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The impact of renewable energies on EEX day-ahead electricity prices

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Agenda

Research question: Did the promotion of renewable energies in Germany lead to lower electricity prices as sustainable energies (wind, photovoltaic etc.) have low or zero marginal costs?

In this talk:

- Overview of energy policy regulations with respect to use of renewable energies
- Fundamental variables that drive electricity prices on the day-ahead market
- Load profiles differ for different times of the day, thus the model is estimated individually for each hour
- Estimation approach
- Results and interpretation

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Promotion of renewable energies in Germany

- Renewable Energy Act (EEG, 2000):
  - Producers of renewable energies (wind, PV etc.) receive a guaranteed compensation (technology dependent feed-in tariffs)
  - Priority is granted to renewable energies
  - The additional costs of renewable energy sources are apportioned to energy suppliers, which pass it ultimately to end consumers through the EEG surcharge
- In the first phase of the implementation (2000 – 2009), a significant increase in electricity production from renewable energy sources could be observed
- Especially the high volume of PV installations made feed-in tariffs unbearable; as a consequence they were reduced
- Simultaneously, the EEG surcharge increased due to the increasing production from renewable energy sources:
  - Its calculation is based on the difference between feed-in tariffs and market prices which dropped significantly due to the merit order effect
  - End consumers finance the extension of renewable energies

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Promotion of renewable energies in Germany

- In a second phase (2009 – 2011), it became clear that the transmission grid is not capable to handle the growing supply of fluctuating renewable energies:
  - Most wind capacities are installed in the north of Germany, energy consumption is concentrated in the south
  - In regions with high supply of renewables, modern and efficient power plants are shut down to avoid a potential grid breakdown while in regions where the grid is not fully developed, inefficient (oil-fired) plants must run to stabilize the grid
- In case of excess supply of electricity, prices can fall down to zero or even below:
  - Renewable energies are fed in with priority
  - A large conventional (nuclear or coal-fired) plant is less flexible and cannot be shut down or ramped up immediately and only at high costs; therefore operators are willing to accept a negative price
- Since demand and supply have to match and storage capacities are limited, large price fluctuations and extreme spikes may occur

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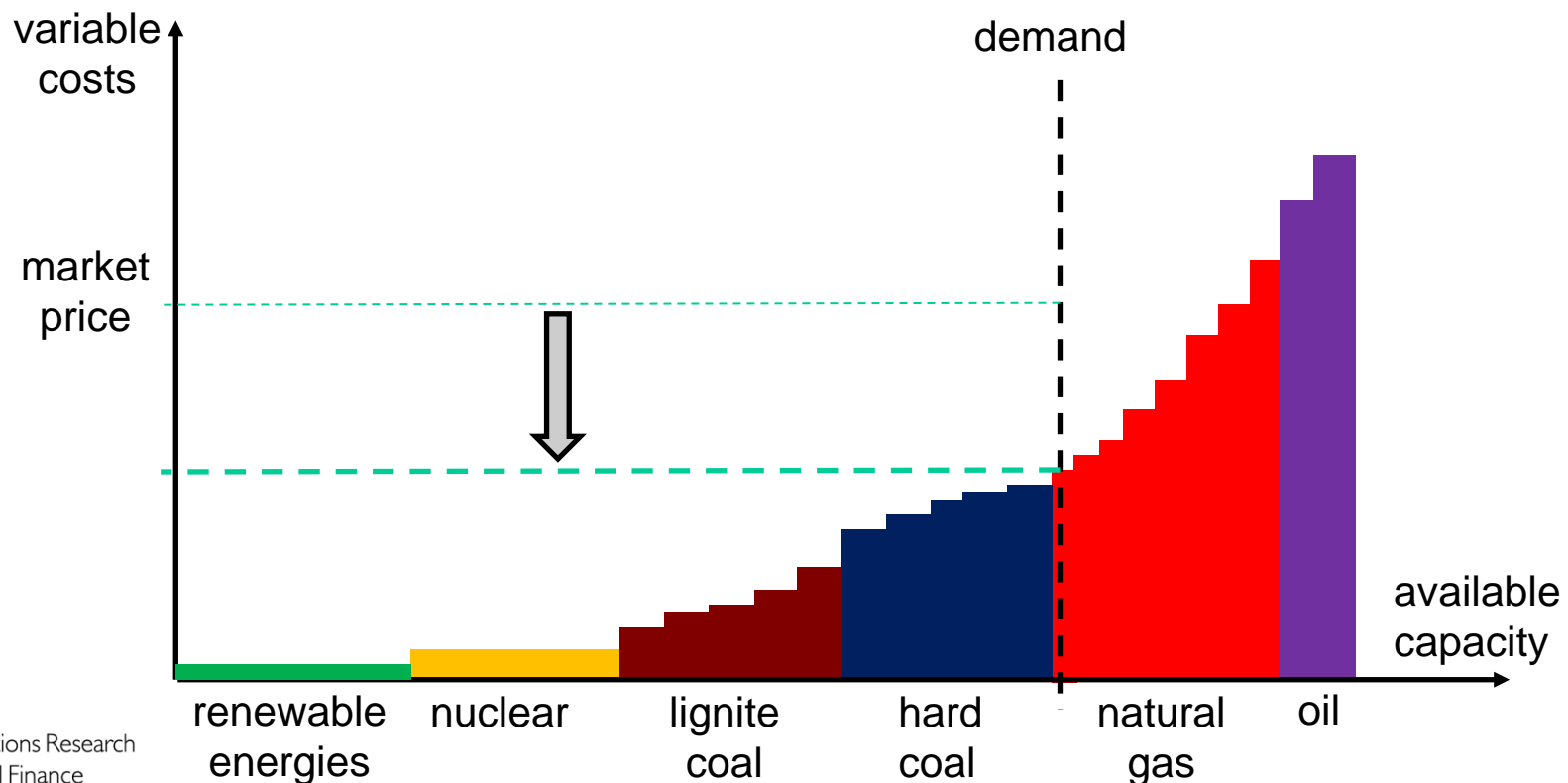
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Merit order curve

- Available sources of energy are ranked in ascending order of their marginal costs of production

- Plants with the lowest marginal cost are the first to be brought online, those with the highest marginal costs are the last

- The plant with the highest marginal costs that is required to meet the demand determines the market clearing price

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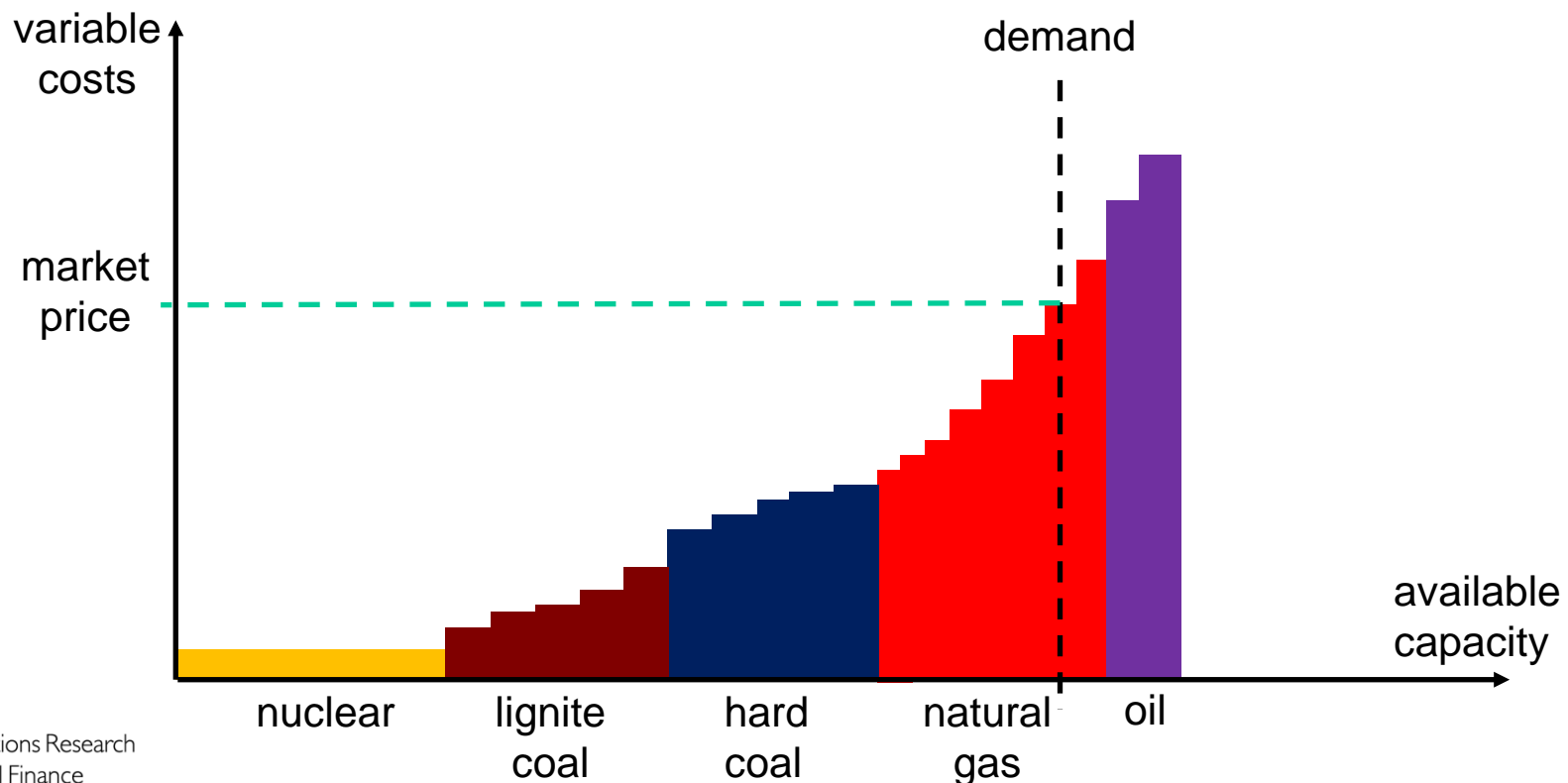
Merit order effect

- Renewable energies have lower marginal costs than traditional sources (wind: 4 €/MWh, nuclear: 10 €/MWh, lignite: 15 €/MWh, gas: 40 €/MWh)

- In times of high feed-in from renewable energies, they replace conventional plants, which should lead then to lower prices on the day-ahead market (grid operators are obliged to market electricity from renewable sources)

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Electricity production in Germany by source [%]

- There was a significant increase in the use of renewable energies during the investigated period

- This caused large changes in the supply mix

	2009	2010	2011	2012	2013
Coal	42.6	41.5	42.8	44.0	45.2
Nuclear	22.6	22.2	17.6	15.8	15.4
Natural Gas	13.6	14.1	14.0	12.1	10.5
Oil	1.7	1.4	1.2	1.2	1.0
Renewable energies from which	15.9	16.6	20.2	22.8	23.9
Wind	6.5	6.0	8.0	8.1	8.4
Hydro power	3.2	3.3	2.9	3.5	3.2
Biomass	4.4	4.7	5.3	6.3	6.7
Photovoltaic	1.1	1.8	3.2	4.2	4.7
Waste-to-energy	0.7	0.7	0.8	0.8	0.8
Other	3.6	4.2	4.2	4.1	4.0

- We have to restrict the following analysis to the time after 2010 due the availability of certain data (e.g., PV infeed)

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Fundamental variables driving electricity prices

- <u>Demand</u> for electricity could be estimated from the vertical net load (VNL) published by all four transmission system operators (TSOs)
- The VNL represents the sum of all power which is transferred from the high voltage transmission grid to the next lower level, i.e., the distribution grid
- Electricity from renewable sources is not fed into the high voltage transmission grid but directly into the medium voltage transmission grid; therefore the VNL does not include wind and PV energy
- The total demand should be calculated as

$$\text{Demand}_t = \text{VNL}_t + \text{Total Wind Infeed}_t + \text{Total PV Infeed}_t$$

- Since day-ahead prices are modeled, we have to take into account expected (rather than realized) demand
- The latter is obtained from an individual model (ARMAX/GARCH):
  - Seasonal effects modeled by dummy variables, weather information
  - Each hour of the day modeled separately

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Fundamental variables driving electricity prices

- <u>Supply</u>: As fundamental variables we take into account
    - prices for coal, gas, oil, CO2 emission allowances,
    - expected infeed from renewable energies (wind, PV),
    - expected power plant availability
- Learning effects:
    - Price of corresponding hour on previous day
    - Average price of all hours on previous day
- Price volatility: Standard deviation of hourly prices of last 5 days
- List of all variables and data granularity:

Variable	Daily	Hourly
Lagged Spot Price		×
Average Lag Spot Price	×	
Spot Price Volatility		×
Coal Price	×	
Gas Price	×	
Oil Price	×	
Price for EU Emission Allowances	×	
Expected Wind and PV Infeed		×
Expected Power Plant Availability	×	
Expected Demand		×
Lag Demand		×

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Estimation

- There has been a shift in the merit order curve due to the increasing infeed from renewable sources

- We expect that the traditional fuels have a decreasing impact on electricity prices while the importance of renewables goes up

- To assess the change in the sensitivities of prices to the various fundamentals, we choose a model with time-varying coefficients for the electricity price $y_{i,t}$ at each hour of the day $i = 1, \ldots, 24$:

$$y_{i,t} = z'_{i,t} \cdot \gamma_{i,t} + \varepsilon_{i,t} \qquad \boxed{\textit{measurement equation}}$$

$$\gamma_{i,t} = \gamma_{i,t-1} + \eta_{i,t} \qquad \boxed{\textit{transition equation}}$$
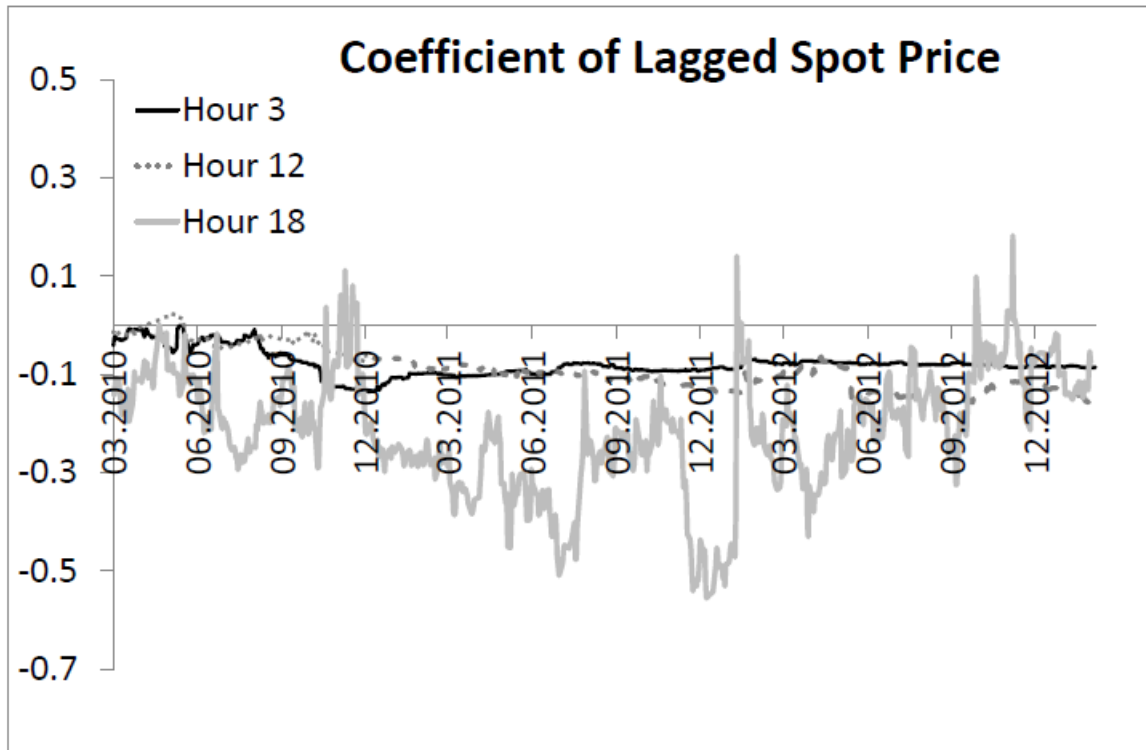
$$\gamma_{i,t} := (\gamma_{i,1,t}, \gamma_{i,2,t}, \ldots, \gamma_{i,k,t})'$$

$$\eta_{i,t} := (\eta_{i,1,t}, \eta_{i,2,t}, \ldots, \eta_{i,k,t})'$$

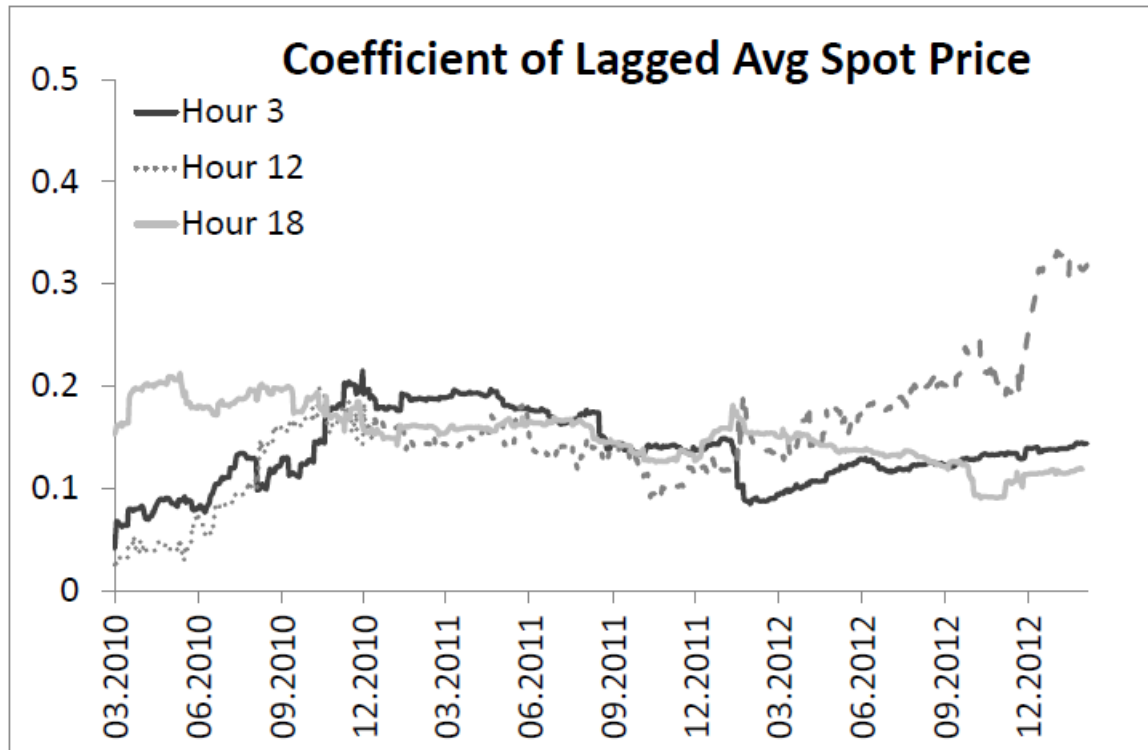$$\varepsilon_{i,t} \sim N(0, \sigma_i), \quad \eta_{i,t} \sim N(0, \Omega_i)$$

- z_i is the vector of the previously described exogenous variables

- The regression coefficients are stochastic variables that follow random walks and are estimated with a <u>Kalman filter</u> approach

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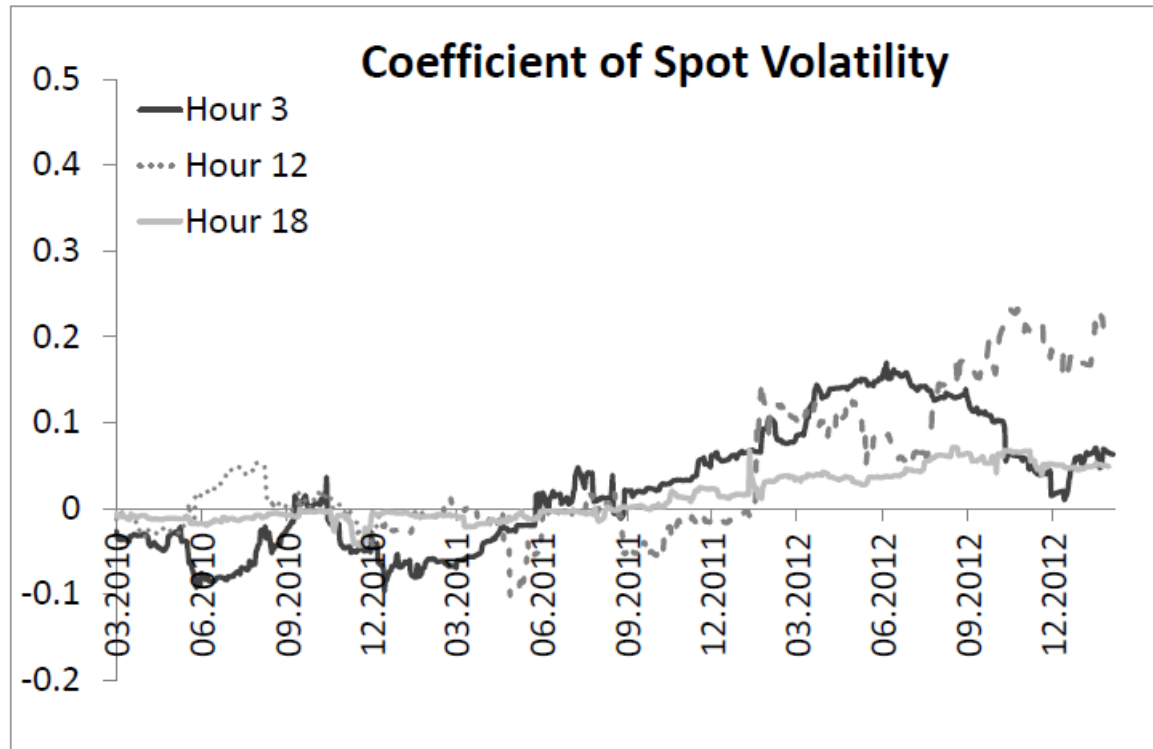University of St.Gallen

Results: Learning (1)

- Results are shown here only for hours 3 (night), 12 (noon) and 18 (evening), as these are representative for different times of the day
- <u>Negative</u> coefficients of lagged spot price for specific hour reverts level of electricity price for that hour on the next day

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Results: Learning (2)
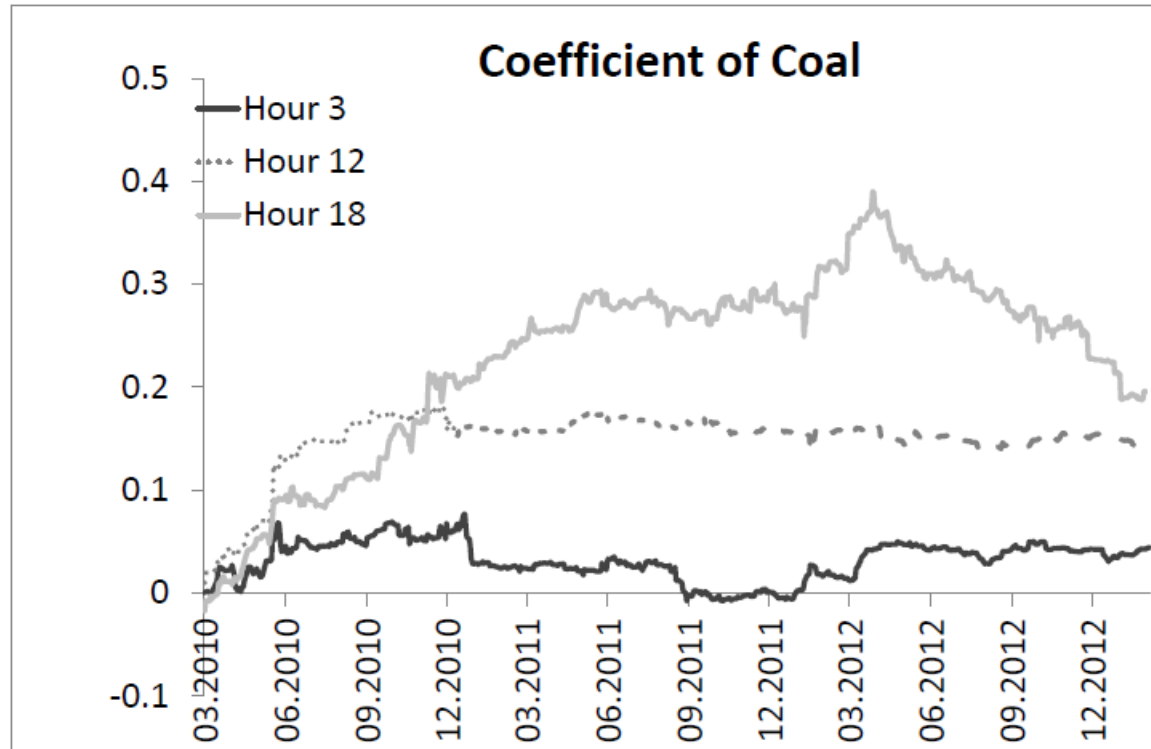

Coefficient of Lagged Avg Spot Price

- Positive coefficients of lagged average spot (signal from last day)
- Consistent with discussion in literature: one would expect a positive elasticity of spot prices to lagged prices:
  - Market agents tend to reinforce previously successful offers in the market which preserves price level
  - Signaling between agents keeps prices moving in the same direction

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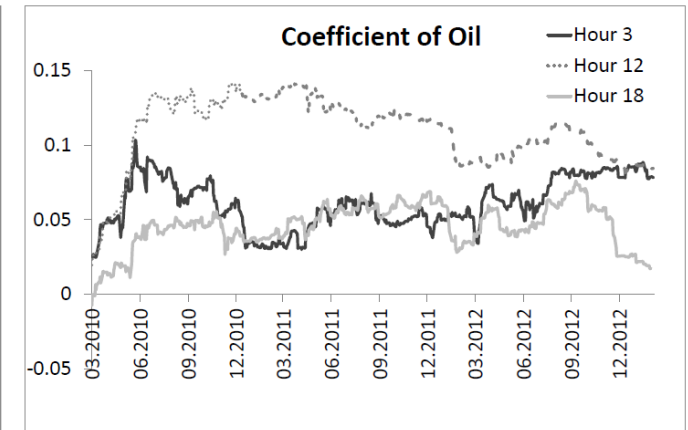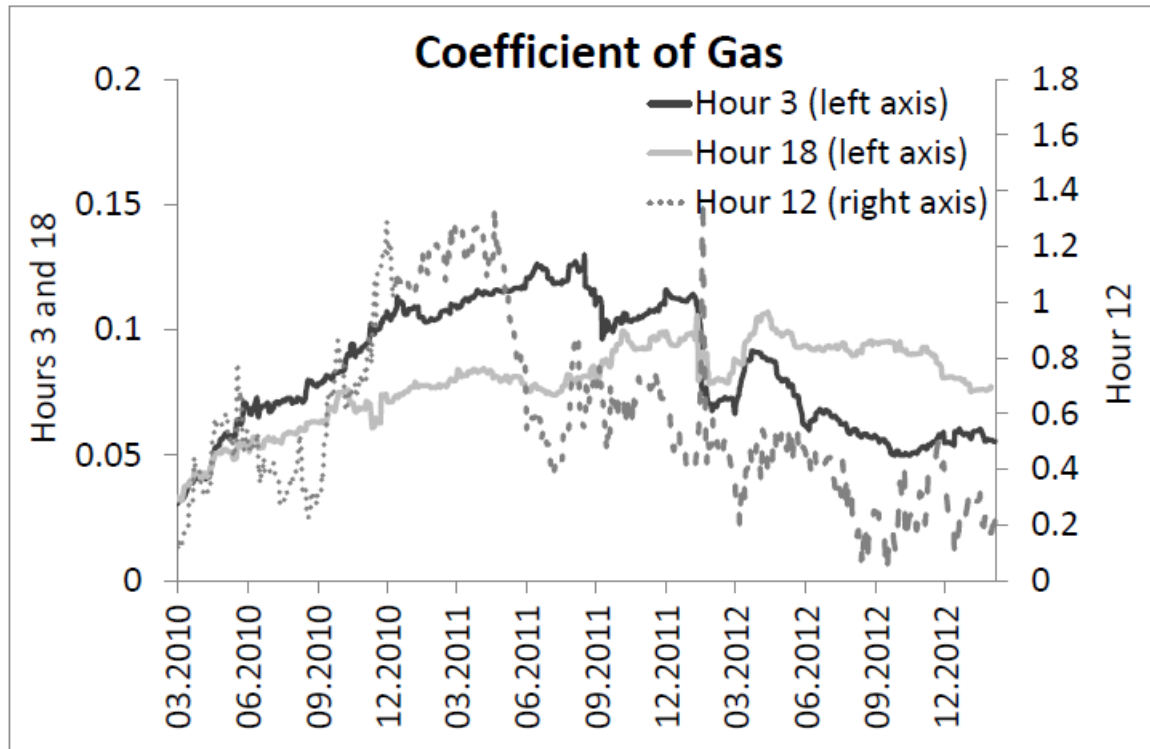prices - Page 13

Results: Volatility

- Coefficient changed from negative to positive after 2012
- Increase may be associated with higher infeed of volatile renewable energies
- Impact of volatility on prices can be interpreted as compensation for risk
- Hedging of price risk via spot market became more expensive

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Responses to fuel prices: Coal

Coefficient of Coal
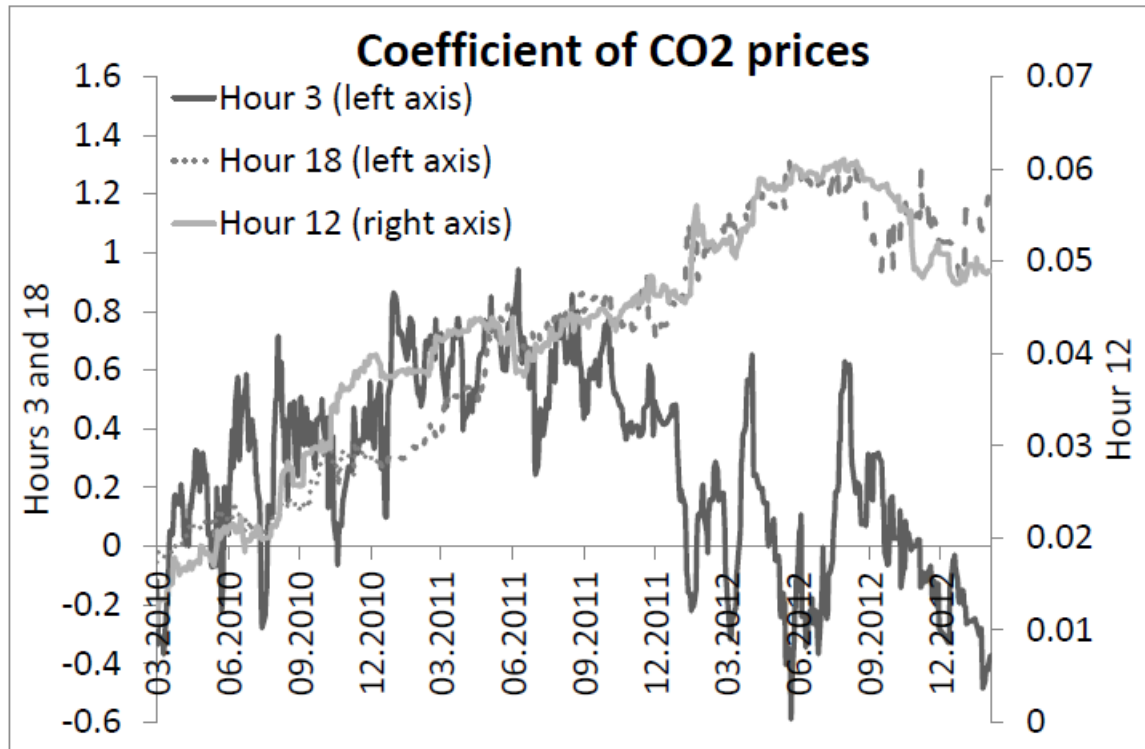
Legend: Hour 3, Hour 12, Hour 18

- It strongly depends on the hourly load profile when production capacities based on coal, gas and oil are in use

- More distinct marginal effects for hours with high demand, in particular hour 18 (production mainly coal based)

- Coal is still most relevant fuel for electricity production in Germany, therefore we observe less price adaption w.r.t. coal than for gas

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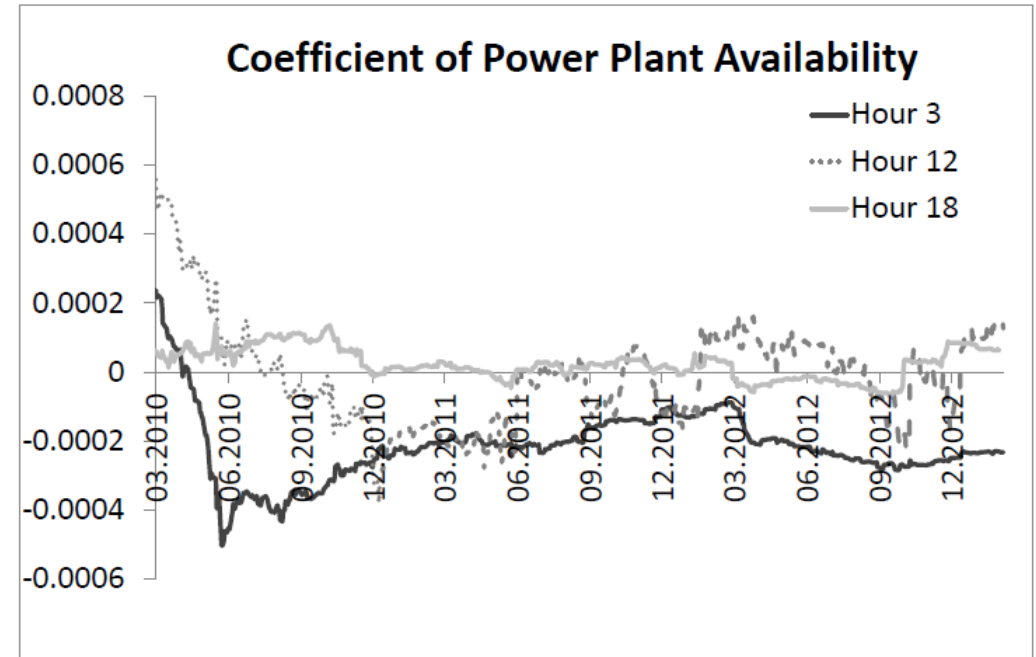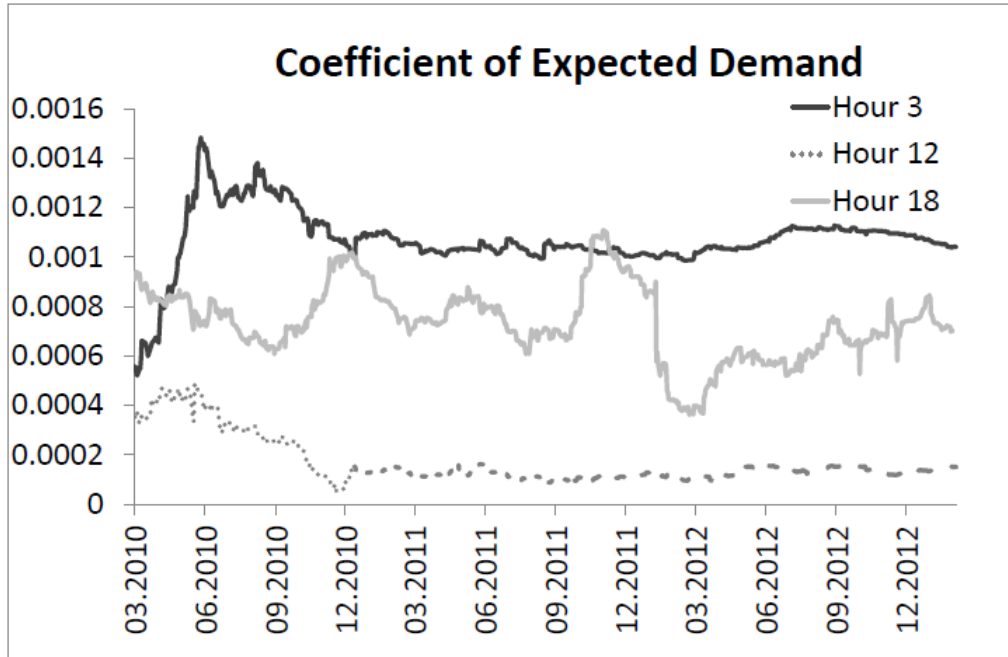
Responses to fuel prices: Gas and oil

- Gas and oil fired plants run in hours of high demand
- We observe higher marginal effects for hour 12 (gas: see right axis)
- Continuous price adaption process, coefficients quite variable
- Since 2011 decrease in coefficients for gas particularly for hour 12 due to growth in PV infeed (highest around noon)

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Response to CO2 prices

Coefficient of CO2 prices
— Hour 3 (left axis)
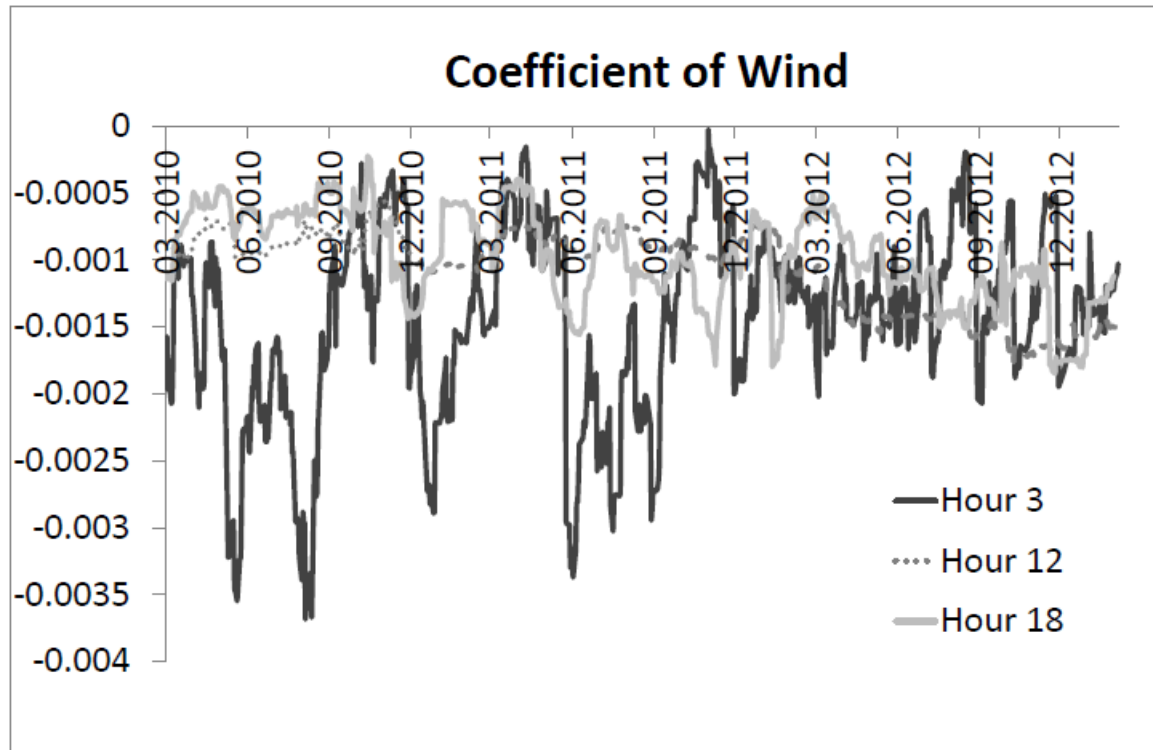···· Hour 18 (left axis)
— Hour 12 (right axis)

- Continuous price adaption process to prices of emission allowances

- Marginal effect is clearly higher for evening and night hours when production is mainly coal based (see left axis)

- Adaption of electricity prices to CO2 prices can be explained by the fact that coal fired plants pollute more than gas and oil fired ones

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Response to demand and supply

Coefficient of Expected Demand
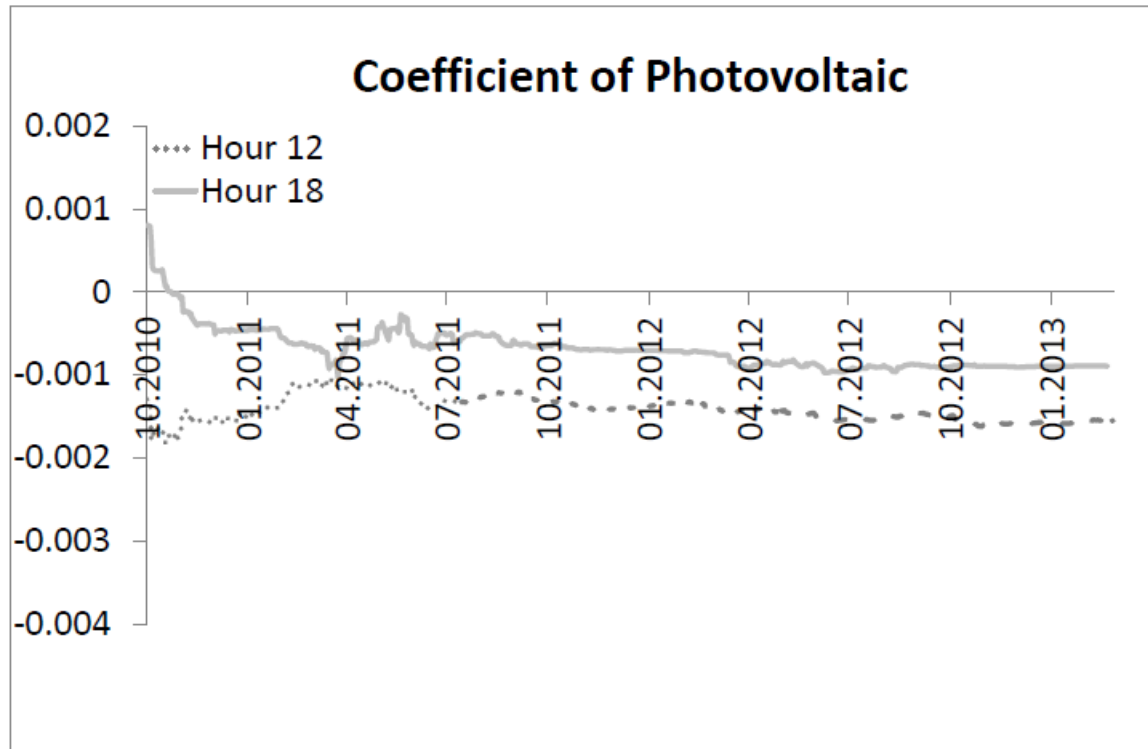
Coefficient of Power Plant Availability

- Apparently no substantial price adaption to demand and supply (i.e., power plant availability, PPA)
- Model is estimated individually for each hour of the day
- Load is (in the short run) inelastic
- Demand and PPA are easily predictable

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Response to renewable energies: Wind

- Negative coefficients imply that wind infeed decreases prices
- Variable price adaption process, particularly at night hours
- During the night, an excess of produced electricity meets a low demand
- Then, even negative prices may occur which are caused to a large extent by wind infeed

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Response to renewable energies: PV

- Again, the negative sign implies that PV infeed decreases prices
- The coefficients fluctuate less since PV infeed in a certain hour is more constant than wind
- The impact on the price reduction is higher at noon since the sunshine is most intense then while demand is large

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Conclusions and outlook

- Sensitivities of day-ahead electricity prices to the fundamental variables coal, gas, oil and renewable energies vary over time
- The increasing infeed of renewable energies (wind, PV) led to a decrease in prices on the day-ahead market in Germany, due to the merit order effect
- There is a continuous adaption process of electricity prices to market fundamentals
- Our results show the importance of linking electricity spot prices to market fundamentals; a purely stochastic model can be too simple
- The promotion of renewable energies simulated their fast development
- Excess supply from renewable energies in the north of Germany must be efficiently distributed to regions with excess demand; this requires an extension of the transportation grid
- Production, transportation and storage cannot be treated separately and must be considered together in future promotion schemes

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