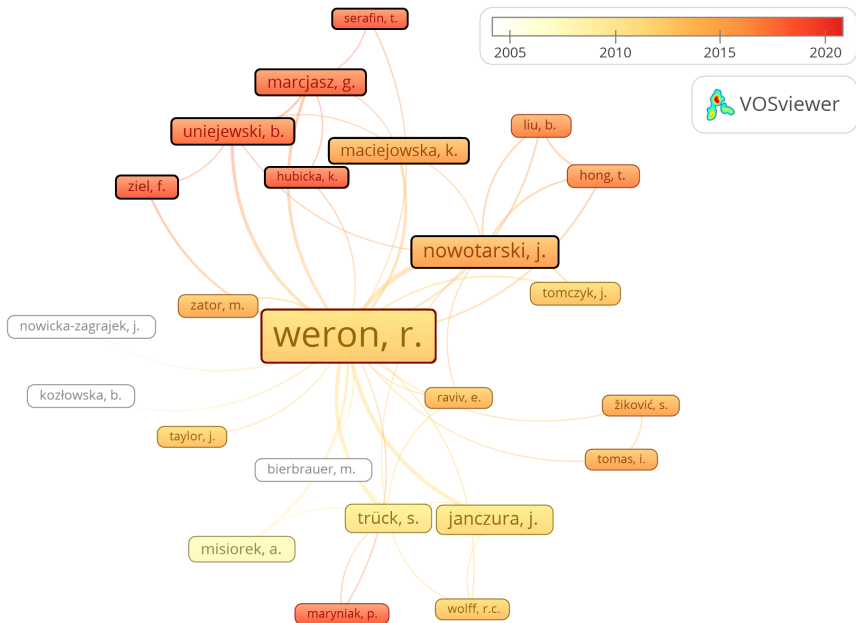


Recent advances in electricity price forecasting: A 2018 perspective

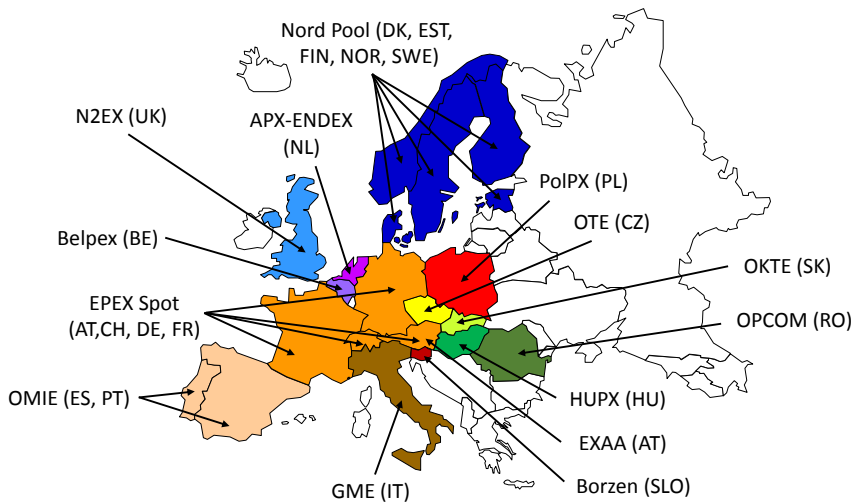


Rafał Weron*

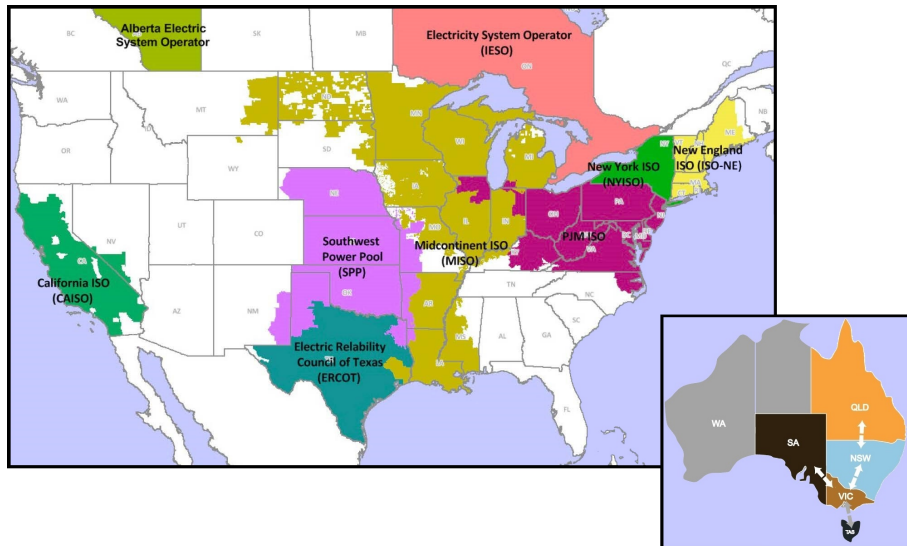
Department of Operations Research
Wrocław University of Science and Technology (PWr), Poland
<http://kbo.pwr.edu.pl/en/staff/rafal-weron/>



Markets for electricity in Europe

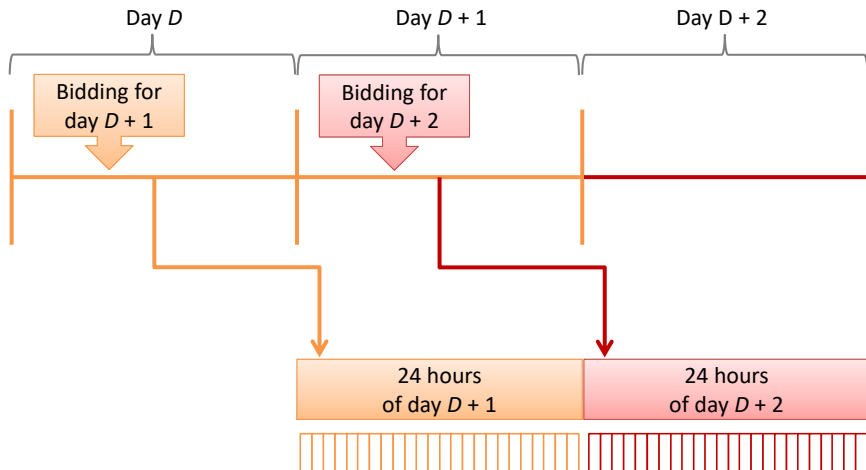


... in North America and Australia

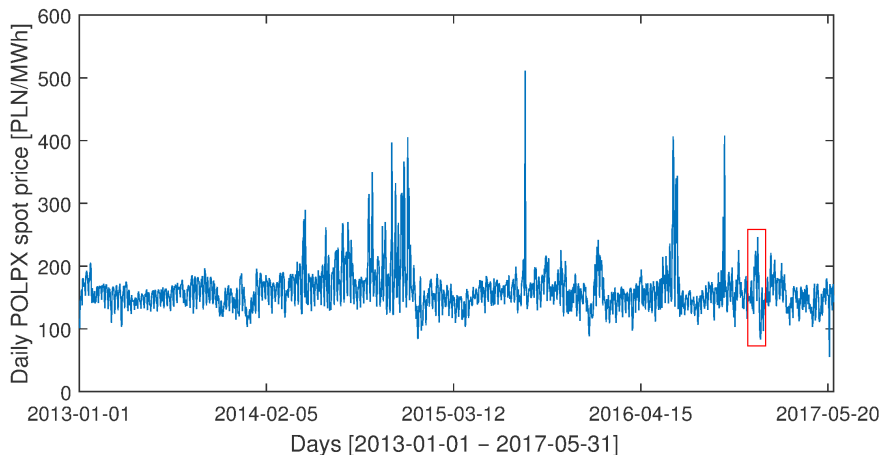


The workhorse of European power trading

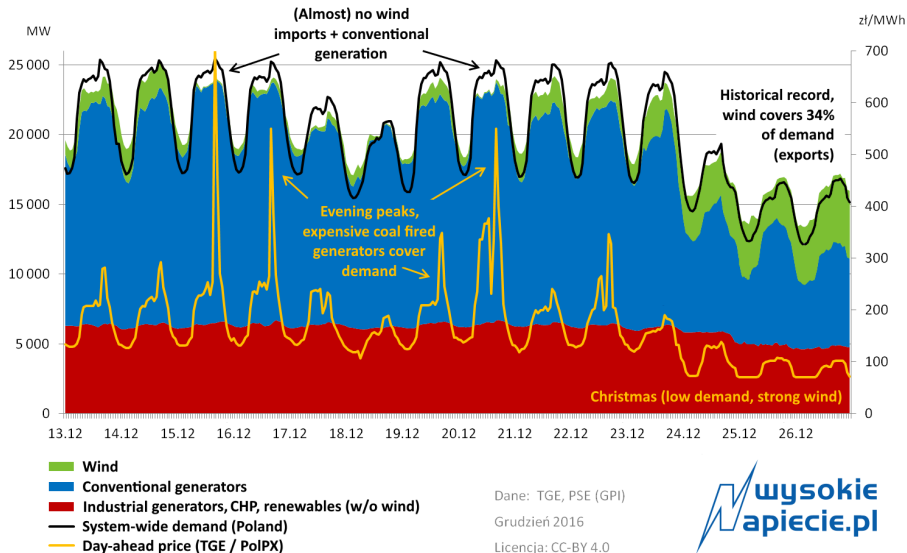
The day-ahead market



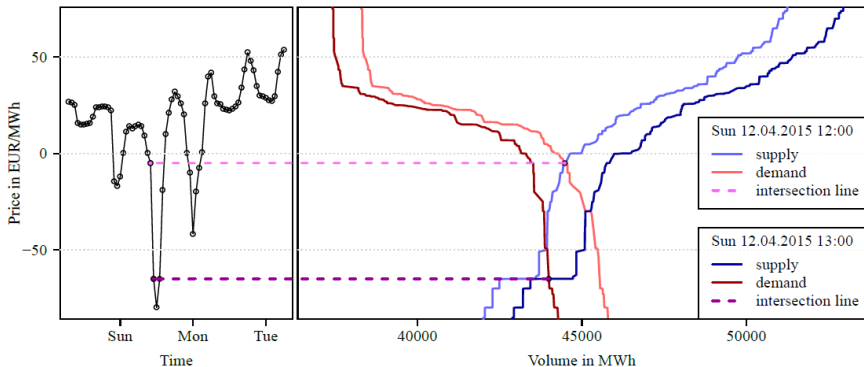
Seasonality, mean-reversion and price spikes



A closeup on two weeks in December 2016

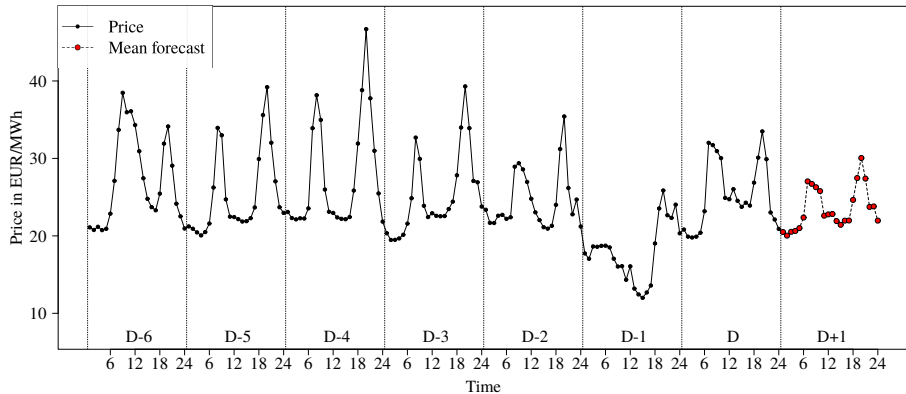


Supply and demand, renewables and negative prices

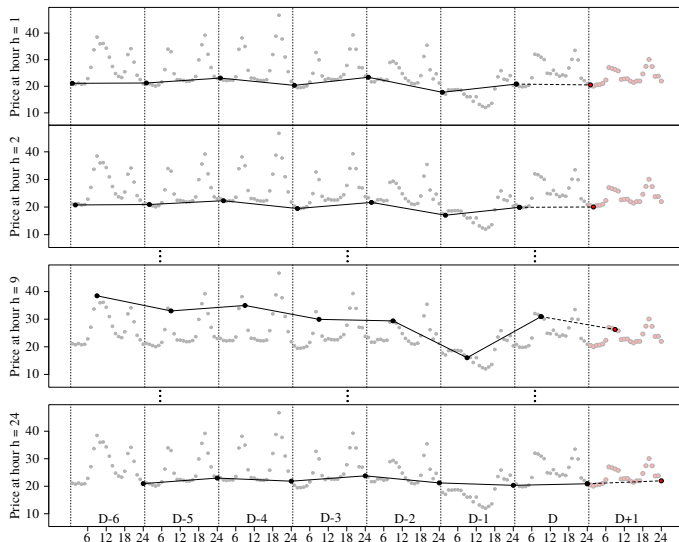


Source: Ziel & Steinert (2016, ENEECO)

Day-ahead point forecasting: Univariate ...



... or multivariate?

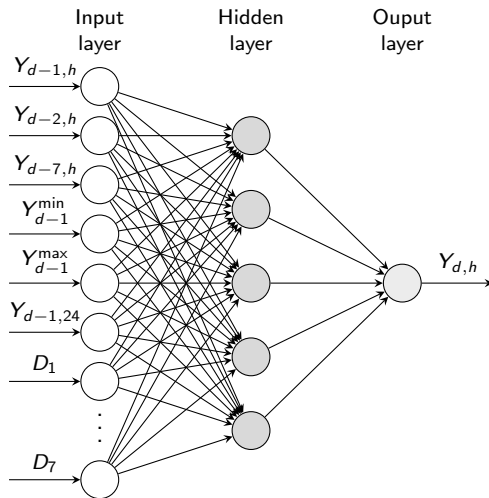


Day-ahead point forecasting: Regression ...

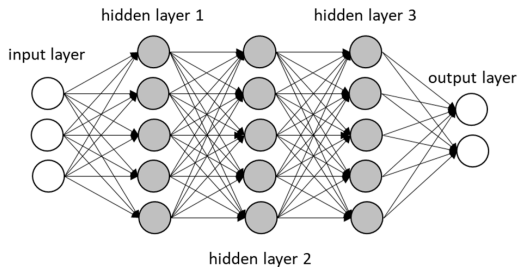
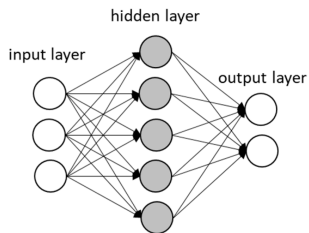
Electricity price for day d and hour h :

$$\begin{aligned}
 Y_{d,h} = & \underbrace{\beta_{h,1} Y_{d-1,h} + \beta_{h,2} Y_{d-2,h} + \beta_{h,3} Y_{d-7,h}}_{\text{autoregressive terms}} \\
 & + \underbrace{\beta_{h,4} Y_{d-1}^{\min} + \beta_{h,5} Y_{d-1}^{\max}}_{\text{non-linear effects}} + \underbrace{\beta_{h,6} Y_{d-1,24}}_{\text{end-of-day effect}} \\
 & + \underbrace{\sum_{j=1}^7 \beta_{h,j+6} D_j}_{\text{weekday dummies}} + \varepsilon_{d,h},
 \end{aligned}$$

... neural nets ...



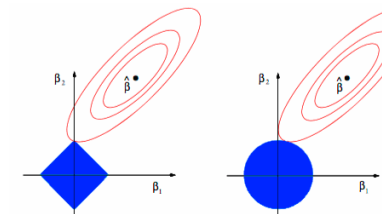
... or deep neural nets (DNN)?



(Uniejewski et al., 2016, Energies; Ziel & Weron, 2018, ENEECO)

Minimize the residual sum of squares (RSS) + a penalty:

$$\hat{\beta} = \underset{\beta_j}{\operatorname{argmin}} \left\{ \text{RSS} + \lambda \sum_{j=1}^n |\beta_j|^q \right\}$$



Blue areas – constraint regions, e.g., $|\beta_1| + |\beta_2| \leq t$

Red ellipses – contours of the LS error function

First read on electricity price forecasting (EPF)

R.Hyndman: "this paper alone is responsible for 0.7 of the current $IF_{2Y}=2.642$ " ;-)

International Journal of Forecasting 30 (2014) 1030–1081



Contents lists available at ScienceDirect

International Journal of Forecasting

journal homepage: www.elsevier.com/locate/ijforecast



Review

Electricity price forecasting: A review of the state-of-the-art with a look into the future

Rafał Weron

Institute of Organization and Management, Wrocław University of Technology, Wrocław, Poland



ARTICLE INFO

Keywords:

Electricity price forecasting
Day-ahead market
Seasonality
Autoregression
Neural network
Factor model
Forecast combination
Probabilistic forecast

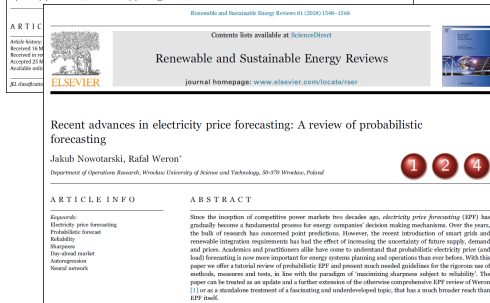
ABSTRACT

A variety of methods and ideas have been tried for electricity price the last 15 years, with varying degrees of success. This review article complexity of available solutions, their strengths and weaknesses, and threats that the forecasting tools offer or that may be encouraged to look ahead and speculates on the directions EPF will or should take or so. In particular, it postulates the need for objective comparative (i) the same datasets, (ii) the same robust error evaluation procedure testing of the significance of one model's outperformance of another



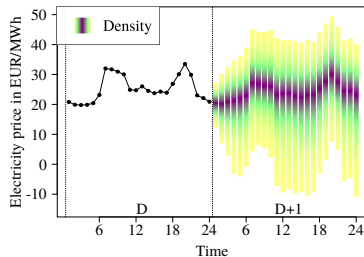
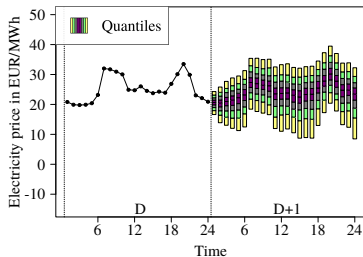
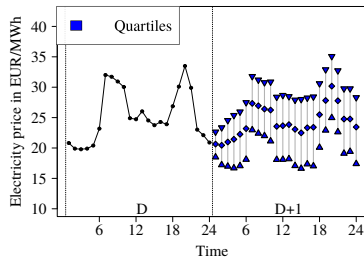
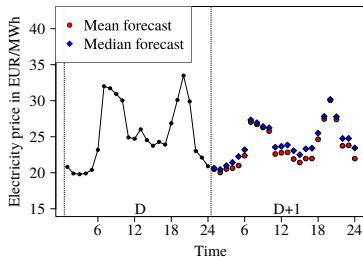
Agenda

- 1 Beyond point forecasts
⇒ probabilistic forecasts
- 2 Combining forecasts
 - Point forecasts
 - Probabilistic forecasts
- 3 New trends in energy forecasting



A new hype: Point $\rightarrow$ probabilistic forecasting

(ca. 7% of EPF papers)



(Very) recent reviews of probabilistic EPF



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(2018)

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Recent advances in electricity price forecasting: A review of probabilistic forecasting



Jakub Nowotarski, Rafał Weron*

Department of Operations Research, Wrocław University of Science and Technology, 50-370 Wrocław, Poland

ARTICLE INFO

Keywords:

Electricity price forecasting
Probabilistic forecast
Reliability
Sharpness
Day-ahead market
Autoregression
Neural network



Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

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Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Probabilistic mid- and long-term electricity price forecasting

Florian Ziel^{a,*}, Rick Steinert^b

^a Universität Duisburg-Essen, Berliner Platz 6-8, 45127 Essen, Germany

^b Europa-Universität Viadrina, Große Schärmstraße 59, 15230 Frankfurt, Oder, Germany



ARTICLE INFO

Keywords:

Electricity prices

ABSTRACT

The liberalization of electricity markets and the development of renewable energy sources has led to new challenges for decision makers. These challenges are accompanied by an increasing uncertainty about future

Global Energy Forecasting Competition 2014

(Hong, Pinson, Fan et al., 2016, IJF)

**GEFCom
2014**

Load Forecasting

**GEFCom
2014**

Price Forecasting

**GEFCom
2014**

Wind Forecasting

**GEFCom
2014**

Solar Forecasting

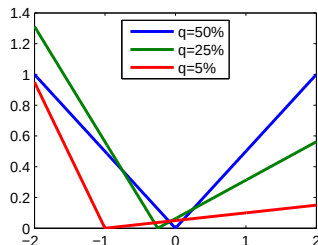


- Incremental data sets released on weekly basis
- Price Track:
 - 287 contestants
 - Submit 99 quantiles (=percentiles) for 24h of the next day
- Evaluation based on the Pinball Score ('discrete' CRPS)

Sharpness and the pinball loss

$$\text{Pinball}(\hat{Q}_{P_t}(q), P_t, q) = \begin{cases} (1 - q) (\hat{Q}_{P_t}(q) - P_t), & \text{for } P_t < \hat{Q}_{P_t}(q), \\ q (P_t - \hat{Q}_{P_t}(q)), & \text{for } P_t \geq \hat{Q}_{P_t}(q), \end{cases}$$

- $\hat{Q}_{P_t}(q)$ is the price forecast at the q -th quantile
- P_t is the actually observed price
- For an aggregate score average:
 - across all hours in the test period
 - across different quantiles



Price Track: Top winning teams

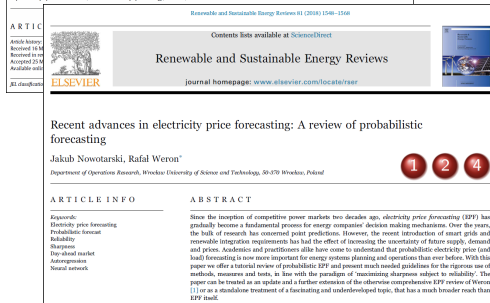
(1st and) 2nd place for QRA!

- 1 Pierre Gaillard, Yannig Goude, Raphaël Nedellec (EDF R&D, F)
- 2 Katarzyna Maciejowska, Jakub Nowotarski (Wrocław UT, PL)
- 3 Grzegorz Dudek (Częstochowa UT, PL)
- 4 Zico Kolter, Romain Juban, Henrik Ohlsson, Mehdi Maasoumy (C3 Energy, USA)
- 5 Frank Lemke (KnowledgeMiner Software, D)

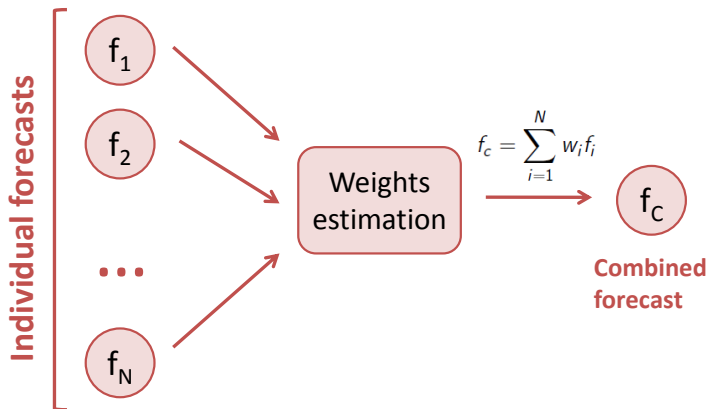


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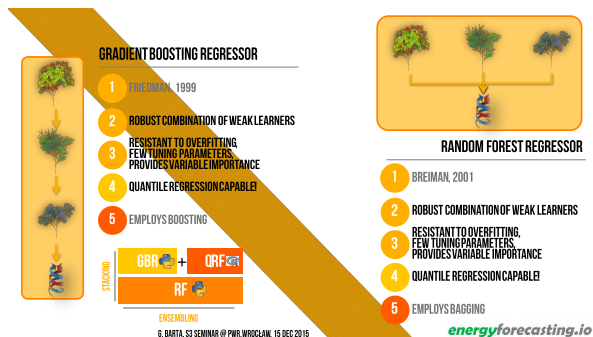
Point forecast averaging: The idea



- Dates back to the 1960s and the works of Bates, Crane, Crotty & Granger

In the 'AI world' ...

- *Committee machines, ensemble averaging, expert aggregation*
- Weron (2014): Forecast combinations and committee machines seem to *evolve independently*, with researchers from both groups not being aware of the parallel developments !



Quantile Regression Averaging (QRA)

(Submitted on 31.12.2013, 21:26 ;-)

Comput Stat (2015) 30:791–803
DOI 10.1007/s00180-014-0523-0



CrossMark

ORIGINAL PAPER



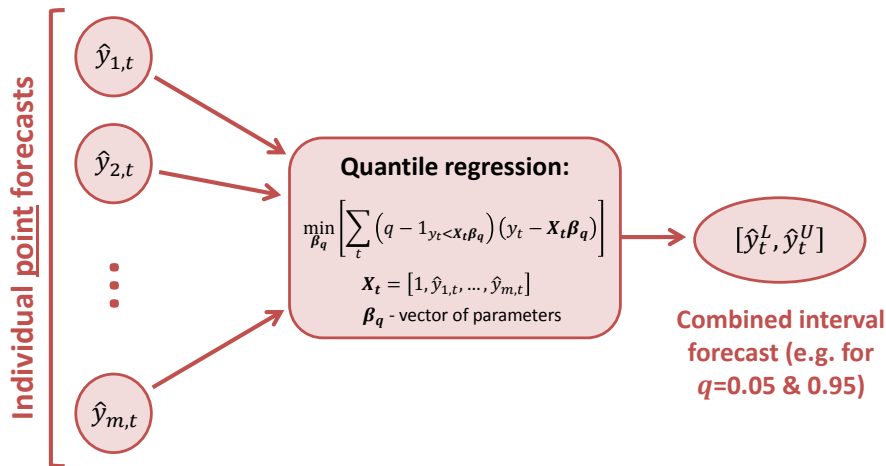
Computing electricity spot price prediction intervals using quantile regression and forecast averaging

Jakub Nowotarski · Rafał Weron

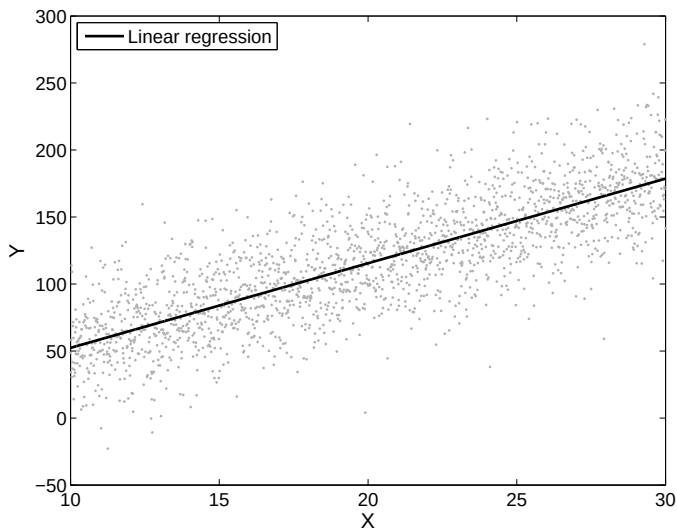
Received: 31 December 2013 / Accepted: 6 August 2014 / Published online: 19 August 2014
© The Author(s) 2014. This article is published with open access at Springerlink.com

Abstract We examine possible accuracy gains from forecast averaging in the context of interval forecasts of electricity spot prices. First, we test whether constructing empirical prediction intervals (PI) from combined electricity spot price forecasts leads to better forecasts than those obtained from individual methods. Next, we propose a new method for constructing PI—Quantile Regression Averaging (QRA)—which utilizes the concept of quantile regression and a pool of point forecasts of individual

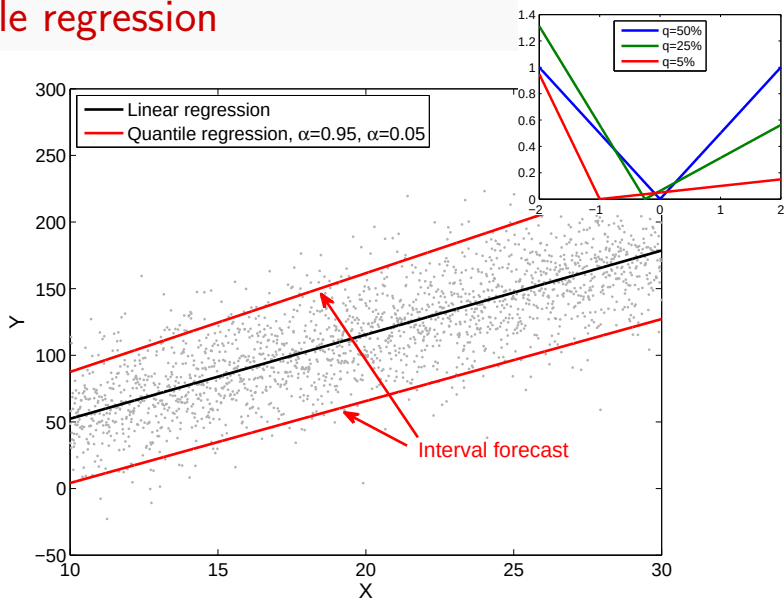
Quantile Regression Averaging: The idea



Quantile regression

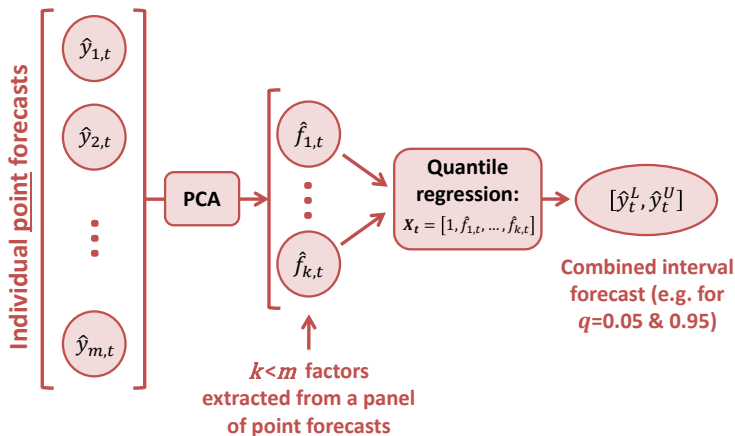


Quantile regression



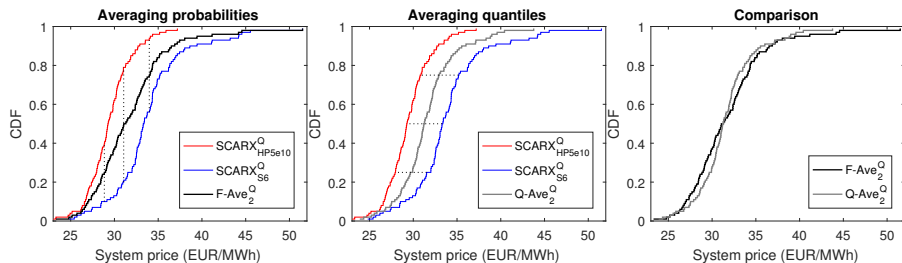
FQRA: When the number of predictors is large

(Maciejowska, Nowotarski & Weron, 2016, IJF)



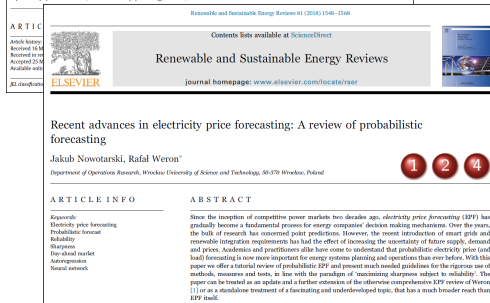
Combining probabilistic forecasts is more tricky

- **Average probability forecast:** $\mathbf{F-Ave}_n^* \equiv \frac{1}{n} \sum_{i=1}^n \hat{F}_i(x)$
 $\Rightarrow$ a vertical average of predictive distributions
- **Average quantile forecast:** $\mathbf{Q-Ave}_n^* \equiv \hat{Q}^{-1}(x)$
 with $\hat{Q}(x) = \frac{1}{n} \sum_{i=1}^n \hat{Q}_i(x)$ and quantile forecast $\hat{Q}_i(x) = \hat{F}_i^{-1}(x)$
 $\Rightarrow$ a horizontal average (always 'sharper' = 'more concentrated')

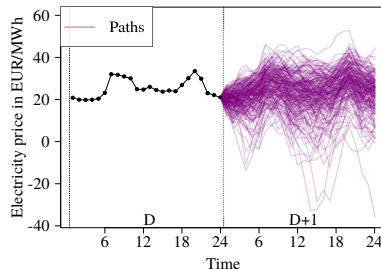
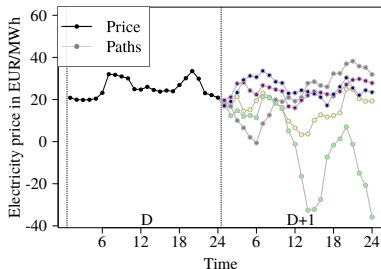


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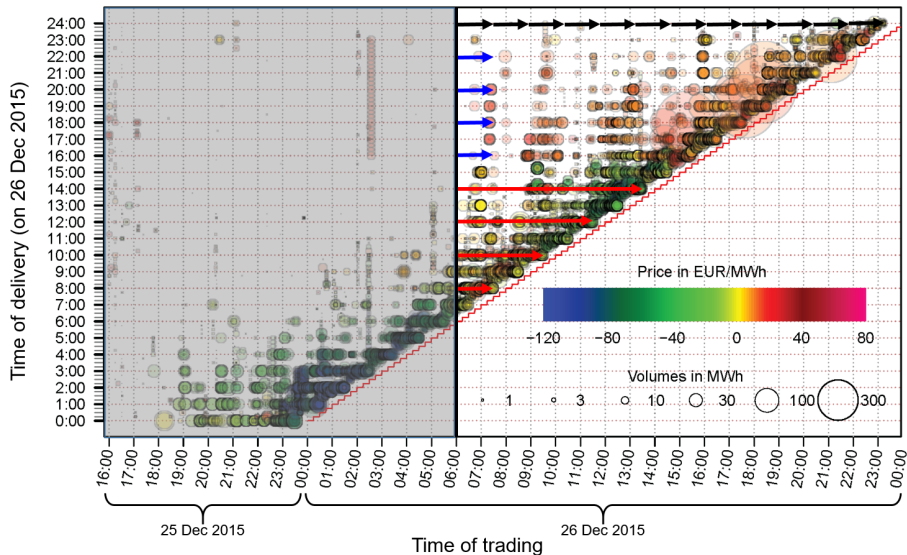


Not yet a hype: Probabilistic $\rightarrow$ path forecasting



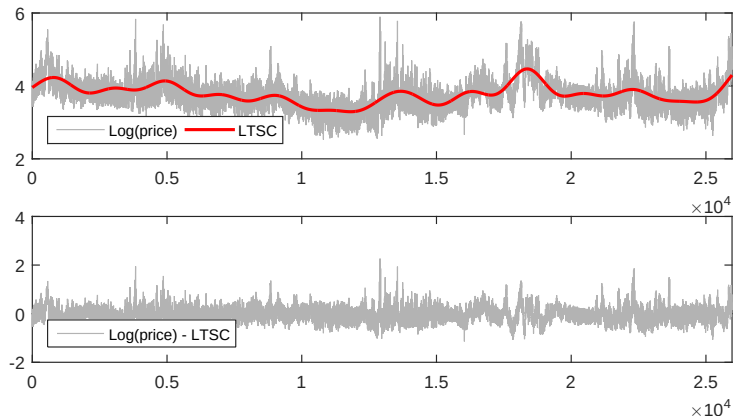
- Relatively novel in EPF (but not in weather forecasting)
- Operational decisions often depend on prices for multiple hours in a row (e.g., ramping costs of power plants)
- Regulatory incentives: in Germany a wind park can receive less subsidies if the electricity price is negative for 6 hours in a row

INREC 2018 hype: Intraday forecasting



LTSC and short-term price forecasting

- Can the long-term trend-seasonal component (LTSC) impact short-term (day-ahead) electricity price forecasts?



LTSC and short-term price forecasting cont.

Energy Economics 57 (2016) 228–235



(2016)

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

On the importance of the long-term seasonal component in day-ahead electricity price forecasting

Jakub Nowotarski, Rafał Weron*

Department of Operations Research, Wrocław University of Technology, Wrocław, Poland

International Journal of Forecasting



Contents lists available at ScienceDirect

International Journal of Forecasting

journal homepage: www.elsevier.com/locate/ijforecast

On the importance of the long-term seasonal component in day-ahead electricity price forecasting with NARX neural networks

Grzegorz Marcjasz^{a,b}, Bartosz Uniejewski^{a,b}, Rafał Weron^{a,*}

^a Department of Operations Research, Wrocław University of Science and Technology, Wrocław, Poland

^b Faculty of Pure and Applied Mathematics, Wrocław University of Science and Technology, Wrocław, Poland

(2018)

Energy Economics xxx (2018) xxx–xxx



(2018)

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journal homepage: www.elsevier.com/locate/eneco

On the importance of the long-term seasonal component in day-ahead electricity price forecasting
Part II – Probabilistic forecasting

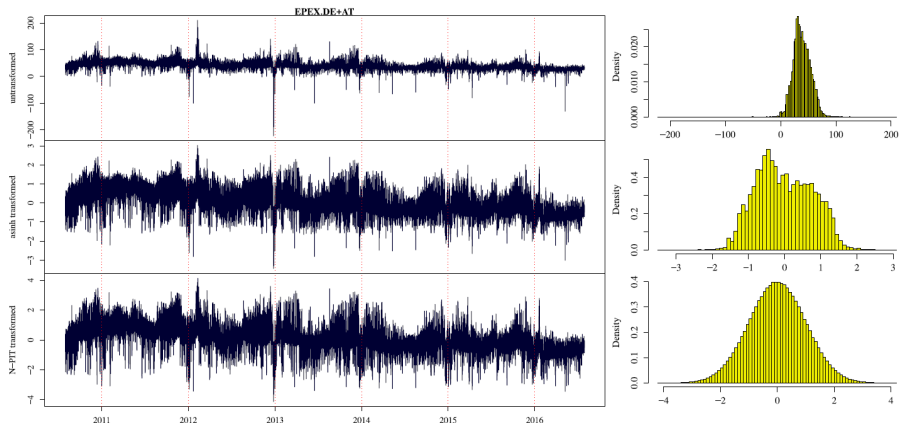
Bartosz Uniejewski^{a,b}, Grzegorz Marcjasz^{a,b}, Rafał Weron^{a,*}

^a Department of Operations Research, Faculty of Computer Science and Management, Wrocław University of Technology, Wrocław, Poland

^b Faculty of Pure and Applied Mathematics, Wrocław University of Technology, Wrocław, Poland

Variance stabilizing transformations (VSTs)

(Uniejewski, Weron & Ziel, 2018, IEEE-TPWRS)



Averaging across calibration windows

(Hubicka et al., 2018, IEEE-TSE; Marcjasz et al., 2018, Energies)

