Institute for Operations Research
and Computational Finance

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Econometric analysis of the determinants of electricity wholesale prices in Switzerland and Germany

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November 2016

Agenda

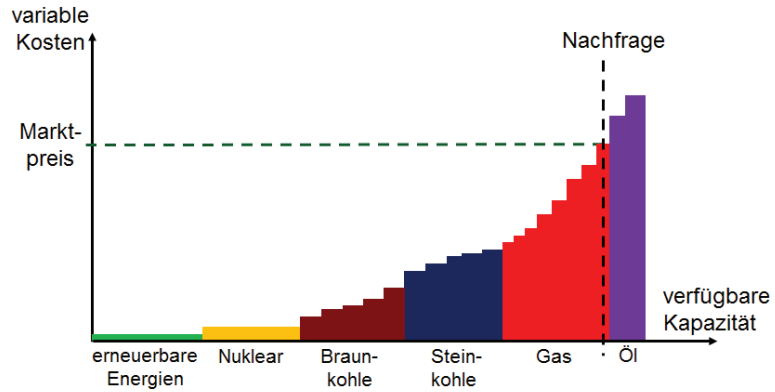
1. **Motivation**
2. Cross-border effects of the German electricity market fundamentals on the Swiss electricity prices (selected results)
3. Conclusion

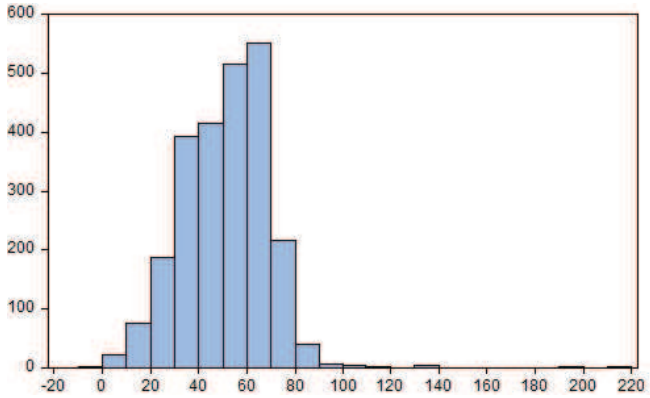
Outlook: The Swiss and German electricity markets are interconnected

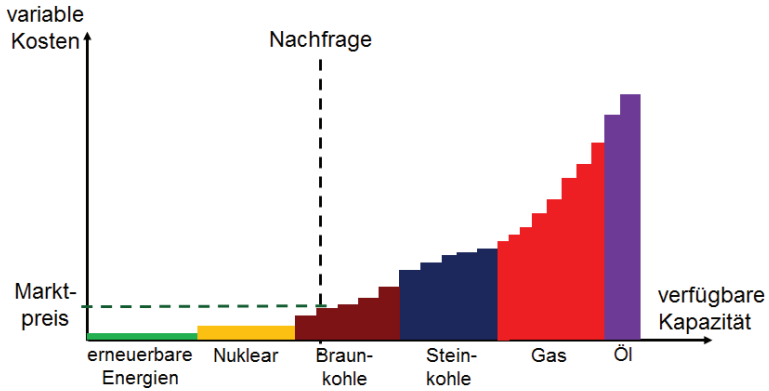
- Given the perspective of the Swiss energy policy to promote renewable energy technologies in the future, it becomes highly relevant at this point **to understand the traditional fundamental factors that impact cross-border Swiss electricity prices**
- Empirical evidence shows that German (Phelix) and Swiss (Swissix) electricity prices **share a common long-term trend**, given that the two markets are interconnected
- Shocks in Phelix prices are transmitted to Swissix
- We investigate the **price adaption of Swiss and German electricity prices to market fundamentals** and how this effect depends on: *time of the day* and *day of the week*
- The understanding of the risk drivers of electricity prices is of great importance for risk management, production planning, as well as for energy policy makers for the derivation of long-term energy scenarios

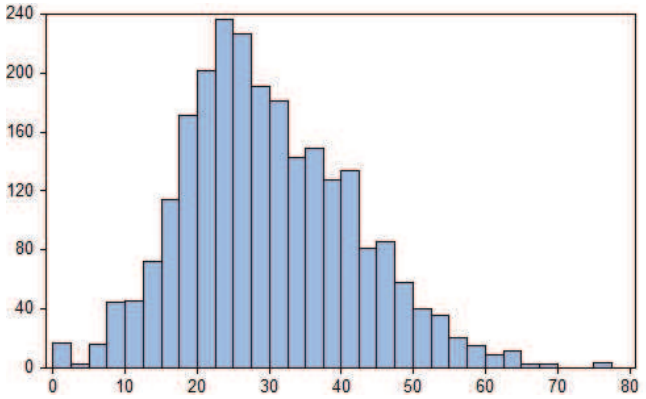
Motivation

- The intersection point between demand/supply curves occurs at different locations for different hours within a day
- Different electricity price "regions" (price quantiles) are influenced by different fundamental variables, due to different input mix









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Market fundamentals driving electricity prices

- Dependent variable: **Swissix prices (01/01/2011–31/08/2016)** modeled separately for:
  - Each hour of the day ($i = 1, \ldots, 24$)
  - Working days (Mo–Thu) versus Weekends (Sa–Su)

- Independent variables:
  - **Demand day-ahead forecast for Germany**
  - **Supply side factors for Germany:**
    - Prices for **coal**, **gas**, **oil**, **CO2** emission allowances
    - Expected infeed from renewable energies (**wind**, **PV**)
    - Expected power plant availability (**PPA**)
  - **Learning effects:** lagged spot prices (autoregressive terms) of
    - Previous day, same hour (lag 1)
    - Previous week, same day and hour (lag 7)

Dynamic fundamental model for electricity prices

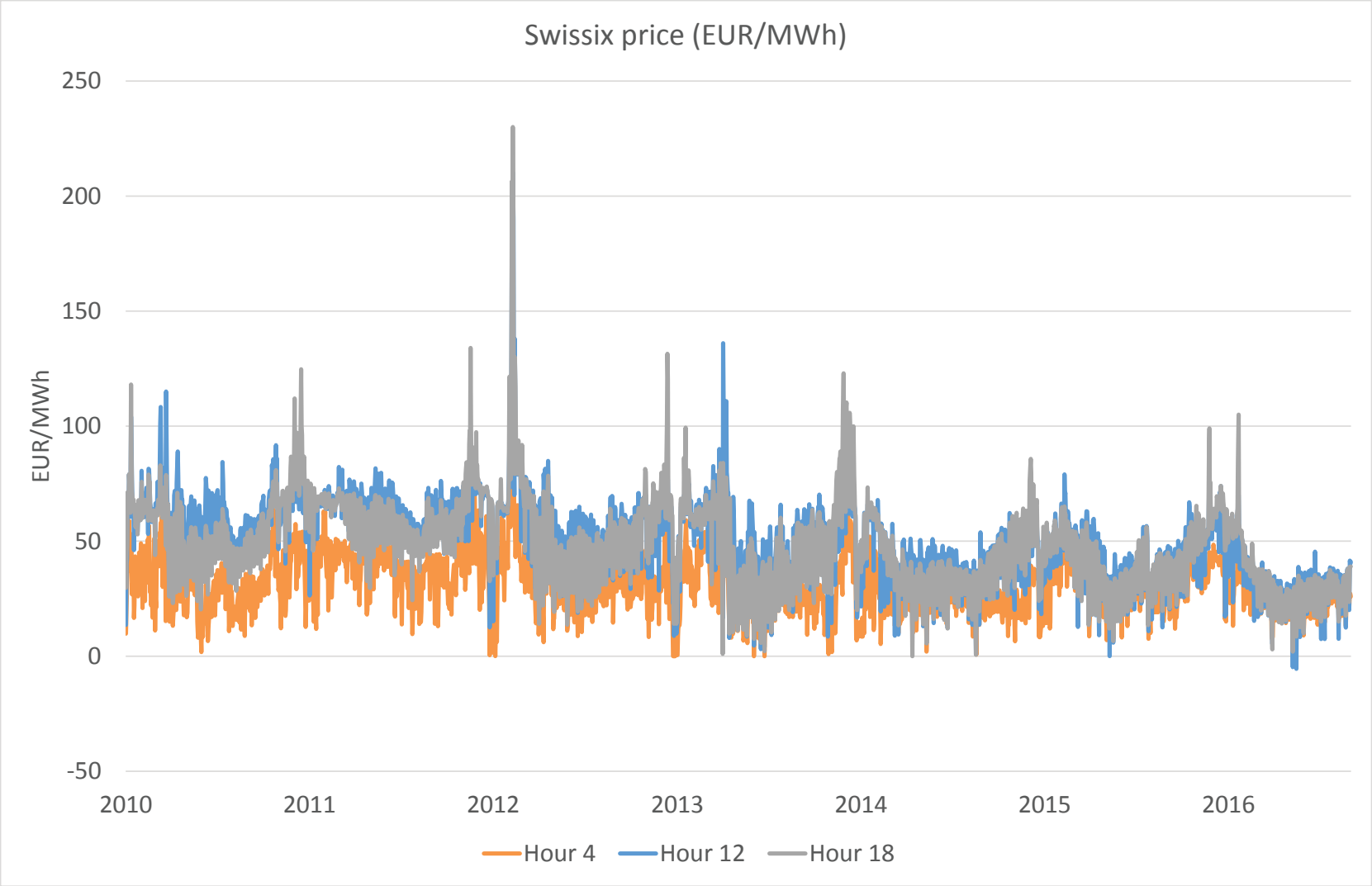
- We assess the inter-temporal changes in the relation of hourly day-ahead electricity prices and market fundamentals in the context of a **time-varying regression model**
- We formulate a **state space model** that allows for changing regression coefficients over time and estimate it with a **Kalman Filter** and **maximum likelihood**:

$$\begin{aligned} y_{i,t} &= z'_{i,t}\beta_{it} + v_{i,t} && \textit{Measurement Equation} \\ \beta_{i,t} &= \beta_{i,t-1} + w_{i,t} && \textit{Transition Equation} \end{aligned}$$

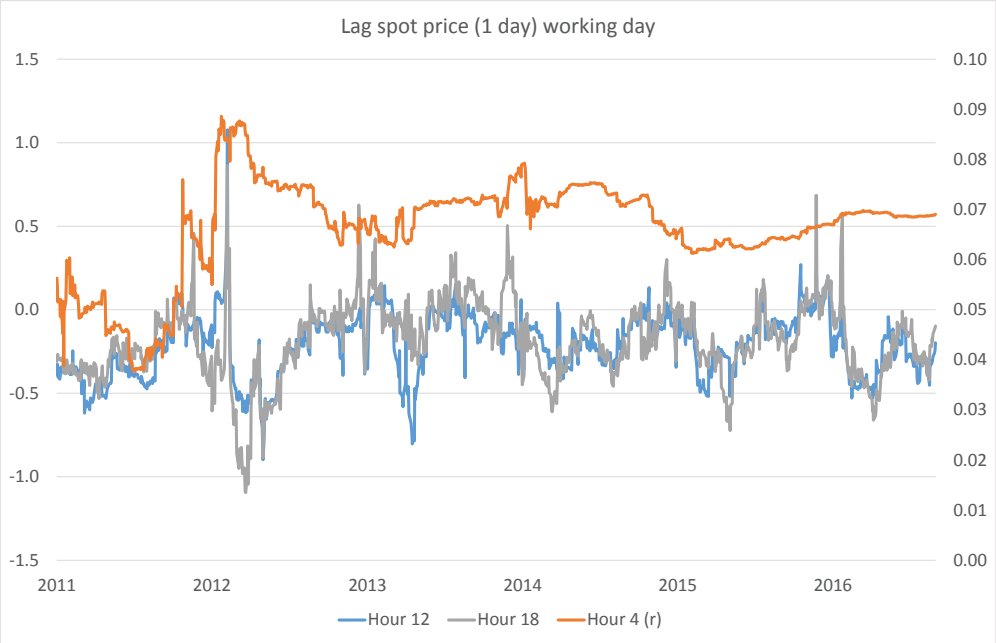
where $i \in \{1, ..., 24\}$ is the index for the hour and $k \in \{1, ..., 11\}$ variable index.

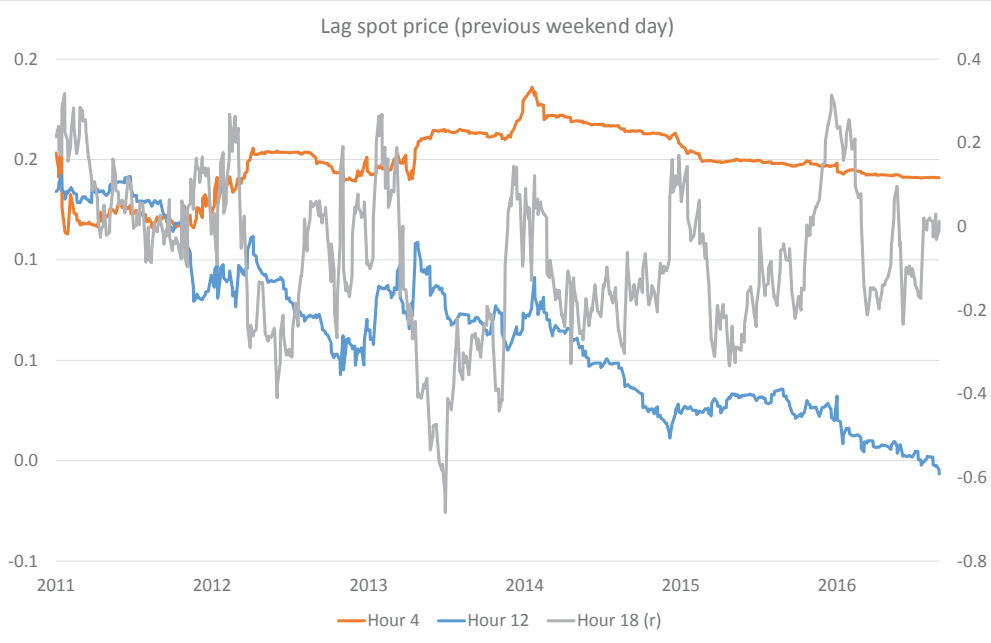
$$\begin{aligned} v_{i,t} &\sim \mathcal{N}(0, R_i) & E(v_{i,t}w_{i,t}) &= 0 \\ \beta_{i,t} &= (\beta_{i,1,t}, \beta_{i,2,t}, ..., \beta_{i,k,t})' & Q_i &= diag\{\sigma^2_{i,1}, \ldots, \sigma^2_{i,k}\} \\ w_{i,t} &= (w_{i,1,t}, w_{i,2,t}, ..., w_{i,k,t})' & w_{i,t} &\sim \mathcal{N}(0, Q_i) \end{aligned}$$

Swissix price evolution



Time-varying coefficients to lag spot price (1-day) working days/weekend





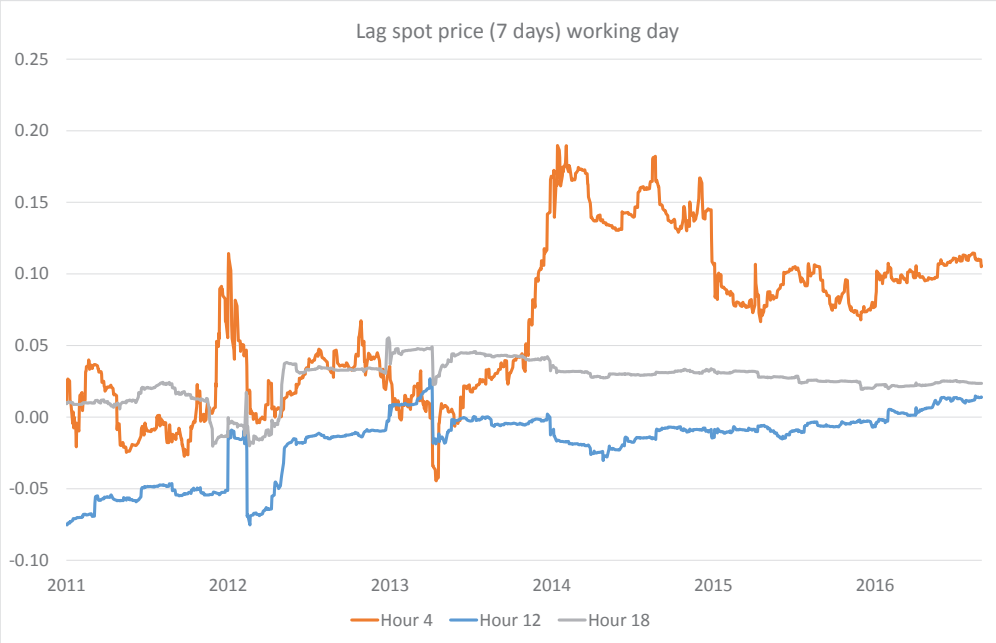
EUR/MWh		Working day			Weekend		
		H4	H12	H18	H4	H12	H18
2011	mean	1.99	-20.62	-15.43	4.87	6.90	4.94
	std.	0.67	11.27	10.74	1.45	1.19	6.46
2012	mean	2.44	-13.27	-14.99	4.27	3.36	-1.10
	std.	1.02	22.23	27.73	1.79	1.36	7.28
2013	mean	2.02	-8.10	1.85	4.15	2.75	-4.13
	std.	0.93	13.12	10.37	2.20	1.29	7.75
2014	mean	1.78	-7.80	-8.52	3.63	1.44	-2.86
	std.	0.54	4.60	7.77	1.34	0.97	3.46
2015	mean	1.92	-6.76	-5.26	4.17	0.88	-1.29
	std.	0.61	8.78	10.59	1.35	0.30	5.90
2016	mean	1.62	-11.01	-8.41	3.04	0.19	0.83
	std.	0.39	4.32	8.43	0.97	0.24	5.22
2011–	mean	1.98	-11.27	-8.47	4.08	2.72	-0.70
2016	std.	0.78	13.49	15.78	1.68	2.41	6.88

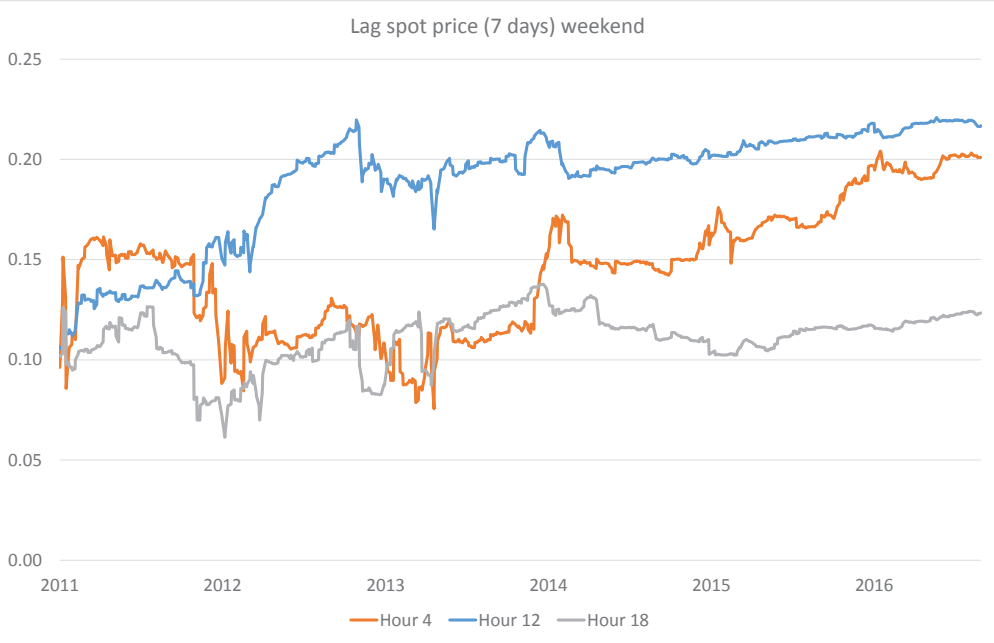
Marginal effects of autorogressive lag spot price (1 day) in EUR/MWh

Interpretation of results: 1-day autoregressive term

- We found negative marginal effects of 1-day lagged Swissix prices for hours 12 and 18 during working days: prices revert to their production costs. Coefficients cross the zero line and become positive at times where extremely large positive Swissix electricity price price spikes have been observed: positive coefficients describe the clustering of upwards spikes.
- For hour 4 – working days and in the weekend we found evidence of the use of market power (positive coefficients): market participants tend to reinforce successful bids previously placed in the market. This pattern is similar for the 7-day lagged Swissix prices.
- With respect to price adaption: it is more pronounced during peak hours 12 and 18 than for hour 4 and more pronounced during working than during weekend days.
- During peak hours there are larger disequilibria between demand/supply and the price has a more pronounced autoregressive nature: market participants learn from the level of the price at the same hour, previous day.

Time-varying coefficients to lag spot price (7-days) working days/weekend

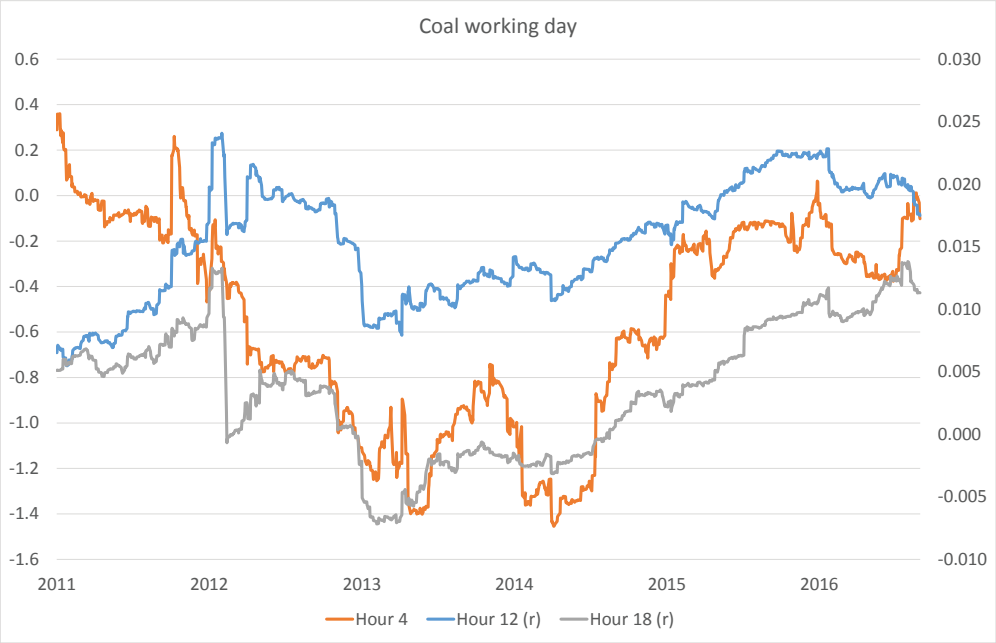




EUR/MWh		Working day			Weekend		
		H4	H12	H18	H4	H12	H18
2011	mean	0.25	-3.82	0.65	5.66	7.53	5.54
	std.	1.01	0.67	0.65	1.65	1.52	0.93
2012	mean	1.02	-1.70	1.03	3.28	8.04	4.19
	std.	0.81	1.98	1.33	1.37	2.32	1.45
2013	mean	0.85	0.01	2.39	2.89	7.24	4.45
	std.	1.47	0.57	0.87	1.71	3.42	2.26
2014	mean	3.70	-0.69	1.39	3.24	5.90	3.76
	std.	1.37	0.29	0.41	1.26	2.28	1.55
2015	mean	2.57	-0.36	1.27	4.79	6.68	3.77
	std.	0.71	0.15	0.34	1.64	2.54	1.55
2016	mean	2.41	0.23	0.84	4.22	4.97	3.19
	std.	0.59	0.21	0.27	1.33	2.20	1.50
2011–	mean	1.77	-1.13	1.29	3.99	6.83	4.20
2016	std.	1.62	1.66	0.95	1.81	2.64	1.74

Marginal effects of autorogressive lag spot price (7 days) in EUR/MWh

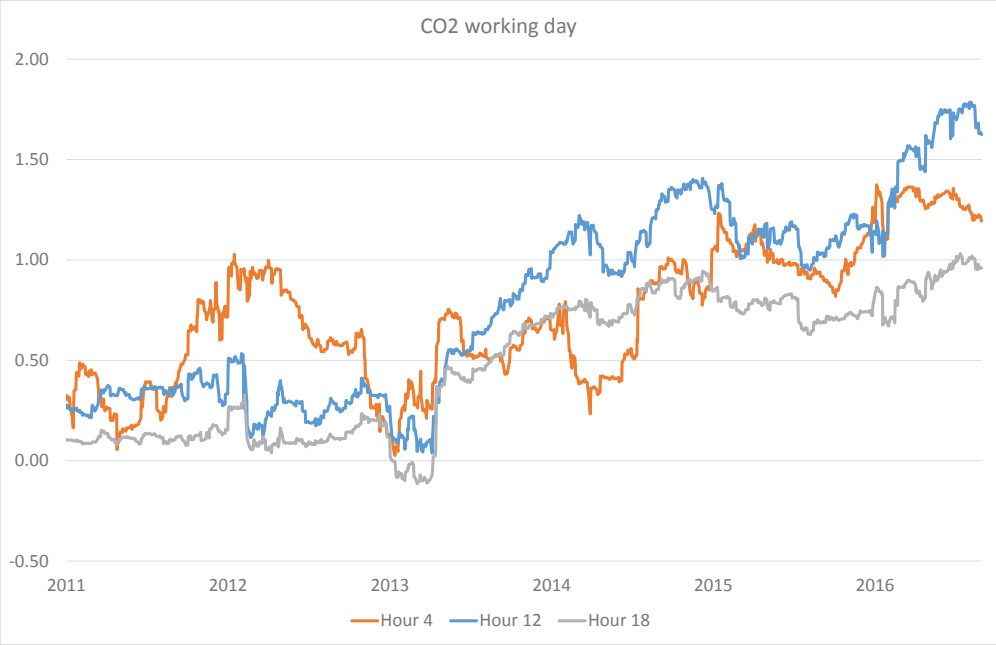
Time-varying coefficients to coal working days/weekend



EUR/MWh		Working day			Weekend		
		H4	H12	H18	H4	H12	H18
2011	mean	-0.52	0.11	0.07	-0.18	0.01	0.05
	std.	1.59	0.03	0.01	0.05	0.01	0.02
2012	mean	-5.99	0.17	0.03	-0.29	-0.04	-0.02
	std.	1.83	0.03	0.04	0.02	0.02	0.02
2013	mean	-8.07	0.08	-0.03	-0.28	-0.10	-0.06
	std.	1.55	0.01	0.02	0.01	0.01	0.01
2014	mean	-6.98	0.10	0.00	-0.25	-0.08	-0.03
	std.	2.11	0.01	0.02	0.01	0.01	0.01
2015	mean	-1.18	0.12	0.04	-0.23	-0.07	-0.03
	std.	0.58	0.01	0.01	0.01	0.01	0.01
2016	mean	-1.26	0.11	0.06	-0.22	-0.06	-0.03
	std.	0.62	0.01	0.02	0.03	0.00	0.00
2011–	mean	-4.15	0.12	0.03	-0.24	-0.06	-0.02
2016	std.	3.46	0.03	0.04	0.05	0.04	0.04

Marginal effects of coal in EUR/MWh

Time-varying coefficients to CO2 prices working days/weekend



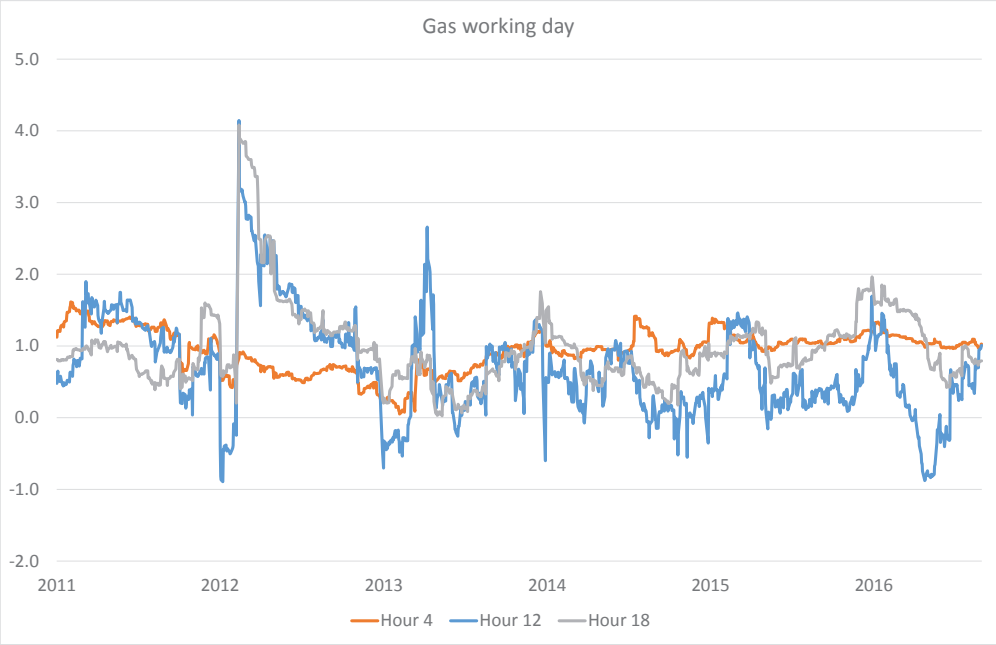
EUR/MWh		Working day			Weekend		
		H4	H12	H18	H4	H12	H18
2011	mean	4.88	4.26	1.46	0.01	0.18	0.19
	std.	1.61	0.93	0.33	0.05	0.05	0.06
2012	mean	5.06	2.13	1.01	-0.04	0.01	0.09
	std.	1.76	0.70	0.49	0.02	0.03	0.04
2013	mean	2.18	2.42	1.61	-0.03	-0.05	0.03
	std.	0.79	1.48	1.35	0.02	0.02	0.02
2014	mean	4.15	7.06	4.85	-0.06	-0.05	0.06
	std.	1.63	1.53	0.91	0.01	0.01	0.01
2015	mean	7.78	8.64	5.75	-0.09	-0.05	0.06
	std.	0.72	0.87	0.37	0.01	0.01	0.01
2016	mean	6.99	8.27	4.79	-0.04	-0.02	0.06
	std.	1.09	1.17	0.71	0.02	0.02	0.01
2011–	mean	5.08	5.31	3.17	-0.04	0.00	0.08
2016	std.	2.27	2.88	2.09	0.04	0.09	0.06

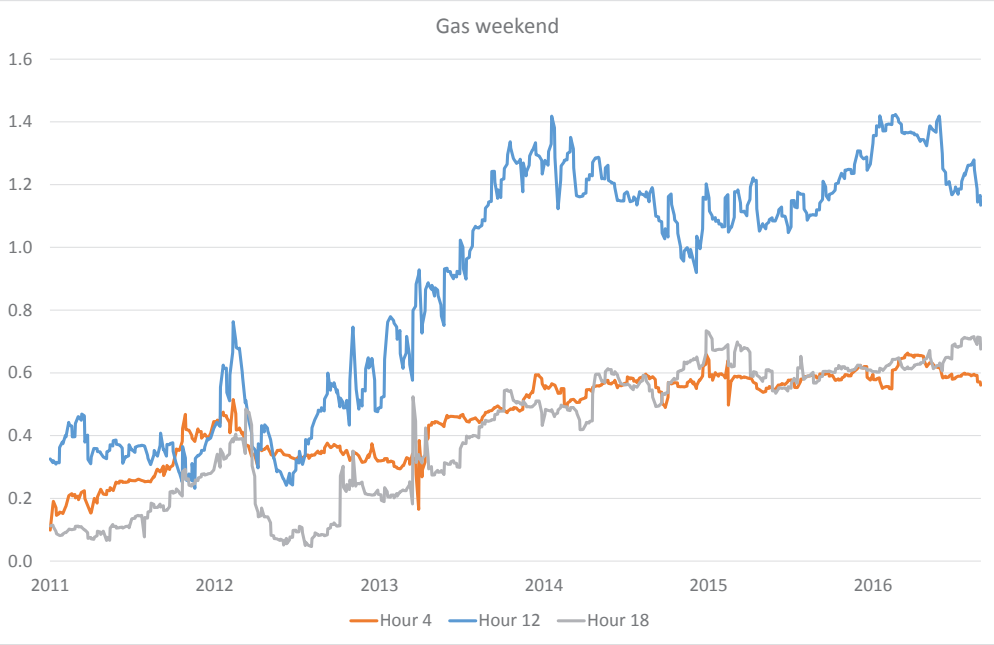
Marginal effects of CO2 prices in EUR/MWh

Interpretation of results: coal and CO2 prices

- We found negative marginal effects of coal prices on Swissix prices: Switzerland imports marginally cheaper coal-based electricity from Germany.
- There are larger marginal effects (in absolute value) of coal prices on Swissix prices for hour 4: in the night coal is the price-setting technology.
- Price adaption to coal:
  - Adaption of electricity prices to fuel prices; change in the production mix over time.
  - *Substitution in production with wind* (especially in the night, when the demand curve meets the supply curve in the concave region of the merit order): when there is high expectation of wind infeed in the system, less coal-based traditional capacity is planned day-ahead.
  - *Substitution in production with gas* (when the intersection point of demand/supply curves occurs in the flat region of the merit order).
- We found increasing marginal effects of CO2 prices during working days: increasing CO2 prices give incentives to power producers to switch to gas, which is a greener, but more expensive technology. Due to this substitution, CO2 prices indirectly marginally increase Swissix prices.

Time-varying coefficients to gas working days/weekend





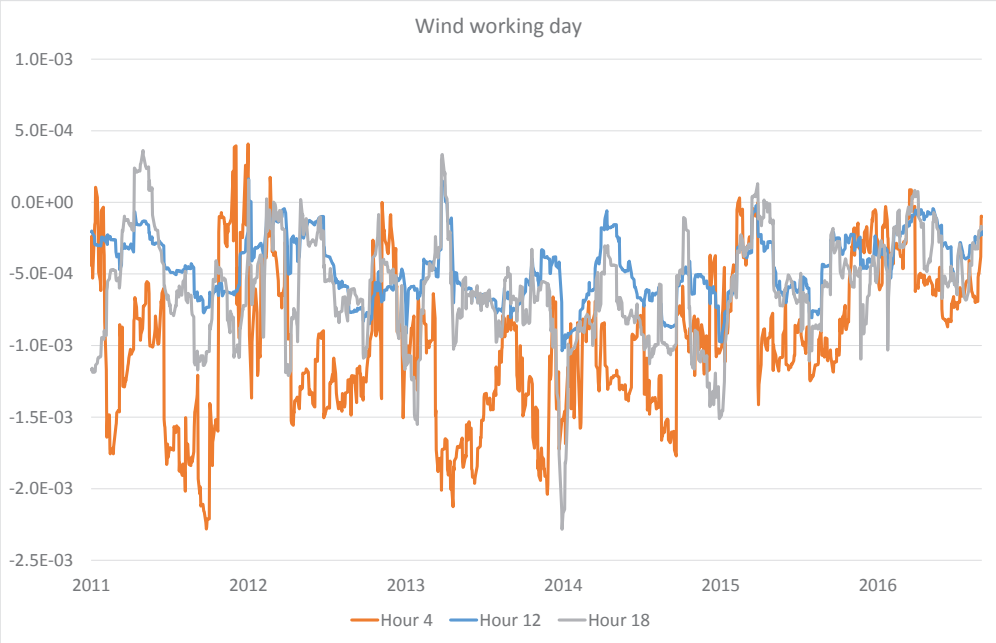
EUR/MWh		Working day			Weekend		
		H4	H12	H18	H4	H12	H18
2011	mean	28.21	23.82	19.78	6.17	8.11	3.48
	std.	4.69	10.10	6.84	2.03	1.12	1.61
2012	mean	15.46	33.34	39.98	9.08	11.88	4.95
	std.	3.62	23.24	22.24	1.20	3.70	3.07
2013	mean	18.52	15.47	16.90	11.64	26.71	10.11
	std.	8.25	18.68	9.98	2.24	6.19	3.01
2014	mean	20.71	7.89	15.24	11.76	24.63	11.55
	std.	2.81	6.99	7.68	1.59	4.51	1.85
2015	mean	21.93	11.07	20.89	11.69	23.05	12.38
	std.	2.87	8.81	4.96	1.05	1.78	1.62
2016	mean	14.27	3.97	14.51	8.00	17.38	8.56
	std.	1.85	8.23	5.65	0.62	1.69	0.89
2011–	mean	20.19	16.60	21.60	9.83	18.72	8.50
2016	std.	6.46	17.32	14.41	2.69	7.93	4.03

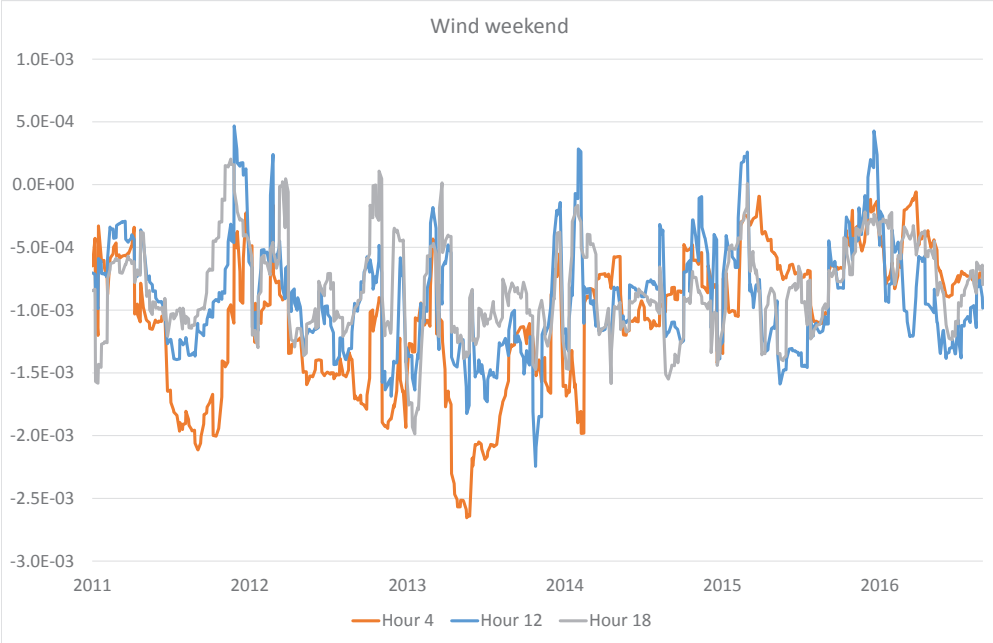
Marginal effects of gas in EUR/MWh

Interpretation of results: gas

- We found positive marginal effects of gas prices on Swissix prices: Switzerland imports marginally more expensive gas-based electricity from Germany.
- Price adaption to gas: it becomes more obvious for the peak hours (12 and 18), when gas is the price setting technology.
- Marginal effects of gas prices on Swissix are particularly high around February 2012, which is reflected in the Swissix price spikes around this time of the year: temperatures dropped significantly and gas power plants have been turned on to supplement the residual demand.
- Adaption of electricity prices to gas prices has several sources: substitution gas/coal (flat region of the merit order), substitution wind/PV: high infeed of renewables shift the merit order to the right; substitution gas/oil (convex region); change in the production mix over time: gas power plants have been gradually shut down in Germany.
- The marginal effects of gas prices on Swissix increase between mid-2012 and 2014 in the weekend. This marginal increasing pressure on electricity prices is supplemented by the large decreasing marginal effects from PV during the same period of time (evidence for the substitution gas/PV in production).

Time-varying coefficients to wind working days/weekend

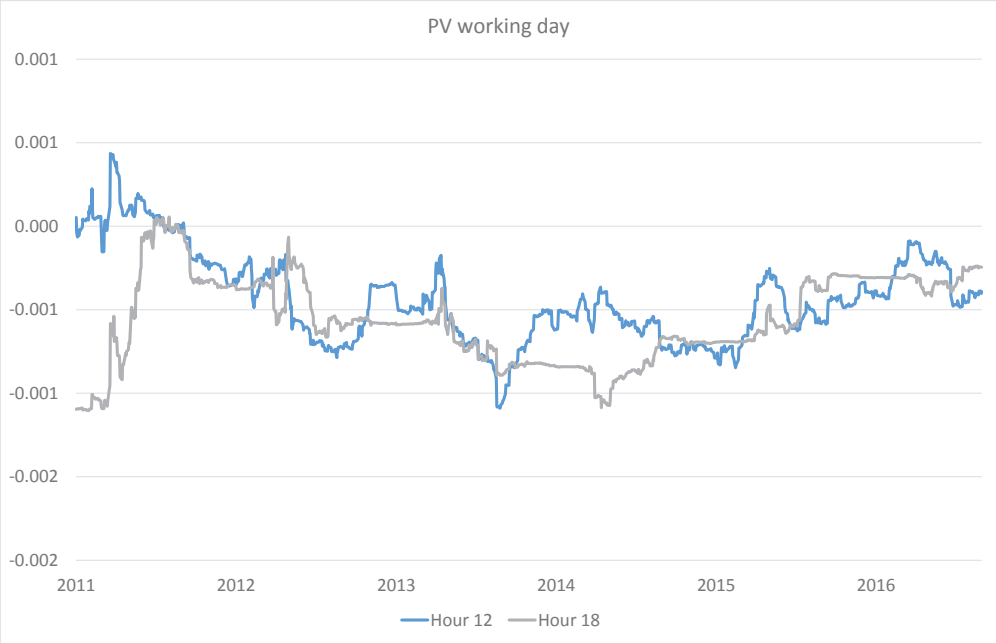


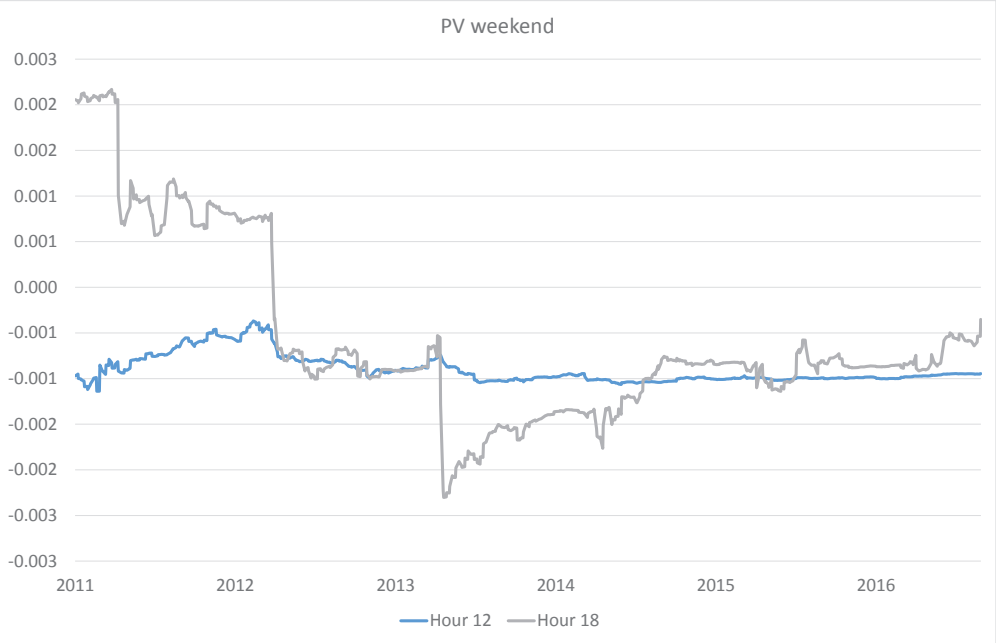


EUR/MWh		Working day			Weekend		
		H4	H12	H18	H4	H12	H18
2011	mean	-4.95	-2.24	-3.43	-5.28	-3.08	-3.90
	std.	5.16	2.49	4.19	4.49	4.28	4.38
2012	mean	-4.42	-2.02	-2.77	-6.51	-5.11	-4.56
	std.	4.27	2.11	3.17	5.08	5.32	5.18
2013	mean	-7.35	-2.87	-4.22	-7.63	-6.69	-6.15
	std.	6.51	3.11	5.85	5.18	6.95	5.43
2014	mean	-6.41	-3.58	-5.65	-6.57	-4.83	-5.92
	std.	5.56	3.94	6.58	7.41	5.63	5.76
2015	mean	-5.73	-3.98	-4.76	-5.01	-4.85	-6.03
	std.	5.54	4.17	5.39	5.04	5.76	5.51
2016	mean	-4.00	-2.28	-2.83	-5.28	-7.06	-5.46
	std.	2.96	2.96	3.51	4.36	5.13	3.86
2011–	mean	-5.56	-2.86	-4.01	-6.10	-5.17	-5.33
2016	std.	5.33	3.31	5.11	5.47	5.72	5.18

Marginal effects of wind in EUR/MWh

Time-varying coefficients to PV working days/weekend





EUR/MWh		Working day			Weekend		
		H4	H12	H18	H4	H12	H18
2011	mean	–	0.11	-0.65	–	-4.41	2.04
	std.	–	1.09	0.99	–	2.31	1.77
2012	mean	–	-5.06	-1.70	–	-7.21	-2.69
	std.	–	3.62	1.77	–	4.20	3.06
2013	mean	–	-6.98	-2.94	–	-9.29	-6.82
	std.	–	4.99	3.08	–	5.73	7.57
2014	mean	–	-6.57	-3.59	–	-11.73	-4.96
	std.	–	3.35	3.59	–	5.83	5.17
2015	mean	–	-5.97	-2.26	–	-12.09	-4.07
	std.	–	3.28	2.44	–	6.26	4.16
2016	mean	–	-3.95	-1.88	–	-12.69	-3.87
	std.	–	2.76	1.46	–	6.00	2.98
2011–	mean	–	-4.78	-2.19	–	-9.39	-3.38
2016	std.	–	4.20	2.62	–	5.96	5.38

Marginal effects of PV in EUR/MWh

Goodness of fit (1)

Hourly blocks	Morning 7–10	Noon 11–14	Afternoon 15–18	Evening 19–24	Night 1–6
R^2	0.491	0.644	0.766	0.785	0.741
adjusted R^2	0.467	0.627	0.754	0.774	0.728
MAE (EUR/MWh)	4.224	4.089	4.163	3.865	3.999
DW	2.354	2.349	2.330	2.238	1.946
LLF	-4086.534	-4050.761	-4051.969	-3931.799	-4060.185

Goodness of fit, for morning, noon and afternoon hourly blocks **working days**

Hourly blocks	Morning 7–10	Noon 11–14	Afternoon 15–18	Evening 19–24	Night 1–6
R^2	0.736	0.806	0.813	0.822	0.714
adjusted R^2	0.710	0.787	0.794	0.804	0.685
MAE (EUR/MWh)	5.457	5.288	5.321	4.067	4.877
DW	2.178	1.948	1.932	2.100	2.119
LLF	-2124.511	-2112.721	-2110.272	-1949.686	-2062.411

Goodness of fit, for morning, noon and afternoon hourly blocks **weekend**

Goodness of fit (2)

Hourly blocks	Morning 7–10	Noon 11–14	Afternoon 15–18	Evening 19–24	Night 1–6
R^2	0.469	0.625	0.763	0.764	0.657
adjusted R^2	0.445	0.608	0.752	0.753	0.641
MAE (EUR/MWh)	4.646	4.346	4.392	4.260	4.676
DW	2.296	2.246	2.227	2.190	1.839
LLF	-4223.906	-4154.082	-4154.176	-4106.158	-4285.626

Goodness of fit, for morning, noon and afternoon hourly blocks **working days**,

excluding renewable energies wind and PV.

Hourly blocks	Morning 7–10	Noon 11–14	Afternoon 15–18	Evening 19–24	Night 1–6
R^2	0.677	0.747	0.756	0.785	0.627
adjusted R^2	0.645	0.722	0.733	0.764	0.590
MAE (EUR/MWh)	6.300	6.239	6.139	4.527	5.639
DW	1.957	1.912	1.851	2.048	2.110
LLF	-2231.725	-2220.441	-2227.014	-2027.281	-2152.368

Goodness of fit, for morning, noon and afternoon hourly blocks **weekend**,

excluding renewable energies wind and PV.

Agenda

1. Motivation
2. Cross-border effects of the German electricity market fundamentals on the Swiss electricity prices (selected results)
3. **Conclusion**

Overall conclusion (1)

- German market fundamentals impact Swiss electricity prices differently, depending on: the steepness of the supply curve and on the demand profile which differ between hours of one day and between working/weekend days
- Autoregressive terms:
  - The coefficients of 1-day lagged prices for peak hours are negative most of the time, reflecting the **mean reversion** behavior of electricity prices
  - The positive sign of coefficients in winter for hour 18 reflects a clustering effect of extreme upwards spikes in Swissix prices
  - The coefficients of 7-day lagged prices (same working day, same hour previous week) are positive which reflects the use of market power

Overall conclusion (2)

- The price adaption to fuel prices and renewable energies occurs in the following situations:
  - Electricity prices adjust to changes in fuel prices
  - Substitution effect depending on the region where demand and supply curves intersect
    - Coal/gas: In the flat region of the German supply curve coal and gas interchange in production; this leads to a competitive relationship of power Swissix prices to gas and coal prices
    - Gas/renewables: High (low) wind/PV production moves the supply function to the right (left) and the higher cost gas facilities are pushed out of (into) action.
    - Gas/oil: In the convex region of the supply curve gas interchanges with oil
  - An additional source of electricity price adaption to fundamentals: shift in the production mix in Germany over time
- German market fundamentals explain between 49% (morning hours) and 79% (evening hours) of the variation in Swissix prices