, esp. in short-term forecasting
2. fundamental/structural/multi-agent models
   - economically motivated
   - electricity price is intersection of supply and demand
   - more popular for long-term forecasting, policy making





Electricity prices and derivative markets

- relationship between spot and future products studied in detail, e.g. [Carmona and Coulon, 2014] or [Benth and Paraschiv, 2017]
- risk premium relationship:

$$\mathrm{RP}_{t,\mathbb{T}} = \mathbb{E}[P_{\mathbb{T}}|I_t] - F_{t,\mathbb{T}}$$

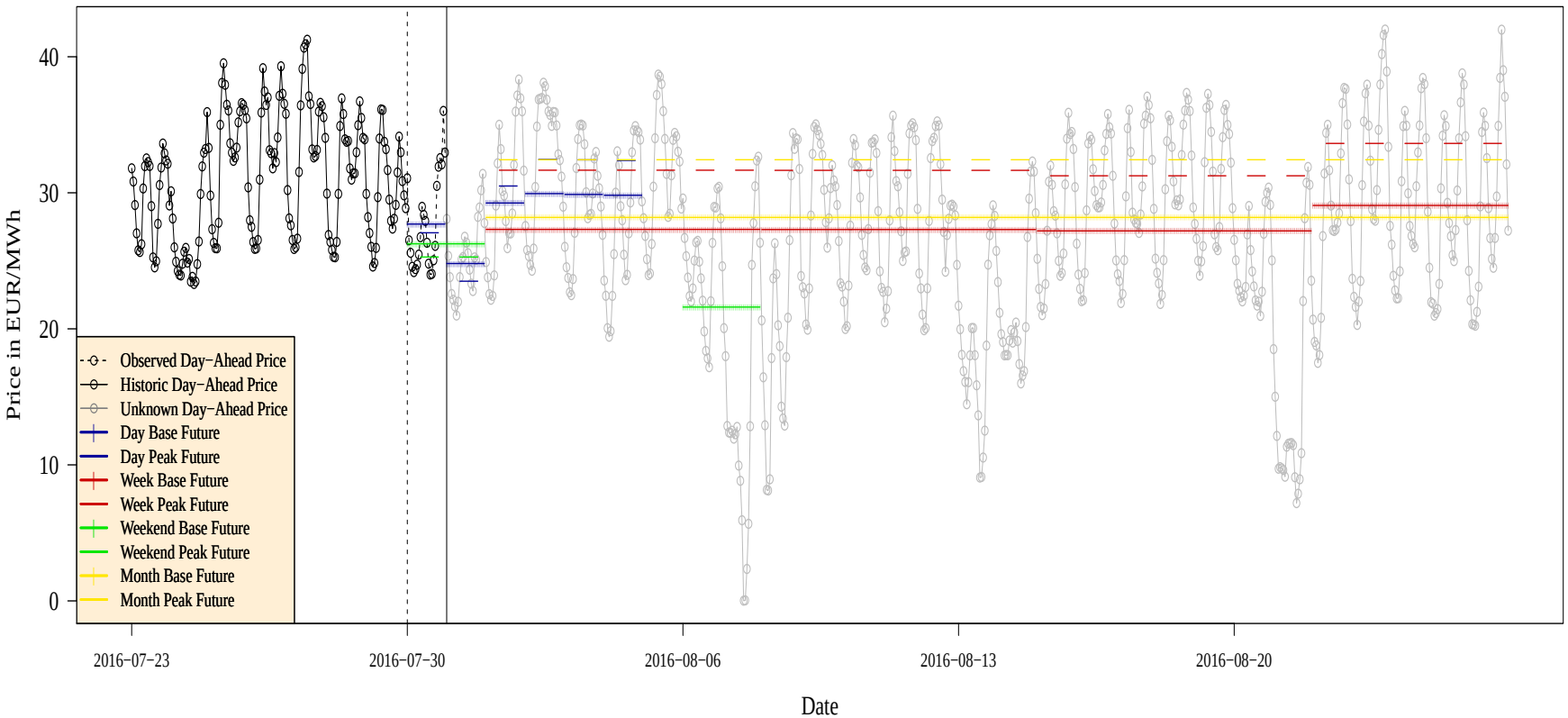
  - $\mathbb{E}[P_{\mathbb{T}}|I_t]$ is the expected electricity price of delivery period $\mathbb{T}$
  - information set I_t at time $t < T$ for $T \in \mathbb{T}$
  - $\mathbb{T}$ delivery period e.g. $\mathbb{T} = [T_1, T_2]$
  - future price at time t
- Musiela parameterization [Musiela, 1993]:

$$f_{t,m} = F_{t,\min(\mathbb{T})-t}$$

for $\mathbb{T} = [T_1, T_2]$ we have $f_{t,m} = F_{t,T_1-t}$

Electricity price and derivative markets

- German Future products traded at EPEX on working days
- different products available:
  - day, weekend, week, month, quarter and annual
  - base, peak (8:00-19:59), [off-peak]
- cash settlement based on EPEX day-ahead electricity price for DE+AT+LU
- *general idea:*
  use future data to forecast day-ahead electricity prices
  as we are interest in $\mathbb{E}\left[P_{\mathbb{T}}\middle|I_t\right]$ rem.:$(\mathbb{E}[P_{\mathbb{T}}|I_t] = \mathrm{RP}_{t,\mathbb{T}} + F_{t,\mathbb{T}})$
- future data should contain relevant market information,
  e.g. meteorologic updates, availability of conventional power plans, demand forecasts, etc.



- Spot prices and future products traded at the end of 29.07.2016

Day-ahead electricity price model for $Y_{d,h}$ (for all hours h)

$$
\begin{aligned}
Y_{d,h} = & \underbrace{\sum_{j=1}^{24}\sum_{k=1}^{K_Y}\beta_{h,j,k}Y_{d-k,h}}_{\text{spot prices}} + \underbrace{\sum_{k=0}^{K_{\text{day}}}\sum_{m=1}^{6}\beta_{f^{\text{day}},h,k,m}f^{\text{day}}_{d-k,m}}_{\text{base day futures}} + \underbrace{\sum_{k=0}^{K_{\text{week}}}\sum_{m\in M_{\text{w}}}\beta_{f^{\text{week}},h,k,m}f^{\text{week}}_{d-7k,m}}_{\text{base week futures}} \\
& + \underbrace{\sum_{k=0}^{K_{\text{wkend}}}\sum_{m\in M_{\text{wk}}}\beta_{f^{\text{wkend}},h,k,m}f^{\text{wkend}}_{d-7k,m}}_{\text{base weekend futures}} + \underbrace{\beta_{f^{\text{month}},h}f^{\text{month}}_{d,1}}_{\text{base month future}} \\
& + \underbrace{\sum_{k=0}^{K_{\text{day}}}\sum_{m=1}^{6}\beta_{f^{\text{day,p}},h,k,m}f^{\text{day,p}}_{d-k,m}}_{\text{peak day futures}} + \underbrace{\sum_{k=0}^{K_{\text{week}}}\sum_{m\in M_{\text{w}}}\beta_{f^{\text{week,p}},h,k,m}f^{\text{week,p}}_{d-7k,m}}_{\text{peak week futures}} \\
& + \underbrace{\sum_{k=0}^{K_{\text{wkend}}}\sum_{m\in M_{\text{wk,p}}}\beta_{f^{\text{wkend,p}},h,k,m}f^{\text{wkend,p}}_{d-7k,m}}_{\text{peak weekend futures}} + \underbrace{\beta_{f^{\text{month,p}},h}f^{\text{month,p}}_{d,1}}_{\text{peak month future}} + \underbrace{\sum_{k=1}^{7}\beta_{k,h}\text{DoW}_k}_{\text{weekdays}} + \epsilon_{d,h}
\end{aligned}
$$

- depends on past spot prices, (past) futures prices and dummies

Day-ahead electricity price model for $Y_{d,h}$

- complex data structure (underlyings and non-trading days) require adjustments
- overview of used future products

	Day Base f^{day}	Day Peak $f^{\text{day,p}}$	Week Base f^{week}	Week Peak $f^{\text{week,p}}$	Weekend Base f^{wkend}	Weekend Peak $f^{\text{wkend,p}}$	Month Base f^{month}	Month Peak $f^{\text{month,p}}$
Current Values	1	1	1	1	1	1	1	1
Historic Values	7	7	3	3	1	1	0	0
Number of Mat.	6	6	4	4	10	5	1	1
Overall # of param.	$48_{=(1+7)\times 6}$	$48_{=(1+7)\times 6}$	$16_{=(1+3)\times 4}$	$16_{=(1+3)\times 4}$	$20_{=(1+1)\times 10}$	$10_{=(1+1)\times 5}$	$1_{=(1+0)\times 1}$	$1_{=(1+0)\times 1}$

- 335 parameters in total

Day-ahead electricity price model for $Y_{d,h}$

- 335 parameters, 365 observations for estimation
- estimated using lasso (shrinkage estimation method) on scaled OLS problem:

$$\widehat{\widetilde{\boldsymbol{\beta}}}_h = \underset{\boldsymbol{\beta}\in\mathbb{R}^{p_h}}{\arg\min} \sum_{d=1}^{n} (\widetilde{Y}_{d,h} - \widetilde{\mathbb{X}}_{d,h}\boldsymbol{\beta})^2 + \lambda_h \sum_{j=1}^{p_h} |\boldsymbol{\beta}_j|$$

- selection of tuning parameter $\lambda \geq 0$ via BIC (Baysian information criterion)
- estimation using coordinate descent, [Friedman et al., 2016]

3 Benchmark models

For model comparison we introduce three extremely competitive benchmarks, the

- AR(p) with AIC-selection, [Ziel et al., 2015]
- AR-HoW(p) with AIC-selection, [Ziel and Weron, 2016]
- AR24(p) with lasso and BIC-selection, [Ziel, 2016]

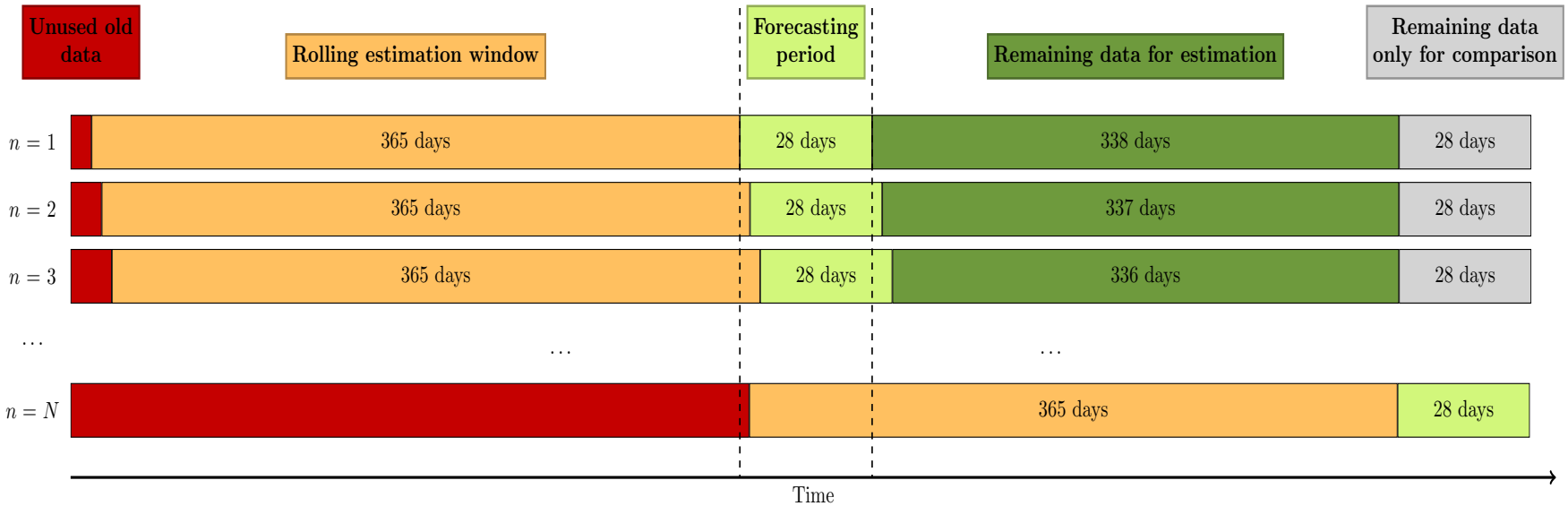
$$\text{AR(p)}: \quad Y_t = \mu + \sum_{k=1}^{p} \beta_k (Y_{t-k} - \mu) + \epsilon_t$$

$$\text{AR-HoW(p)}: \quad Y_t = \overline{Y_{\text{HoW},t}} + \sum_{k=1}^{p} \beta_k (Y_{t-k} - \overline{Y_{\text{HoW},t}}) + \epsilon_t$$

$$\text{AR24(p)}: \quad Y_{d,h} = \sum_{j=1}^{24} \sum_{k=1}^{K_Y} \beta_{h,j,k} Y_{d-k,h} + \sum_{k=1}^{7} \beta_{k,h} \text{DoW}_k + \epsilon_{d,h}$$

- with univariate price series: $Y_{24(d-1)+h} = Y_{d,h}$

Forecasting study design



- 1 year in-sample, forecasting horizon 28 days
- evaluation measures (h = horizon,):

$$\mathrm{MAE}_{c,h} = \frac{1}{N}\sum_{n=1}^{N}\left|\widehat{\epsilon}_{c,h,n}\right| \tag{1}$$

$$\mathrm{MAE}_{k} = \mathrm{MAE}_{\lfloor (k-1)/24+1 \rfloor, k \bmod 24+1} \tag{2}$$

$$\mathrm{MMAE}_{K} = \frac{1}{K}\sum_{k=1}^{K}\mathrm{MAE}_{k} \tag{3}$$

Results

	Future-Model	AR(p)	AR-HoW(p)	AR24(p)
$MMAE_{672}$	7.19	7.80	8.06	8.31

Table: MMAE for a forecast of four weeks for the final model and every benchmark model

- Future-Model superior to other models, esp. to nested AR24(p)

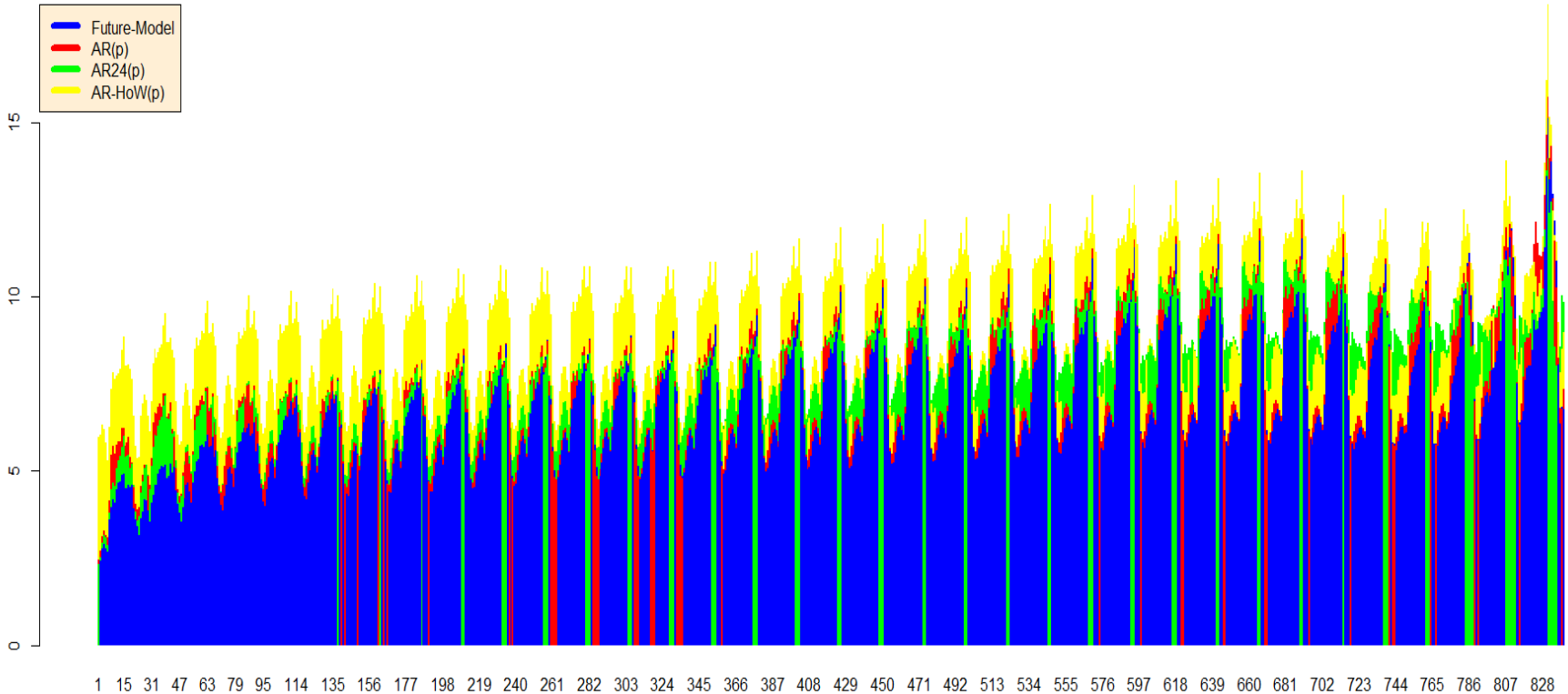


Figure: Stacked bar chart of MAE_h, sorted by best model.

- Clear improvement on peak hours of day 2 and 3
- At forecasting horizon of 3 weeks substantial accuracy gain in peak hours

Multivariate Diebol-Marioano tests, see [Ziel and Weron, 2016]

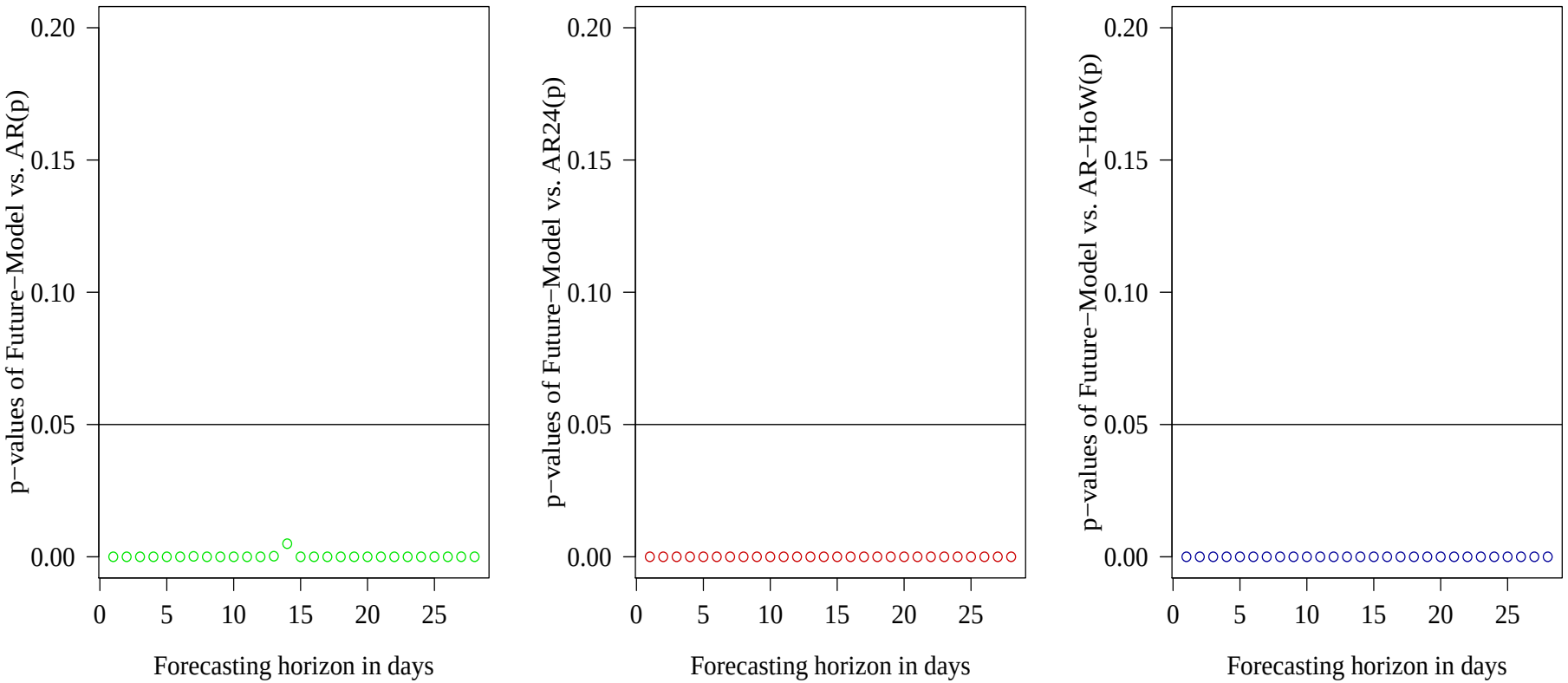


Figure: p-Values of the DM-Test for every day of the first 28 days of forecasting. Blue dots show days for which the future model was significantly better than the competing model.

Variable selection of future model for $Y_{d,h}$: Spot prices

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
da h 1 lag 1	0.00	0.00	0.00	0.80	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
da h 2 lag 1	0.00	0.00	27.35	2.41	22.79	4.56	2.95	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.95	0.00	0.00	0.00	0.00	1.88	0.00
da h 3 lag 1	0.00	0.27	0.00	0.00	0.00	0.54	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.56	0.00	0.00	0.00	0.00	0.00	0.00
da h 4 lag 1	6.43	13.67	30.03	58.98	45.31	23.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	2.68	0.00	0.00	0.00
da h 5 lag 1	0.00	0.00	0.27	10.19	9.65	16.35	0.00	0.00	0.00	1.88	0.27	0.80	0.00	0.00	0.00	0.00	0.00	7.77	4.29	0.00	0.00	0.00	2.95	5.09
da h 6 lag 1	0.00	0.27	0.54	0.27	1.07	8.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
da h 7 lag 1	0.00	18.50	43.43	87.40	100	93.03	3.49	1.07	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.00	1.88	0.00	0.00	0.00	0.00	0.00	0.00
da h 8 lag 1	0.00	56.84	10.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
da h 9 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.54	0.00	0.00	0.00	0.00	0.00	0.00
da h 10 lag 1	0.00	0.00	0.00	0.00	0.54	0.00	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
da h 11 lag 1	0.00	0.00	0.00	0.00	0.00	0.54	2.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27
da h 12 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.00	0.00	0.00	0.27	2.14	0.00	0.00	0.00	0.27	1.07	0.00	0.00	4.83	0.00	0.00	0.00	0.00
da h 13 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.02	78.82	78.02	44.50	16.89	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
da h 14 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.13	27.88	24.40	22.52	5.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
da h 15 lag 1	0.00	0.00	1.34	0.00	0.00	0.27	3.49	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.66	26.27	4.56	0.00
da h 16 lag 1	25.20	27.35	27.35	27.35	27.35	5.63	0.00	0.00	0.00	0.00	0.00	0.00	4.83	29.22	29.22	4.29	4.29	0.00	0.00	0.00	5.36	0.00	8.31	0.00
da h 17 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	3.49	0.00	0.00	0.27	16.62	9.92	21.45	38.61	41.82	25.74	23.06	0.00	0.00	0.00	8.31	16.09	3.49	11.53
da h 18 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.33	10.19	46.38	12.33	23.59	27.35	83.11	97.05	100	0.00	0.00	6.17	1.07	1.07	6.70
da h 19 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.07	2.95	13.40	0.80	0.80	0.00	0.00	0.00	2.95	100	0.00	3.22	35.39	38.61	3.22
da h 20 lag 1	8.04	63.00	68.36	90.08	80.43	58.18	1.07	72.39	86.60	82.04	82.57	41.55	0.27	0.00	0.00	0.00	0.00	0.00	4.02	77.75	0.00	0.00	3.22	0.00
da h 21 lag 1	62.20	93.57	76.14	69.97	52.28	75.60	100	100	100	95.17	9.65	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.42	59.25	4.83	0.00	0.00
da h 22 lag 1	73.99	13.67	0.00	3.22	28.42	84.99	97.86	4.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	93.57	100	5.09	0.00
da h 23 lag 1	12.87	0.80	2.68	0.00	0.00	0.54	9.12	35.39	16.09	38.07	52.55	49.87	1.34	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.70	100	63.54
da h 24 lag 1	100	100	100	100	100	100	85.25	24.93	5.90	47.18	44.24	49.33	28.15	12.06	0.54	0.00	0.00	0.00	0.00	0.00	0.00	5.36	49.33	94.37

- Yesterdays electricity price at same hour $Y_{d-1,h}$ only for evening hours relevant
- Yesterdays last electricity price $Y_{d-1,24}$ for night hours relevant

Variable selection of future model for $Y_{d,h}$: Day futures

mat1 lag 0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mat1 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54
mat1 lag 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mat1 lag 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mat1 lag 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mat1 lag 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mat1 lag 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.83
mat1 lag 7	0.00	0.00	0.27	0.00	0.80	0.00	0.00	0.54	0.27	0.00	0.00	0.00	0.80	2.95	1.61	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mat2 lag 0	39.95	92.49	99.20	99.73	99.73	100	33.78	72.65	67.29	72.65	90.88	89.28	92.23	58.98	58.18	45.58	58.45	73.46	76.68	77.75	71.05	59.25	70.78	77.48
mat2 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.27	7.24	9.38	2.14	0.00	0.00	0.00	0.00	0.00	0.00
mat2 lag 2	0.00	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mat2 lag 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.00	0.00	0.00	0.27	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.80	0.27
mat2 lag 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.27
mat2 lag 5	0.00	0.00	0.00	0.00	0.00	0.00	0.54	74.26	79.62	58.98	61.93	73.19	41.55	7.77	0.00	0.00	0.00	0.27	6.43	0.00	0.00	0.00	0.54	3.22
mat2 lag 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00	0.00
mat2 lag 7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.00	0.00	0.00
mat3 lag 0	0.00	0.00	0.00	0.00	0.00	3.22	4.02	33.78	0.00	0.00	0.00	22.79	9.12	17.16	13.14	52.01	97.32	100	100	100	100	77.48	88.20	99.73
mat3 lag 1	54.96	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99.73	99.30	32.44	1.07	8.31
mat3 lag 2	6.97	0.00	0.00	0.00	0.00	0.00	0.27	1.61	0.00	0.00	0.00	0.00	0.00	0.27	0.27	5.36	7.77	0.27	0.54	5.36	5.63	1.34	0.00	0.27
mat3 lag 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	3.22	2.14	3.22
mat3 lag 4	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	1.61	0.00	0.00	0.00	0.00	0.00	1.88	0.54	2.41
mat3 lag 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34	0.27	0.00
mat3 lag 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34	7.77	12.06	0.80	0.00	0.00	0.00	0.00	0.00	1.88	0.00	1.07
mat3 lag 7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00
mat4 lag 0	0.54	9.65	18.23	13.67	24.66	21.18	4.29	5.63	7.77	22.25	0.00	8.31	5.63	1.07	0.27	4.56	8.04	3.49	2.95	1.07	0.54	0.00	0.00	0.00
mat4 lag 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.29	29.22	18.23	78.82	99.20	93.83	97.32
mat4 lag 2	0.00	0.00	0.00	0.54	35.92	36.19	91.96	97.32	100	89.81	47.72	50.40	49.87	63.54	77.75	82.57	76.41	67.29	12.87	5.09	3.22	2.68	0.00	1.34
mat4 lag 3	0.54	1.61	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.07	0.00	0.00	1.34	7.24	0.80	0.00	0.54
mat4 lag 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	1.61	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mat4 lag 5	0.00	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34
mat4 lag 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	26.81	17.96	12.06	3.49	0.54	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mat4 lag 7	0.00	0.00	0.00	0.00	0.00	0.00	0.27	4.29	6.43	1.88	0.00	0.27	3.49	8.31	4.83	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

- Day futures of matching maturity relevant (mat 2 lag 0, mat 3 lag 1, mat 4 lag 2)
- For evening hours matur. of following day are relevant (mat 3 lag 0, mat 4 lag 1)

Variable selection of future model for $Y_{d,h}$: Dummies + Weekend

Mo	0.00	0.00	0.00	0.00	0.00	0.00	92.76	81.77	83.65	73.99	40.75	22.52	29.22	27.61	26.54	26.27	43.97	89.54	39.41	7.51	11.26	0.00	0.00	0.00
Tu	0.00	0.00	0.00	0.00	0.27	3.22	0.00	26.01	49.33	69.17	37.00	22.52	27.88	5.90	0.27	1.07	0.54	0.27	5.90	0.00	1.34	0.27	0.27	0.00
We	0.00	0.00	0.00	1.34	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	1.88	0.54	0.27	0.00	0.00	0.00	0.00	0.00	0.00
Thu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fr	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.00	1.34	0.00	0.00	0.00	0.00	0.00	2.68	6.97	55.50
Sa	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Su	34.85	81.50	15.82	27.35	39.95	96.25	94.10	87.40	91.42	91.96	37.53	0.27	0.00	15.55	30.29	34.85	24.13	9.92	35.39	21.98	2.14	0.27	0.00	0.00
wkend mat 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54	1.07	0.00	0.00	0.00	0.27	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
wkend mat 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.83	31.90	24.13	9.38	0.80	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.54	2.41
wkend mat 3	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	1.34
wkend mat 4	0.00	1.34	0.00	0.27	0.00	0.00	0.00	0.54	7.51	15.28	6.17	0.00	0.00	0.00	0.00	0.00	0.00	6.97	0.00	0.00	0.00	0.00	0.00	0.00
wkend mat 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.75	59.52	61.93	20.38	0.54	1.07	0.00	0.54	7.77	28.15	28.95	17.43	5.63	19.84	9.92	0.00	0.00
wkend mat 8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.00	0.00	0.00	5.36	3.75	0.00	16.09	13.14	7.51	8.85	2.41	2.68	0.27	4.02
wkend mat 9	0.00	0.00	0.00	0.00	0.80	29.22	71.85	77.48	51.47	25.47	40.48	41.02	45.58	16.09	11.80	25.20	9.12	1.61	6.70	20.91	37.80	49.06	11.80	0.27
wkend mat 10	0.00	0.00	0.00	0.00	4.83	12.87	19.03	11.26	2.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.77	20.64	7.24	5.09
wkend mat 11	0.00	6.17	9.12	0.00	0.54	8.04	2.95	11.80	13.67	4.02	7.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.38	6.43	23.32	13.40	8.85
wkend mat 12	0.00	0.00	0.00	0.00	0.00	0.00	16.62	63.81	78.82	70.24	48.26	21.98	21.45	35.66	35.12	64.08	64.88	69.97	58.98	7.77	23.59	0.00	0.00	0.00
wkend lag1 mat 1	0.00	0.00	0.00	0.00	0.00	0.00	54.69	89.28	73.99	25.20	3.22	0.54	0.27	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
wkend lag1 mat 2	0.00	0.00	0.00	0.00	0.00	0.00	40.75	21.98	45.31	0.80	9.65	3.22	2.41	3.22	4.02	7.51	6.17	2.95	1.61	4.02	3.22	0.27	0.00	0.00
wkend lag1 mat 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.14	0.54	1.61	0.27	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
wkend lag1 mat 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	8.85	52.82	58.98	60.05	44.50	37.53	54.69	45.84	2.14	0.80	0.27	0.27	0.00	0.00	0.00
wkend lag1 mat 5	0.00	0.00	0.00	0.00	0.00	0.00	7.24	7.24	7.77	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00
wkend lag1 mat 8	0.00	0.00	0.00	0.00	0.00	0.00	8.31	36.46	5.90	1.34	49.87	31.64	9.38	7.24	6.70	0.00	3.22	1.34	0.00	0.00	0.00	0.00	0.00	0.00
wkend lag1 mat 9	0.00	2.14	1.07	0.00	3.75	13.14	29.49	59.79	15.82	19.03	10.99	5.09	3.49	0.00	1.61	4.02	9.92	13.67	1.34	0.00	3.75	8.31	0.80	8.58
wkend lag1 mat 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.17	12.60	13.14	15.28	12.87	0.00	0.00	0.00	0.80	10.99	0.54	1.88
wkend lag1 mat 11	0.00	0.00	0.80	0.00	2.14	21.45	18.23	43.70	31.10	25.74	12.87	0.00	0.00	0.27	0.27	1.88	0.00	1.61	6.43	11.80	15.82	7.77	0.00	6.43
wkend lag1 mat 12	0.00	0.54	0.00	0.00	2.68	85.79	79.62	13.40	11.26	12.87	12.87	7.51	2.14	3.22	0.27	1.88	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
month	0.00	30.56	55.76	59.25	49.60	20.11	0.00	0.00	0.00	0.00	0.27	0.54	1.34	0.80	0.00	0.00	1.88	45.84	46.38	18.77	4.83	0.00	16.09	0.00

- Dummies 'lose' impact, esp. Saturday dummy is hardly relevant
- Weekend futures 'take over' at least partially

Summary and conclusion

- considering future data for forecasting day-ahead prices can substantially improve the forecasts
- relevant dependency structure of selection algorithm makes sense
- more effort needed:
  improvement if external regressors are considered


Benth, F. E. and Paraschiv, F. (2017).
A space-time random field model for electricity forward prices.
Journal of Banking & Finance.


Carmona, R. and Coulon, M. (2014).
A survey of commodity markets and structural models for electricity prices.
In *Quantitative Energy Finance*, pages 41–83. Springer.


Friedman, J., Hastie, T., Tibshirani, R., and Simon, N. (2016).
glmnet: lasso and elastic-net regularized generalized linear models.
R package version 2.0-5.


Musiela, M. (1993).
Stochastic pdes and term structure models.
Journées Internationales de Finance, IGR-AFFI, La Baule.


Ziel, F. (2016).
Forecasting electricity spot prices using lasso: On capturing the autoregressive intraday structure.
IEEE Transactions on Power Systems, 31(6):4977–4987.


Ziel, F., Steinert, R., and Husmann, S. (2015).
Forecasting day ahead electricity spot prices: The impact of the exaa to other european electricity markets.
Energy Economics, 51:430–444.


Ziel, F. and Weron, R. (2016).
Day-ahead electricity price forecasting with high-dimensional structures: Univariate vs. multivariate models.
Technical report, Hugo Steinhaus Center, Wroclaw University of Technology.