Assessing the impact of renewable energy sources on the electricity price level and variability - a Quantile Regression approach

K. Maciejowska
Wroclaw University of Science and Technology,
Poland

EFC 2018

Electricity markets

Stylized facts

- the supply MUST meet the demand at every hour on every day
- limited storage possibilities
- changes of the production structure: from centrally planed generators into variable renewable units

Increase of RES share in generation mix

The direct effect of the rise of the RES share:

- the fall of marginal costs
- the uncertainty of generation
- difficulties of balancing the market

Increase of RES share in generation mix

The direct effect of the rise of the RES share:

- the fall of marginal costs
- the uncertainty of generation
- difficulties of balancing the market

Do RES impact electricity prices?

Literature

- Merit-order effect: Ketterer (2014), Woo et al. (2011), Nihcolson et al. (2010), Gürtler, Paulsen (2018)
- Effect on variance:
  - Wind increases the volatility: Ketterer (2014), Cló et al. (2015), Rintamäki et al. (2017), Woo et al. (2011)
  - Solar reduces the volatility: Rintamäki et al. (2017), Paraschiv wt al. (2014)
- Different models: ARX-GARCH (Ketterer, 2014), ARX (Woo et al., 2011 and Cló et al., 2015), realized volatility

Literature

- Merit-order effect: Ketterer (2014), Woo et al. (2011), Nihcolson et al. (2010), Gürtler, Paulsen (2018)
- Effect on variance:
  - Wind increases the volatility: Ketterer (2014), Cló et al. (2015), Rintamäki et al. (2017), Woo et al. (2011)
  - Solar reduces the volatility: Rintamäki et al. (2017), Paraschiv wt al. (2014)
- Different models: ARX-GARCH (Ketterer, 2014), ARX (Woo et al., 2011 and Cló et al., 2015), realized volatility
- No formal comparison of strength of the effect for different RES

Questions

- How do RES impact the level and variability of prices?
- Which RES: Solar or Wind have a stronger price-reduction effect?
- Do both RES increase or reduce the price variance?
- Does the effect of RES on the day-ahead prices depend on the level of demand/total load?

Data

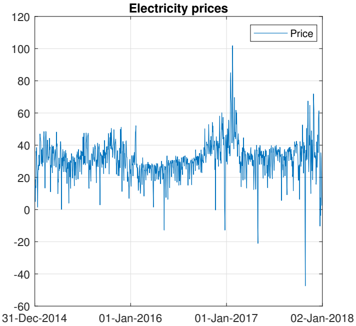
Data

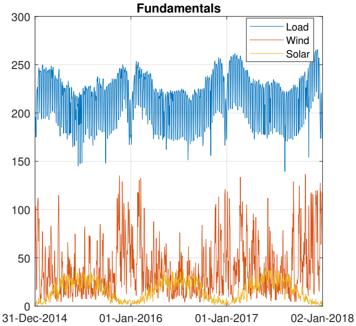
- Germany (EPEX)
- period: 01.01.2015-31.12.2017

The market is described by daily averages of:

- the day-ahead price, P_t
- the forecast of load, L_t
- the forecast of wind generation, W_t
- the forecast of solar generation, S_t

Data


Electricity prices
Price
120
100
80
60
40
20
0
-20
-40
-60
31-Dec-2014
01-Jan-2016
01-Jan-2017
02-Jan-2018


Fundamentals
Load
Wind
Solar
300
250
200
150
100
50
0
31-Dec-2014
01-Jan-2016
01-Jan-2017
02-Jan-2018

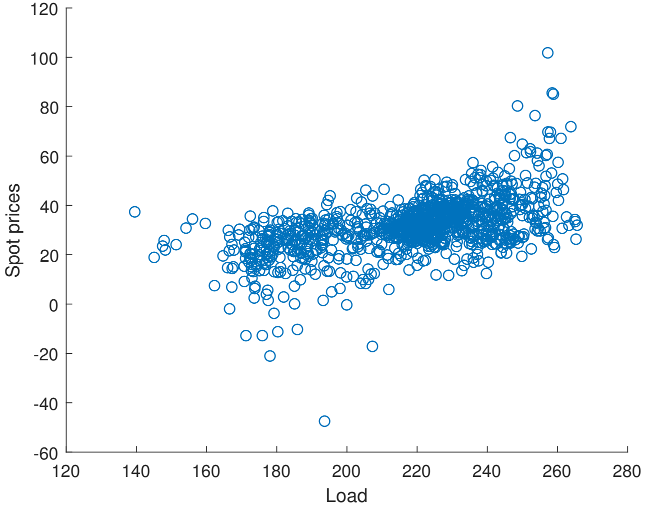
Data statistics

Table: Statistical properties.

	Prices	Load	Wind	Solar
	Normality test (J-B)			
test	1838.8	58.21	258.0	75.68
p-value	< 0.01	< 0.01	< 0.01	< 0.01
	Non-stationarity (ADF)			
test	-6.992	-3.825	-7.723	-3.091
p-value	< 0.01	0.003	< 0.01	0.028

Note: the ADF test is based on a regression with seven lags and allows for a drift under the alternative.

Data


Spot prices
Load
120
100
80
60
40
20
0
-20
-40
-60
120
140
160
180
200
220
240
260
280

Qunatile regression (QR) model - a linear effect

A linear model

$$P_t(\tau) = \alpha_{0,\tau} D_t + \beta_\tau^L L_t + \beta_\tau^S S_t + \beta_\tau^W W_t + \sum_{p=1}^{7} \theta_{p,\tau} P_{t-p}, \qquad (1)$$

where

- $P_t(\tau)$ is a τ conditional quantile of the price P_t
- β_τ^L, β_τ^S and β_τ^W describe the influence of corresponding fundamentals: L_t, S_t and W_t on $P_t(\tau)$
- $\theta_{p,\tau}$ are the autoregressive parameters

QR model - a non-linear effect

A non-linear model (2)

$$P_t(\tau) = \alpha_{0,\tau} D_t + \sum_{i=1}^{3} \beta_{i,\tau}^{L} L_{i,t} + \sum_{i=1}^{3} \beta_{i,\tau}^{S} S_{i,t} + \sum_{i=1}^{3} \beta_{i,\tau}^{W} W_{i,t} + \sum_{p=1}^{7} \theta_{p,\tau} P_{t-p},$$

where

- $L_{i,t} = I_i L_t$, $S_{i,t} = I_i S_t$ and $W_{i,t} = I_i W_t$,
- $I_1 = 1_{L_t < L(0.1)}$, $I_2 = 1_{L(0.1) \leq L_t \leq L(0.9)}$ and $I_3 = 1_{L_t > L(0.9)}$, where $L(\tau)$ describes the τ unconditional quantile of L

Estimation of QR models

The estimator minimized the pinball loss function (Koenker and Bassett, 1978)

$$min_{\psi_\tau \in \Psi} \sum_t \rho_\tau(P_t - X_t\psi_\tau),$$

where

$$\rho_\tau(P_t - X_t\psi_\tau) = \begin{cases} \tau(P_t - X_t\psi_\tau) & \text{when } P_t > X_t\psi_\tau \\ (\tau - 1)(P_t - X_t\psi_\tau) & \text{when } P_t \leq X_t\psi_\tau. \end{cases}$$

The variables

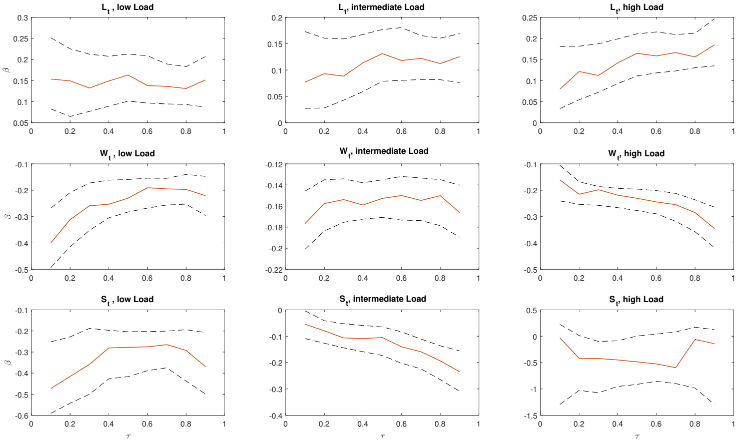
- $X_t = [D_t, L_t, S_t, W_t, P_{t-1}, ..., P_{t-p}]$ for model (1)
- $X_t = [D_t, L_{1,t}, L_{2,t}, L_{3,t}, S_{1,t}, S_{2,t}, S_{3,t}, W_{1,t}, W_{2,t}, W_{3,t}, P_{t-1}, ..., P_{t-p}]$ for model (2).

Describing and testing the merit order effect

Merit order effect hypothesis:

- the influence of RES on prices is negative: $\beta_\tau^S \leq 0$ and $\beta_\tau^W \leq 0$ or $\beta_{i,\tau}^S \leq 0$ and $\beta_{i,\tau}^W \leq 0$,
- an increase of Load (L_t) leads to higher prices: $\beta_\tau^L \geq 0$ or $\beta_{i,\tau}^L \geq 0$
- the level of Load impact the merit-order effect

Estimates of $\beta_{i,\tau}$ for different quantiles and Load levels



The comparison of Wind and Solar effects

Which, Wind or Solar, has a stronger price dampening effect?

- both RES have $\beta^W_{i,\tau} < 0$, $\beta^S_{i,\tau} < 0$

The comparison of Wind and Solar effects

Which, Wind or Solar, has a stronger price dampening effect?

- both RES have $\beta^{W}_{i,\tau} < 0$, $\beta^{S}_{i,\tau} < 0$
- if Wind has a stronger effect than Solar then

$$\beta^{W}_{i,\tau} < \beta^{S}_{i,\tau}$$

$$\beta^{W}_{i,\tau} - \beta^{S}_{i,\tau} < 0$$

The comparison of Wind and Solar effects

Which, Wind or Solar, has a stronger price dampening effect?

- both RES have $\beta^W_{i,\tau} < 0$, $\beta^S_{i,\tau} < 0$
- if Wind has a stronger effect than Solar then

$$\beta^W_{i,\tau} < \beta^S_{i,\tau}$$

$$\beta^W_{i,\tau} - \beta^S_{i,\tau} < 0$$

- We can test $H_0 : \beta^W_{i,\tau} - \beta^S_{i,\tau} = 0$ vs. $H_1 : \beta^W_{i,\tau} - \beta^S_{i,\tau} \neq 0$

The comparison of Wind and Solar effects

Which, Wind or Solar, has a stronger price dampening effect?

- both RES have $\beta^W_{i,\tau} < 0$, $\beta^S_{i,\tau} < 0$
- if Wind has a stronger effect than Solar then

$$\beta^W_{i,\tau} < \beta^S_{i,\tau}$$

$$\beta^W_{i,\tau} - \beta^S_{i,\tau} < 0$$

- We can test $H_0 : \beta^W_{i,\tau} - \beta^S_{i,\tau} = 0$ vs. $H_1 : \beta^W_{i,\tau} - \beta^S_{i,\tau} \neq 0$
- p-values obtained by block bootstrap with block size equal 14, as in Fitzenberger (1998).

The comparison of Wind and Solar effects

τ	$\beta^W_\tau - \beta^S_\tau$	$\beta^W_{1,\tau} - \beta^S_{1,\tau}$	$\beta^W_{2,\tau} - \beta^S_{2,\tau}$	$\beta^W_{3,\tau} - \beta^S_{3,\tau}$
0.1	-0.111***	0.073	-0.122***	-0.132
0.2	-0.059***	0.104	-0.078***	0.204
0.3	-0.045**	0.100	-0.047***	0.225
0.4	-0.027	0.027	-0.050**	0.231
0.5	-0.029	0.048	-0.048	0.255
0.6	0.010	0.085	-0.010	0.281
0.7	0.027	0.070**	0.004	0.342
0.8	0.058**	0.095**	0.043	-0.224
0.9	0.083*	0.149**	0.068	-0.204

Note: the asterisks *, ** and *** indicate rejection of null $H_0 : \beta^W_\tau - \beta^S_\tau = 0$ at the significance levels 10%, 5% and 1%, respectively.

Describing the impact on the variability

The variability is decried by the $IQR_t = P_t(0.9) - P_t(0.1)$

$$IQR_t = \alpha_0 D_t + \sum_{i=1}^{3} \beta_i^L L_{i,t} + \sum_{i=1}^{3} \beta_i^S S_{i,t} + \sum_{i=1}^{3} \beta_i^W W_{i,t} + \sum_{p=1}^{7} \theta_p y_{t-p},$$

where

- $\alpha_0 = \alpha_{0,0.9} - \alpha_{0,0.1}$
- $\beta_i^* = \beta_{i,0.9}^* - \beta_{i,0.1}^*$
- $\theta_p = \theta_{p,0.9} - \theta_{p,0.1}$

Testing the impact on variability

The impact of fundamentals on IQR_t is described by β_i^*

- when $\beta_i^* > 0$ then an increase of the variable leads to a higher uncertainty,
- when $\beta_i^* < 0$ then an increase of the variable leads to a fall of uncertainty,
- p-values obtained with block bootstrap

The impact on the price volatility

Variable	Coeficient	Value
Load	β^L	0.0812
	β_1^L	-0.0021
	β_2^L	0.0483
	β_3^L	0.1053*
Wind	β^W	-0.0061
	β_1^W	0.1794**
	β_2^W	0.0104
	β_3^W	-0.1844***
Solar	β^S	-0.200***
	β_1^S	0.1037
	β_2^S	-0.1805***
	β_3^S	-0.1127

Conclusions

- The merit-order effect is observable for all the fundamental variables
- The impact on the price level depends on the level of the load:
  - for the median, both RES have the same merit order effects
  - the effect of Wind is stronger than that of Solar for low quantiles of prices and the intermediate Load
  - the effect of Wind is weaker than that of Solar for high quantiles and the low Load

Conclusions

The influence on price variability:

- Load increases the *IQR* when Load is high
- Wind rises the variability when Load is low and reduces it when Load is high
- Solar reduces the *IQR* for intermediate Load

Conclusions

- The Quantile Regression approach offers an interesting alternative for estimating the changes of volatility:
  - a semi-parametric approach
  - is simpler to estimate then the ARX-GARCH model
  - is flexible when specifying the form the conditional heteroscedasticity
  - standard errors could be obtained via simulation techniques (bootstrap)