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 forecasting* (EPF) over the last 15 years, with varying degrees of success. This review article aims to explain the complexity of available solutions, their strengths and weaknesses, and the opportunities and threats that the forecasting tools offer or that may be encountered. The paper also looks ahead and speculates on the directions EPF will or should take in the next decade or so. In particular, it postulates the need for objective comparative EPF studies involving (i) the same datasets, (ii) the same robust error evaluation procedures, and (iii) statistical testing of the significance of one model's outperformance of another.

Contents

1. Introduction 1031
2. Literature query 1032
   2.1. Bibliometrics of 'electricity price forecasting' 1032
   2.2. Major review and survey publications 1034
3. What and how are we forecasting? 1036
   3.1. The electricity 'spot' price 1036
   3.2. Forecasting horizons 1038
   3.3. Evaluating point forecasts 1038
   3.4. Overview of modeling approaches 1039
   3.5. Multi-agent models 1040
      3.5.1. Nash-Cournot framework 1040
      3.5.2. Supply function equilibrium 1040
      3.5.3. Strategic production-cost models 1041
      3.5.4. Agent-based simulation models 1041
      3.5.5. Strengths and weaknesses 1042
   3.6. Fundamental models 1042
      3.6.1. Parameter-rich fundamental models 1043
      3.6.2. Parsimonious structural models 1043
      3.6.3. Strengths and weaknesses 1044

E-mail address: rafal.weron@pwr.wroc.pl.

http://dx.doi.org/10.1016/j.ijforecast.2014.08.008

3.7. Reduced-form models ... 1044
3.7.1. Jump-diffusion models ... 1045
3.7.2. Markov regime-switching models ... 1047
3.7.3. Strengths and weaknesses ... 1049
3.8. Statistical models ... 1049
3.8.1. Similar-day and exponential smoothing methods ... 1049
3.8.2. Regression models ... 1050
3.8.3. AR-type time series models ... 1051
3.8.4. ARX-type time series models ... 1052
3.8.5. Threshold autoregressive models ... 1054
3.8.6. Heteroskedasticity and GARCH-type models ... 1055
3.8.7. Strengths and weaknesses ... 1056
3.9. Computational intelligence models ... 1056
3.9.1. Taxonomy of neural networks ... 1057
3.9.2. Feed-forward neural networks ... 1057
3.9.3. Recurrent neural networks ... 1059
3.9.4. Fuzzy neural networks ... 1060
3.9.5. Support vector machines ... 1060
3.9.6. Strengths and weaknesses ... 1060
4. A look into the future of 'electricity price forecasting' ... 1061
4.1. Fundamental price drivers and input variables ... 1061
4.1.1. Modeling and forecasting the trend-seasonal components ... 1061
4.1.2. Spike forecasting and the reserve margin ... 1062
4.2. Beyond point forecasts ... 1065
4.2.1. Interval forecasts ... 1065
4.2.2. Density forecasts ... 1066
4.2.3. Threshold forecasting ... 1067
4.3. Combining forecasts ... 1067
4.3.1. Point forecasts ... 1068
4.3.2. Probabilistic forecasts ... 1070
4.4. Multivariate factor models ... 1071
4.5. The need for an EPF-competition ... 1073
4.5.1. A universal test ground ... 1073
4.5.2. Guidelines for evaluating forecasts ... 1074
4.6. Final word ... 1075
Acknowledgments ... 1075
References ... 1075

1. Introduction

Since the early 1990s, the process of deregulation and the introduction of competitive markets have been reshaping the landscape of the traditionally monopolistic and government-controlled power sectors. In many countries worldwide, electricity is now traded under market rules using spot and derivative contracts. However, electricity is a very special commodity. It is economically non-storable, and power system stability requires a constant balance between production and consumption (Kaminski, 2013; Shahidehpour, Yamin, & Li, 2002). At the same time, electricity demand depends on weather (temperature, wind speed, precipitation, etc.) and the intensity of business and everyday activities (on-peak vs. off-peak hours, weekdays vs. weekends, holidays and near-holidays, etc.). On the one hand, these unique and specific characteristics lead to price dynamics not observed in any other market, exhibiting seasonality at the daily, weekly and annual levels, and abrupt, short-lived and generally unanticipated price spikes. On the other hand, they have encouraged researchers to intensify their efforts in the development of better forecasting techniques.

At the corporate level, electricity price forecasts have become a fundamental input to energy companies' decision-making mechanisms (Bunn, 2004; Eydeland & Wolyniec, 2003; Weron, 2006). As the California crisis of 2000–2001 showed, electric utilities are the most vulnerable, since they generally cannot pass their costs on to the retail consumers (Joskow, 2001). The costs of over-/under-contracting and then selling/buying power in the balancing (or real-time) market are typically so high that they can lead to huge financial losses or even bankruptcy. Extreme price volatility, which can be up to two orders of magnitude higher than that of any other commodity or financial asset, has forced market participants to hedge not only against volume risk but also against price movements. Price forecasts from a few hours to a few months ahead have become of particular interest to power portfolio managers. A generator, utility company or large industrial consumer who is able to forecast the volatile wholesale prices with a reasonable level of accuracy can adjust its bidding strategy and its own production or consumption schedule in order to reduce the risk or maximize the profits in day-ahead trading.

A variety of methods and ideas have been tried for *electricity price forecasting* (EPF), with varying degrees of success. This review article aims to explain the complexity of the available solutions, with a special emphasis on the strengths and weaknesses of the individual methods. In an attempt to determine which approaches are the most popular, In Section 2 we provide an overview of the