

Recent advances in electricity price forecasting: A 2019 perspective

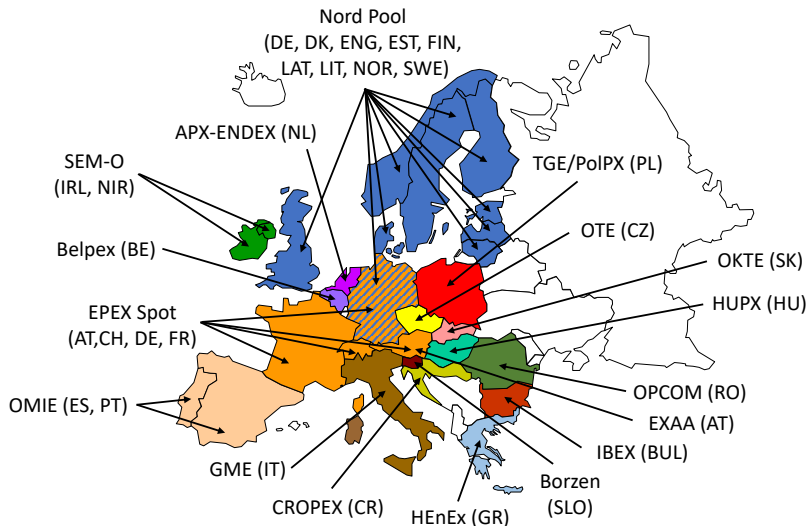


Rafał Weron*

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<http://kbo.pwr.edu.pl/en/staff/rafal-weron/>

*Based on work with K.Hubicka, K.Maciejowska, G.Marcjasz, T.Serafin, B.Uniejewski (PWr)
J.Nowotarski (BNY Mellon), F.Ziel (Essen)

Markets for electricity in Europe ...

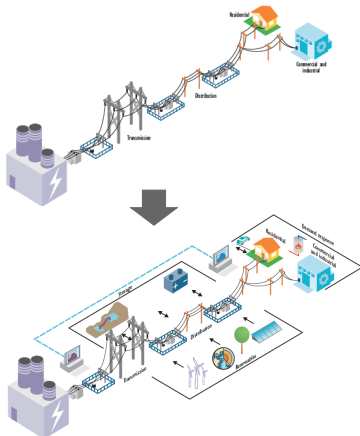
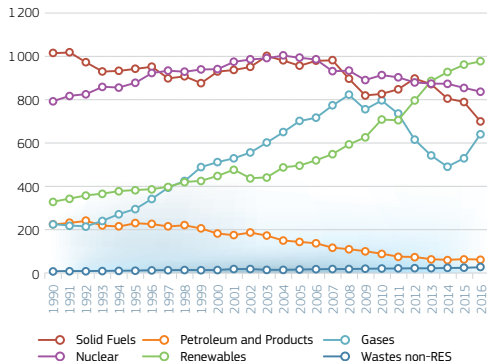


... are undergoing a transformation ...

The resource mix transitions from fossil fuels to renewables

2.6.2 Gross Electricity Generation

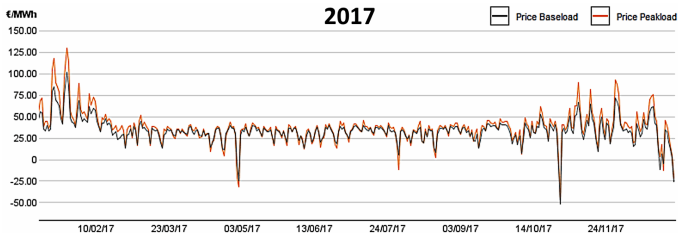
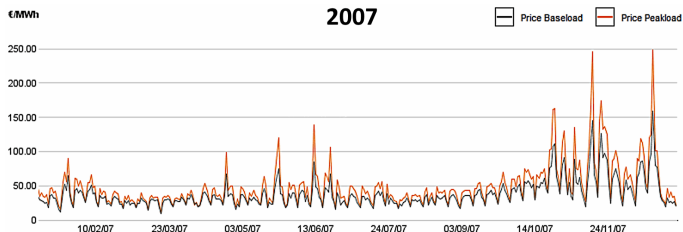
BY FUEL – EU-28 – ALL FUELS – 1990-2016 (TWh)



Sources: EU (2018), Adigbli (2017)

... and the price characteristics are changing ...

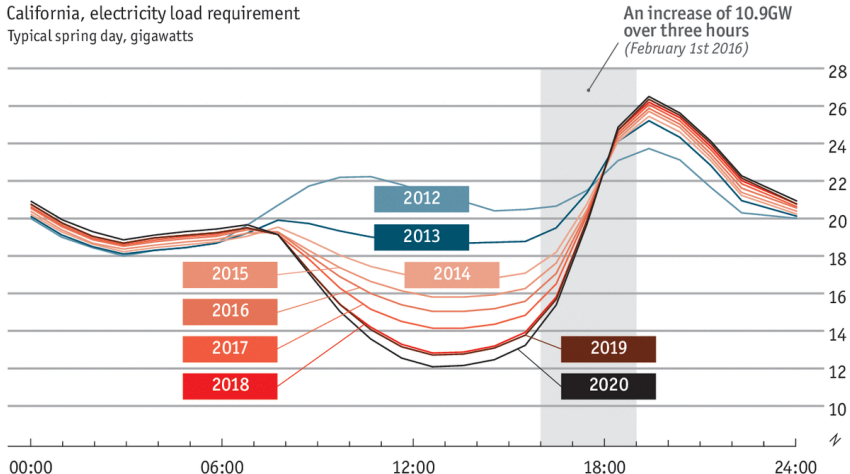
Here: 2007 vs. 2017 average daily EPEX prices for Germany/Austria



... in particular due to the 'duck curve' effect

Who gets the bill?

California, electricity load requirement
Typical spring day, gigawatts

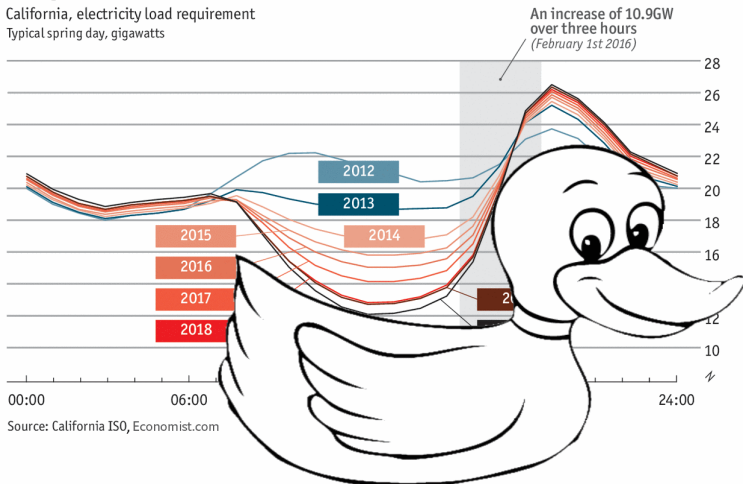


Source: California ISO, Economist.com

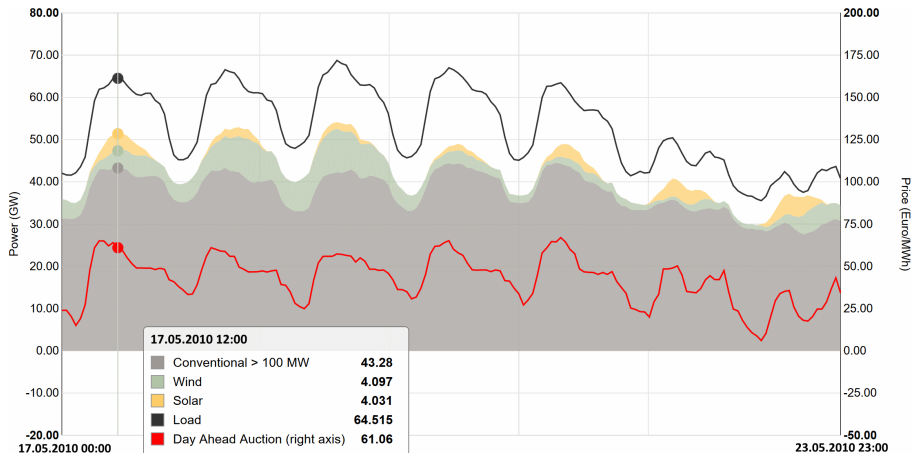
Where's the duck?

Who gets the bill?

California, electricity load requirement
Typical spring day, gigawatts

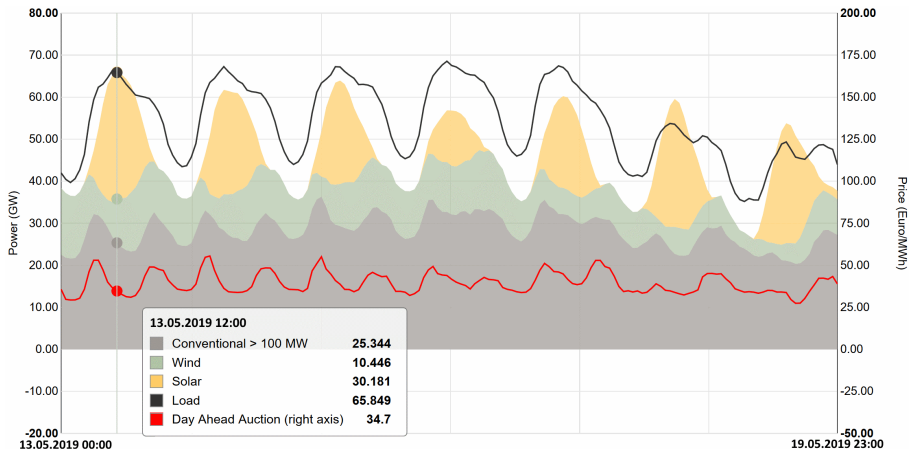


Germany 2010: No ducks



Source: www.energy-charts.de

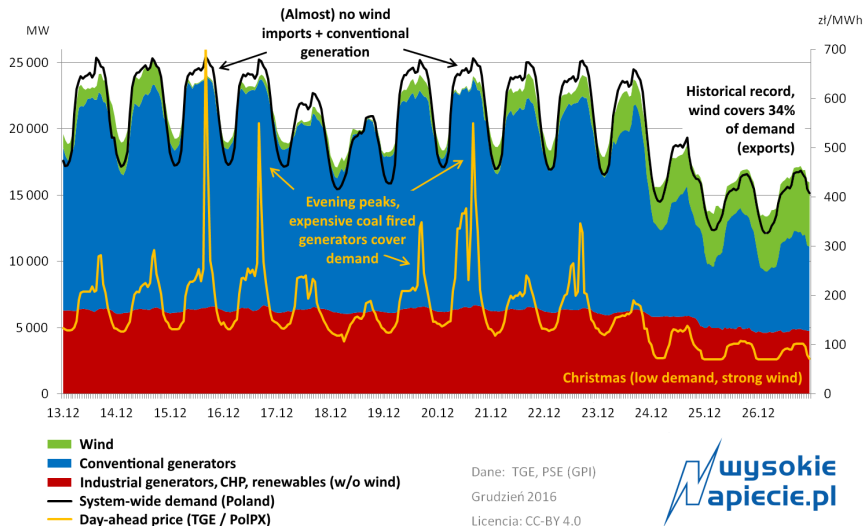
Germany 2019: 'Duck curve' (or 'peak shaving')



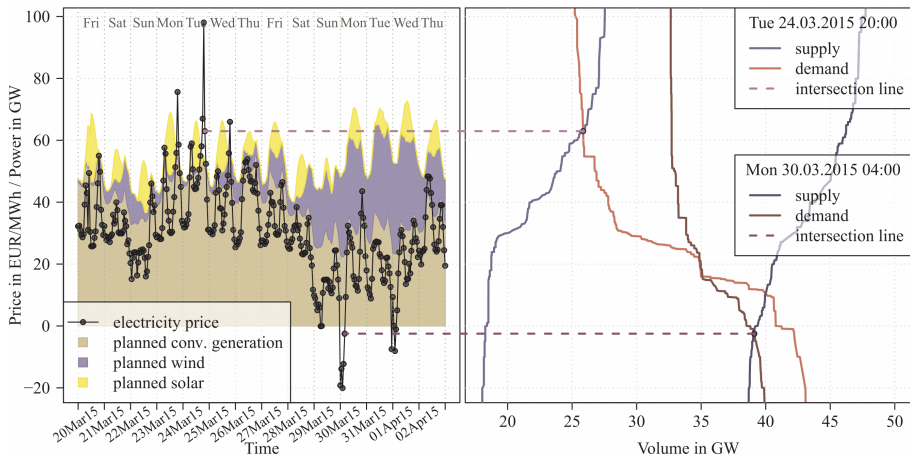
Source: www.energy-charts.de

What about wind infeed?

A closeup on two weeks in December 2016 in Poland



Supply and demand, renewables and negative prices



Source: Ziel & Steinert (2018, RSER)

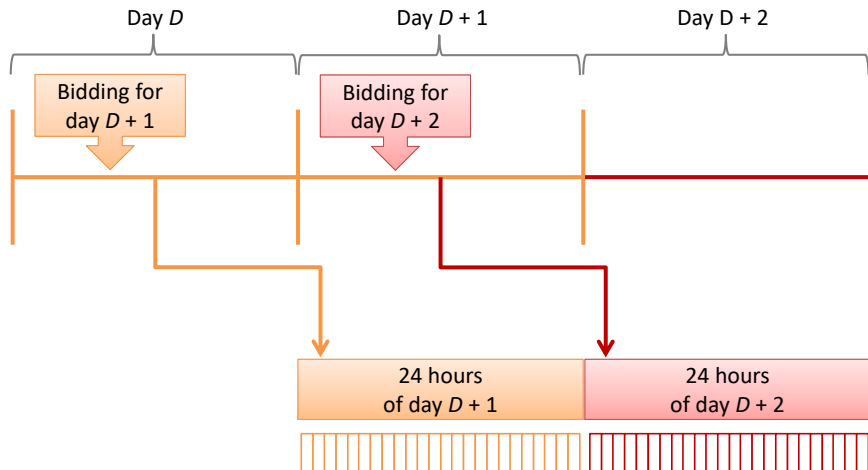
But why forecast electricity spot prices?

- Risk is managed against **recourse to the spot markets**
- Forward prices are assessed **based on spot price forecasts**, adjusted by risk premia
 - Electricity is non-storable → no physical cost-of-carry theory
- The workhorse of European trading is the **day-ahead market**

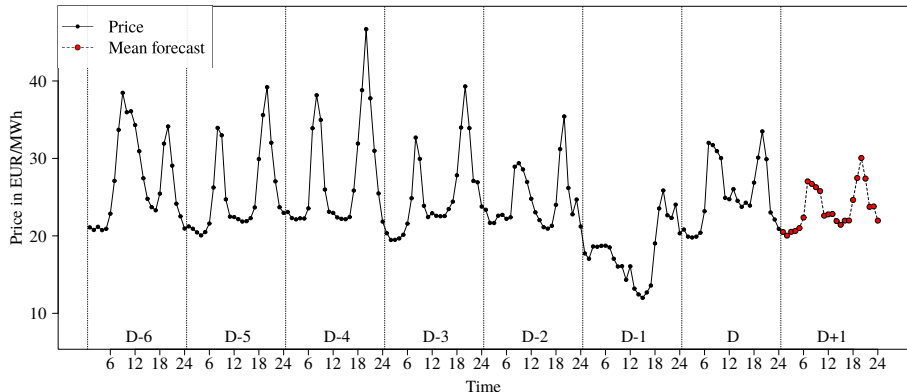


The workhorse of European power trading

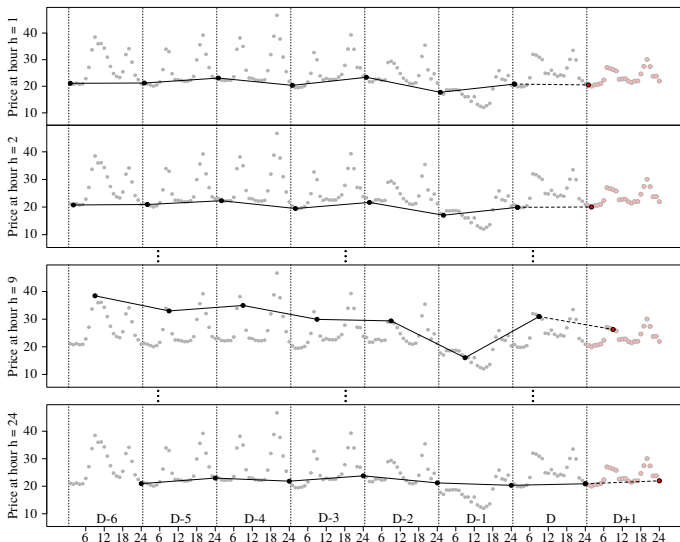
The day-ahead market (ca. 93% of papers)



Day-ahead point forecasting: Univariate ...



... or multivariate?

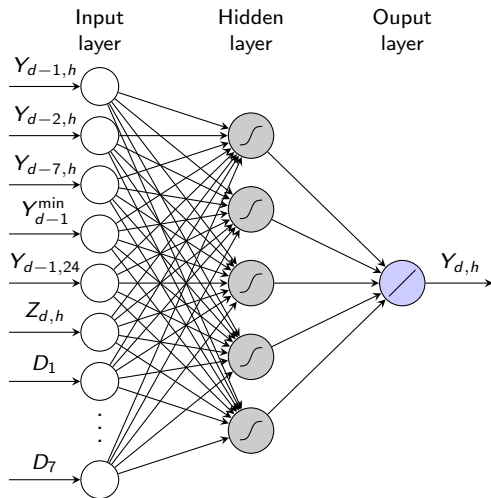


Day-ahead point forecasting: Regression ...

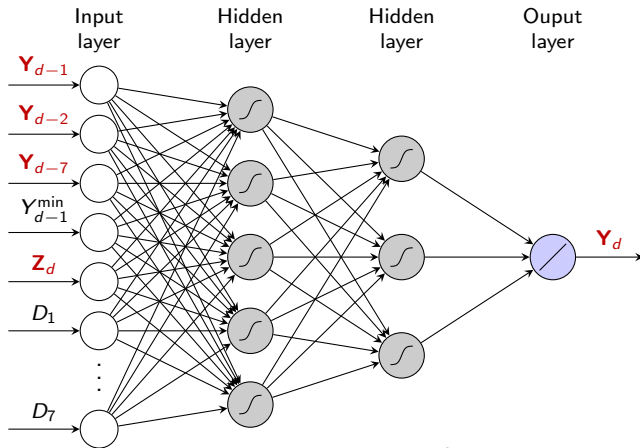
Electricity price for day d and hour h :

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

... neural nets ...



... or deep neural nets (DNN)?



NOTE: Y_d and Z_d are 24×1 vectors

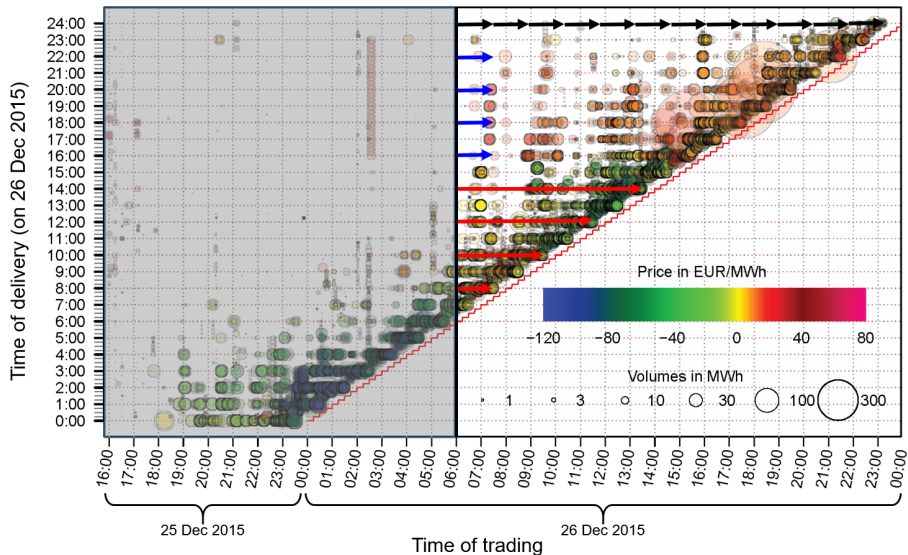
Flexibility comes at a cost

DNNs have many 'hyper-parameters' which can be fine-tuned *ex-ante* using similar datasets, e.g., in Keras/Python:

- network structure (#layers, #neurons in layers, recurrence)
- optimization algorithms: **ADAM** & variants (**ADAMAX**, **ADAGRAD**), SGD, RMSprop
- activation functions: eLU, ReLU, tanh, **sigmoid**
- max training epochs allowed: 50, 100, 200, **500**
- batch size: 16, **32**, 64, 96, 128, **192**, 256, 384, 768

~ **5% decrease** in MAE, compared to default values

What about the intraday market?



First read on electricity price forecasting (EPF)

R.Hyndman (EIC): "this paper alone is responsible for 0.7 of the $IF_{2016}=2.642$ " ;-)

International Journal of Forecasting 30 (2014) 1030–1081



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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

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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 encountered looks 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 Variable selection
- 2 Beyond point forecasts
⇒ probabilistic forecasts
- 3 Combining forecasts
 - Point forecasts
 - Probabilistic forecasts
- 4 Preprocessing
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Renewable and Sustainable Energy Reviews 85 (2018) 1548–1564

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

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

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Price autocorrelation: Today vs. yesterday

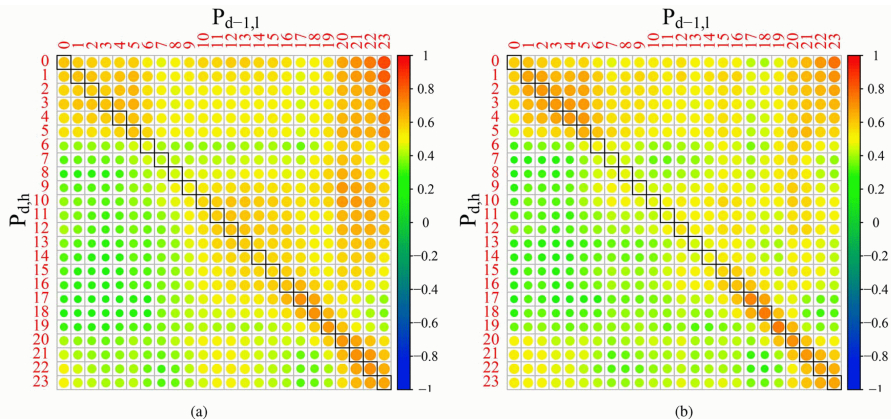
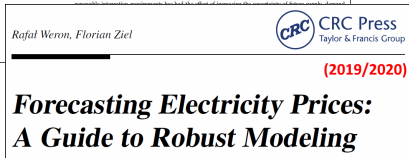
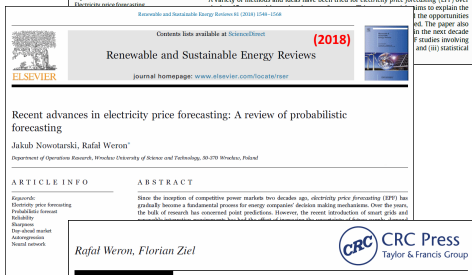


Fig. 1. Sample correlations of $\text{Cor}(P_{d,h}, P_{d-1,l})$ for $h, l = 0, \dots, 23$ and two markets from 17.12.2009 to 12.08.2014. (a) EPEX spot price for Germany and Austria, (b) APX spot price for Netherlands.

Source: Ziel (2016, IEEE-TPWRS)

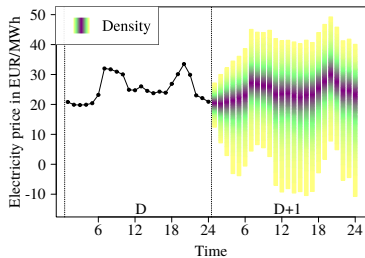
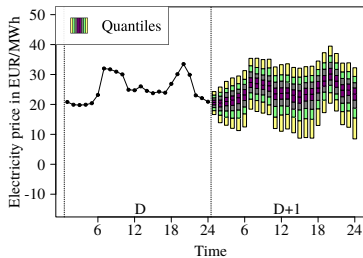
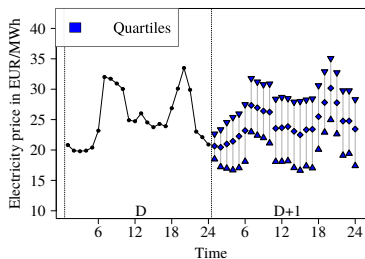
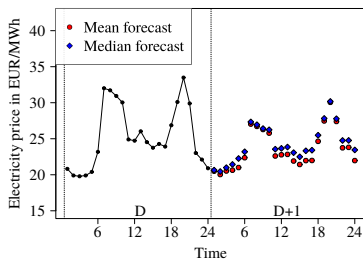
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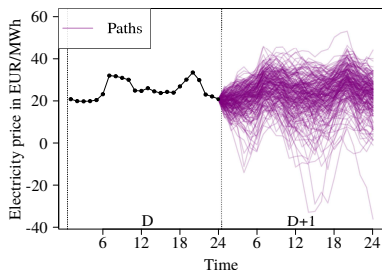
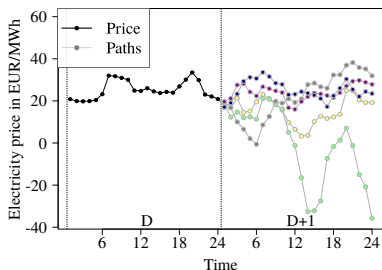


A new hype: Point \rightarrow probabilistic forecasting

(ca. 7% of EPF papers)



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

(Very) recent reviews of probabilistic EPF



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(2018)

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 Sharpness
 Day-ahead market
 Autoregression
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Probabilistic mid- and long-term electricity price forecasting

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ARTICLE INFO

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Electricity prices
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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 electricity price movements. The forecasted movements of energy prices are model and modeler dependent and

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

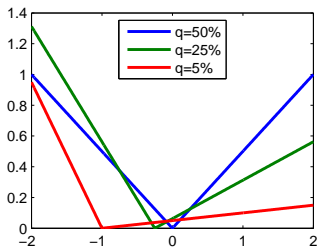


- Incremental data sets released on weekly basis
- Price Track:
 - 287 contestants
 - Submit 99 quantiles (=percentiles) for 24h of the next day
- Evaluation based on the Pinball Score ('discrete' CRPS)

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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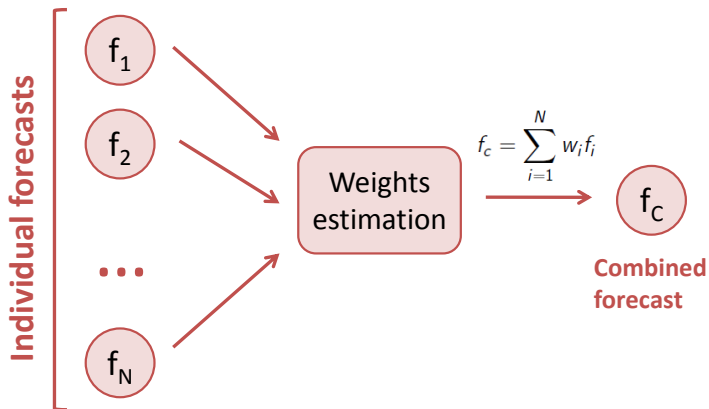
Rafal Weron, Florian Ziel

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Point forecast averaging: The idea



- Dates back to the 1960s and the works of Bates, Crane, Crotty & Granger
- 'AI world': *committee machines*, *ensemble averaging*, *expert aggregation*

Quantile Regression Averaging (QRA)

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



ORIGINAL PAPER



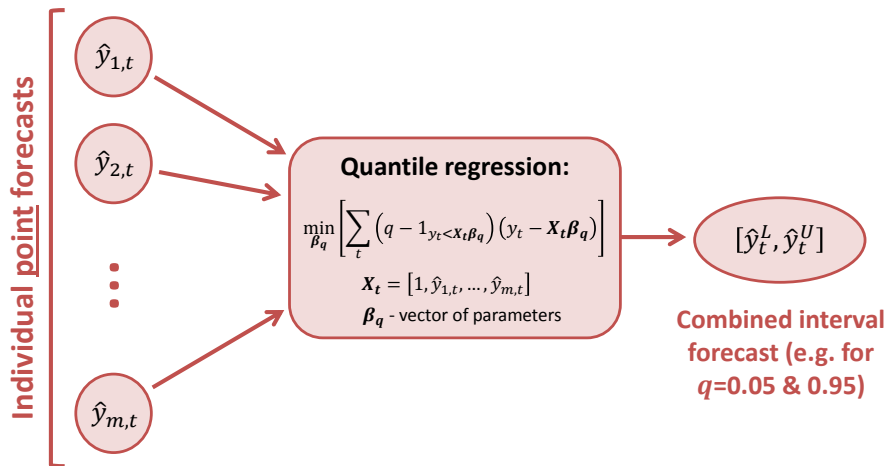
Computing electricity spot price prediction intervals using quantile regression and forecast averaging

Jakub Nowotarski · Rafał Weron

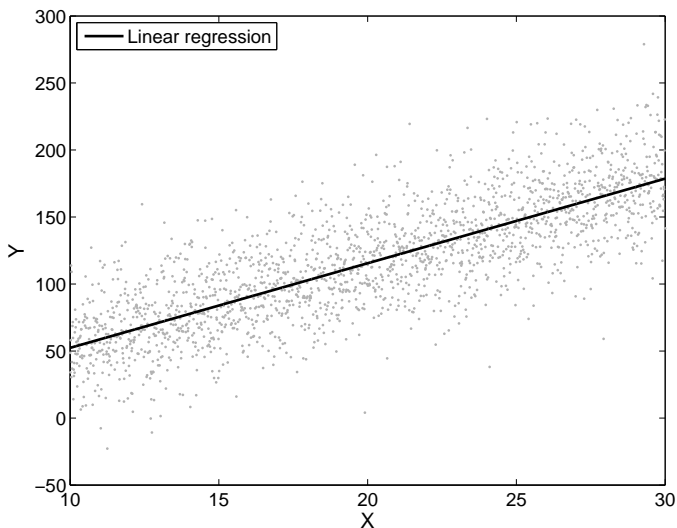
Received: 31 December 2013 / Accepted: 6 August 2014 / Published online: 19 August 2014
© The Author(s) 2014. This article is published with open access at Springerlink.com

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

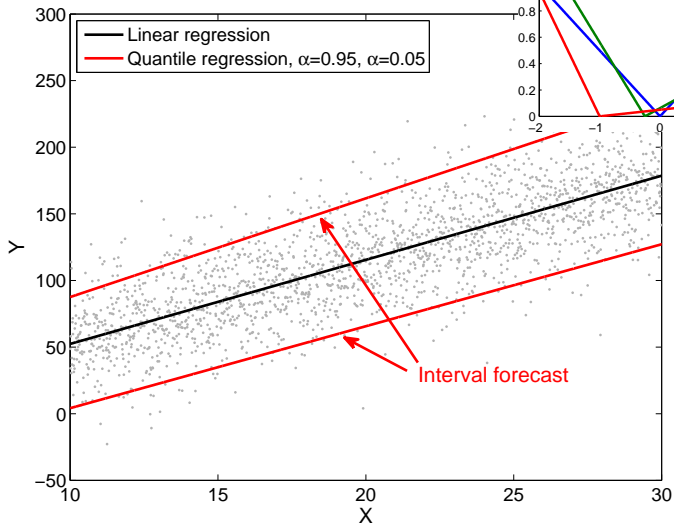
Quantile Regression Averaging: The idea



Quantile regression

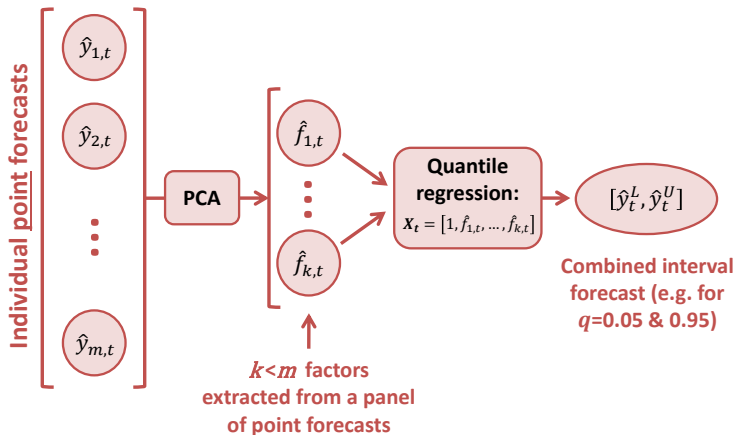


Quantile regression



FQRA: When the number of predictors is large

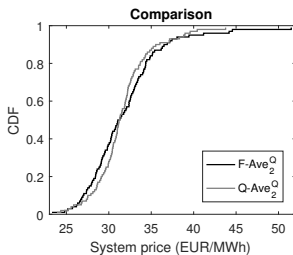
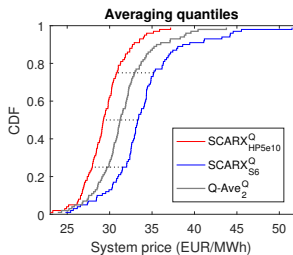
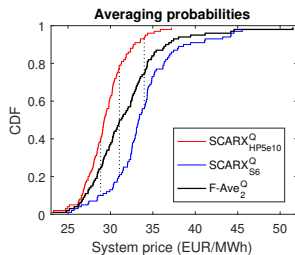
(Maciejowska, Nowotarski & Weron, 2016, IJF)



Combining probabilistic forecasts is more tricky

(Lichtendahl et al., 2013, Mngt Sci)

- **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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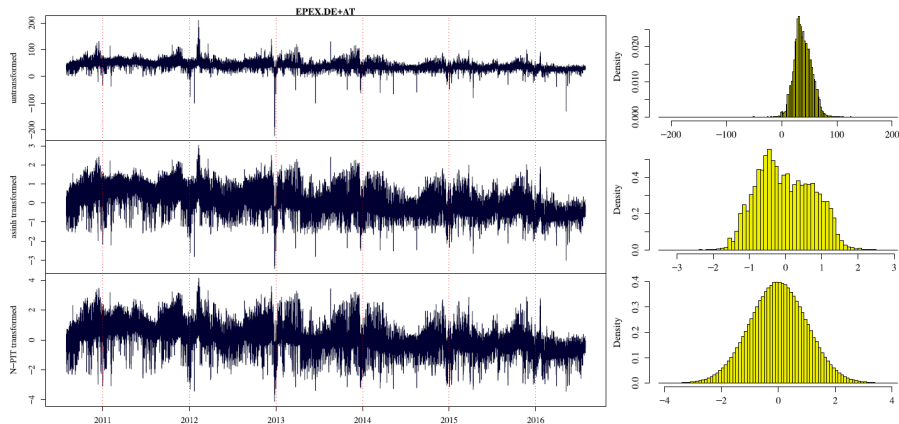
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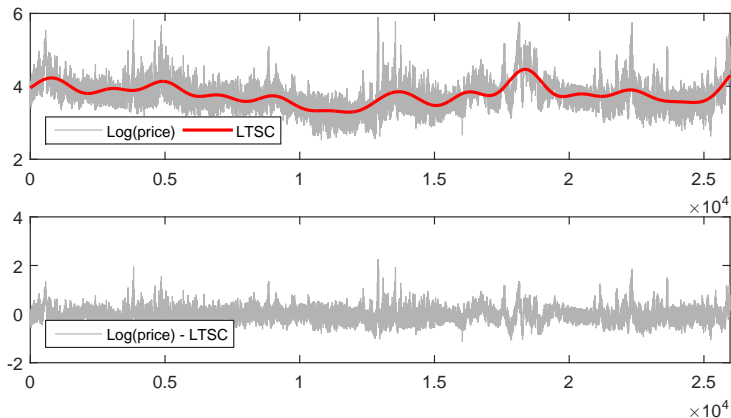
Variance stabilizing transformations (VSTs)

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



Seasonal decomposition and short-term EPF

- 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



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



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ARTICLE INFO

Article history:

Received 16 March 2016
 Received in revised form 21 May 2016
 Accepted 25 May 2016
 Available online 2 June 2016

JEL classification:

ABSTRACT

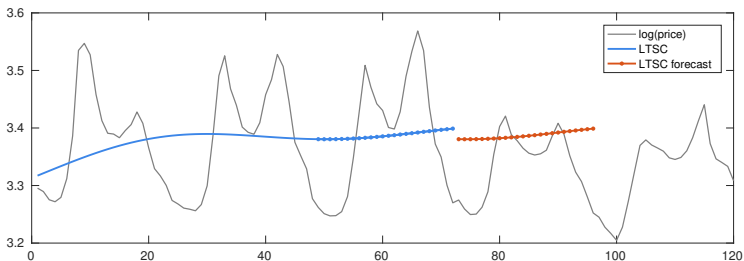
In day-ahead *electricity price forecasting* (EPF) the daily and weekly seasonalities are always taken into account, but the long-term seasonal component (LTSC) is believed to add unnecessary complexity to the already parameter-rich models and is generally ignored. Conducting an extensive empirical study involving state-of-the-art time series models we show that (i) decomposing a series of electricity prices into a LTSC and a stochastic component, (ii) modeling them independently and (iii) combining their forecasts can bring – contrary to a common belief – an accuracy gain compared to an approach in which a given time series model is calibrated to the prices themselves.

The Seasonal Component (SCAR) framework

(Marcjasz et al., 2019, IJF; Uniejewski et al., 2019, ENEECO)

- 1 Decompose the VST-transformed price (and exogenous series) in the calibration window: $Y_{d,h} \rightarrow T_{d,h} + q_{d,h}$
- 2 Fit **AR(X)** to deseasonalized prices and compute forecasts for the 24h of the next day (24 separate series): $q_{d,h} \rightarrow \hat{q}_{d+1,h}$
- 3 Add persistent (naive) LTSC forecasts: $\hat{q}_{d+1,h} + \hat{T}_{d+1,h} \rightarrow \hat{Y}_{d+1,h}$
- 4 Convert into price forecasts: $\hat{Y}_{d+1,h} \rightarrow \hat{P}_{d+1,h}$

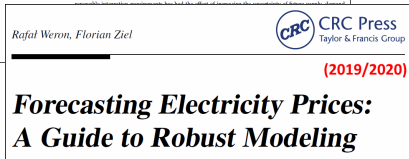
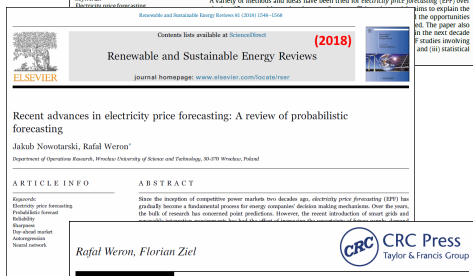
Can we do better?



- Persistent forecasts are naive
- Preliminary results → yes, we can do better

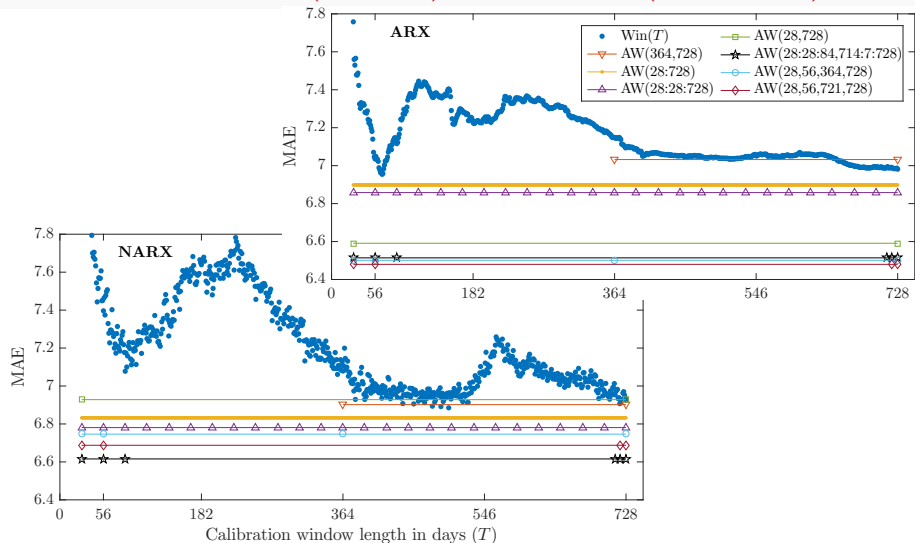
Agenda

- 1 Variable selection
- 2 Beyond point forecasts
⇒ probabilistic forecasts
- 3 Combining forecasts
 - Point forecasts
 - Probabilistic forecasts
- 4 Preprocessing
 - Transformations
 - SCAR framework
- 5 Combining revisited
 - Calibration windows



Averaging across calibration windows

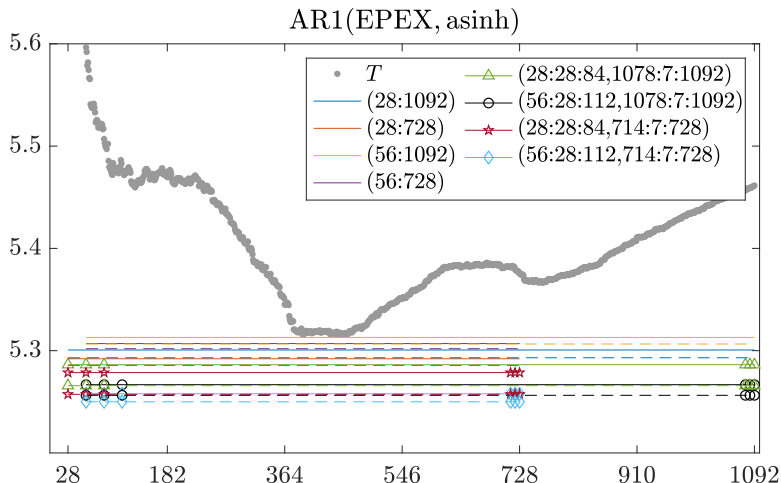
Structural breaks: Pesaran, Pick (2011, JBES); EPF: Hubicka et al. (2019, IEEE-TSE)



Past performance-weighted averaging

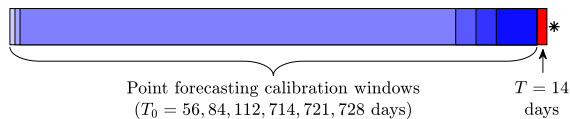
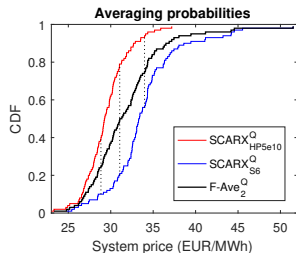
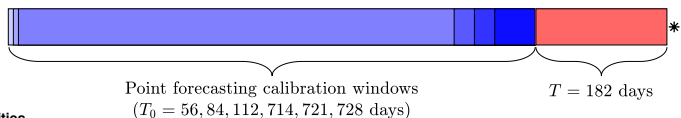
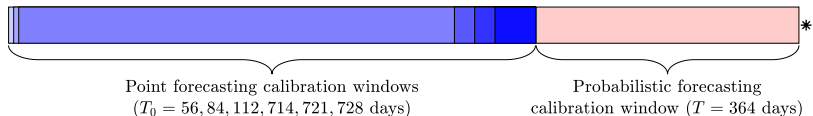
(Marcjasz, Serafin & Weron, 2018, Energies)

'—' AW, '- -' WAW

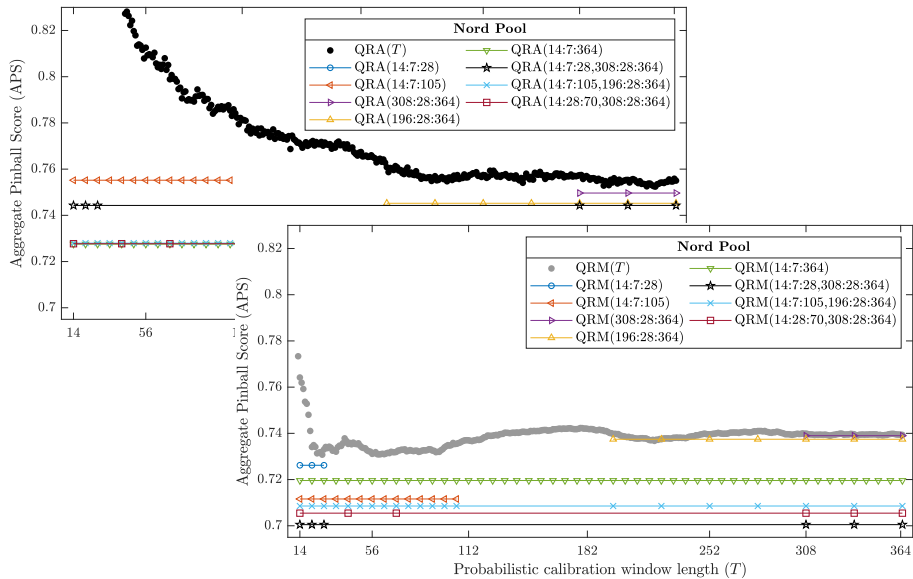


Also works for probabilistic forecasts

(Serafin, Uniejewski & Weron, 2019, WP)



QRA vs. QRM (QR Machine)



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International Journal of Forecasting 30 (2014) 1030–1081

Contents lists available at ScienceDirect

(2014)

International Journal of Forecasting

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

ELSEVIER

Review

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

Rafal Weron
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ARTICLE INFO ABSTRACT

OPEN ACCESS

Keywords: Electricity price forecasting

A variety of methods and ideas have been tried for electricity price forecasting (EPF) over the last decade. The paper aims to explain the opportunities and challenges of the opportunities in the next decade. The paper also reviews the state-of-the-art in EPF studies involving (in) statistical

Renewable and Sustainable Energy Reviews 85 (2018) 1548–1564

Contents lists available at ScienceDirect

(2018)

Renewable and Sustainable Energy Reviews

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

ELSEVIER

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

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ARTICLE INFO ABSTRACT

Keywords: Electricity price forecasting; Probabilistic forecast; Reliability; Elgarsson; Day-ahead market; Autoregressive; Neural network

Since the inception of competitive power markets two decades ago, electricity price forecasting (EPF) has gradually become a fundamental process for energy companies' decision making mechanisms. Over the years, the bulk of research has concerned point predictions. However, the recent introduction of smart grids and

Rafal Weron, Florian Ziel

CRC Press
Taylor & Francis Group

(2019/2020)

Forecasting Electricity Prices: A Guide to Robust Modeling

