Energy Economics 49 (2015) 72–81

Contents lists available at ScienceDirect

Energy Economics

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

Predictability of price movements in deregulated electricity markets

Olga Y. Uritskaya [a,*], Vadim M. Uritsky [b]

[a] Quantitative Dynamics LLC, 2205 Darrow St, Silver Spring, MD, USA
[b] Catholic University of America, 620 Michigan Ave NE, Washington DC, USA

ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form 22 January 2015
Accepted 25 January 2015
Available online 2 February 2015

Jel Classificaton:
C12 Hypothesis Testing: General
C46 Specific Distributions • Specific Statistics
C53 Forecasting and Prediction Methods • Simulation Methods
E32 Business Fluctuations • Cycles
E37 Forecasting and Simulation: Models and Applications
Q47 Energy Forecasting

Keywords:
Deregulated electricity markets
Efficient market hypothesis
Detrended fluctuation analysis
Financial forecasting

ABSTRACT

In this paper we investigate predictability of electricity prices in the Canadian provinces of Alberta and Ontario, as well as in the US Mid-C market. Using scale-dependent detrended fluctuation analysis, spectral analysis, and the probability distribution analysis we show that the studied markets exhibit strongly anti-persistent properties suggesting that their dynamics can be predicted based on historic price records across the range of time scales from 1 h to one month. For both Canadian markets, the price movements reveal three types of correlated behavior which can be used for forecasting. The discovered scenarios remain the same on different time scales up to one month as well as for on- and off-peak electricity data. These scenarios represent sharp increases of prices and are not present in the Mid-C market due to its lower volatility. We argue that extreme price movements in this market should follow the same tendency as the more volatile Canadian markets. The estimated values of the Pareto indices suggest that the prediction of these events can be statistically stable. The results obtained provide new relevant information for managing financial risks associated with the dynamics of electricity derivatives over time frame exceeding one day.

1. Introduction

The modern electricity market is not only a system for arranging the purchase and sale of electricity using supply and demand to set the price, but, for most major grids, is a basis for electricity derivatives, such as electricity futures and options, which are actively traded. The practical significance of this part of the market is increasing as is the importance of the related scientific research (Weron, 2007; Garcia et al., 2005; Murthy et al., 2013). The markets of electricity derivatives have developed as a result of the liberalization and deregulation of electric power systems around the world. Deregulation, introduced initially to reduce and simplify the control of the business in this field, had a final goal to reach financial efficiency of electricity markets (Rader and Norgaard, 1996; Arciniegas et al., 2003). However, electricity is unique as it is a non-storable commodity, and the markets remain extremely inefficient (Serletis and Bianchi, 2007; Uritskaya and Serletis, 2008).

Electricity prices are not a result of long-term but instant, usually on an hourly interval, balance of supply and demand. Moreover, as a consequence of the complexity of a wholesale electricity market, it can show an extremely high price volatility at times of peak demand and supply shortages. These price spikes are hard to predict and financial risk management is still a high priority for participants in deregulated electricity markets due to the substantial price and volume risks that the markets can exhibit (Angelus, 2001; Vehvilainen, 2002; Sioshansi, 2011).

The problem of predictability of electricity prices in deregulated markets has been considered in many previous studies (for instance, S.K. Aggarwal et al., 2009; Möst and Keles, 2010; Alvarez-Ramirez and Escarela-Perez, 2010; Benth et al., 2012). The values of prices can vary by a factor of 100 over a time scale of just several hours. These dramatic changes tend to occur in a seemingly spontaneous fashion which is sometimes erroneously interpreted as a signature of a random uncorrelated process (see for example Mayer et al., 2012). A more detailed mathematical analysis reveals nontrivial auto-correlations in these sudden price jumps (Knittel and Roberts, 2005; Fanone et al., 2013; Wang et al., 2013a,b) which indicate a possibility of prediction of electricity price movements based on the information on their historic evolution (Uritskaya and Serletis, 2008). However, it is a widely recognized fact that price fluctuations in energy markets display heavy distribution tails (Knittel and Roberts, 2005; Fanone et al., 2013; Lucia and Schwartz, 2002; Bystrm, 2005; Chan and Gray, 2006; Klüppelberg et al., 2010) causing substantial difficulties in building quantitative forecasting models of price behavior. Less attention has been paid to the analysis of temporal patterns underlying the observed statistical structure of

* Corresponding author.

http://dx.doi.org/10.1016/j.eneco.2015.01.012
0140-9883/

electricity markets and as a result modeling of their dynamics is still in its infancy and is typically limited to day-ahead models (Garcia et al., 2005; Nogales et al., 2002; Taylor et al., 2006; Huisman et al., 2007; Shafie-khah et al., 2011).

In this study, we take a few next steps toward answering fundamental questions related to the predictability of electricity prices. First of all, can deregulated electricity markets reach the state of efficiency with the Hurst index value close to other well-known markets, or this state is not reachable in the usual sense (Uritskaya, 2005a,b; Nakajima, 2013)? This is crucially important because if the electricity markets are inherently inefficient, the forecast can be built at various time scales. In this context, the inefficiency means that price history is relevant to the future price changes and can be used for their forecasting (Malkiel and Fama, 1970). The problem with Pareto-type statistics plays a special part, because not all heavy distribution tails can be approximated by a single probabilistic model. They can include several dynamic ranges described by distinct Pareto exponents. If such markets are predictable in principle, there might be particular price intervals for which the forecast is statistically stable, and these intervals are important to identify.

Another central question related to the predictability of electricity prices is how universal can be a model of electricity price behavior across different markets. In the present work, this question is addressed in frames of a quantitative analysis of electricity prices in three independent markets with different levels of liberalization — Alberta, Ontario (Canada) and Mid-C (USA) markets.

Dynamical and statistical properties of price fluctuations are investigated using several methods. First, we evaluate correlations in price dynamics across different time scales using the method of scale-dependent fractal exponent (Uritskaya and Serletis, 2008) obtained from detrended fluctuation analysis (DFA) (Peng et al., 1994, 1995; Wang and Liu, 2010; Wang et al., 2013c). We also use the Fourier spectral analysis to identify cyclic components in the electricity price dynamics, as well as the Pareto probability distribution analysis for testing the stability of statistical moments of the studied data. Spectral and DFA analysis results show no evidence of informational efficiency of electricity price fluctuations at any time scale. All three markets demonstrate different levels of inefficiency which could reflect their different sizes and structural diversification. Price movements in these markets are strongly anti-persistent (Uritskaya, 2005a). Together with Pareto analysis results, this anti-persistence indicates that electricity price movements can be predicted based on historic price records.

Next, we verify the possibility of price forecasting using phase diagrams representing the correlation of previous and current price increments. According to our results, the diagrams have a complex asymmetric shape revealing three basic scenarios of price movements. These scenarios remain the same for price movements at different time scales, from 1 h up to one month, and are found to represent strongly volatile market conditions. Based on these results, we show that price fluctuations in deregulated electricity markets are predictable by their nature. Our findings lay a foundation for future mathematical description of multiscale dynamics in deregulated electricity markets.

The plan of the paper is the following. Section 2 contains a detailed description of the analyzed data sets. Section 3 describes main results of our statistical analysis demonstrating the possibility of electricity price forecasting. This possibility is explored further in Section 4. Section 5 provides a brief summary of our study.

2. Data

As an outcome of the liberalization policies pursued in several countries from the 80s on, the so called day-ahead electricity market provides economists with a very challenging phenomenon. Electricity cannot be economically stored, which implies that demand and supply must be continuously balanced, so that the market price mainly reflects the demand and supply conditions prevailing at the very moment it has to be delivered to final users. Then, rather complex market systems have been set up, with the aim of reaching a reasonable trade-off between economic efficiency and system reliability. These systems are built around a market operator, whose task is to manage uniform-price, sealed-bid, bilateral auctions in order to construct aggregate demand and supply curves, and to determine equilibrium prices and quantities. The knife-edge character of such a price setting mechanism is pushed to the extreme by a very low price elasticity of demand, and by technical constraints which time by time lead to network congestion (see e.g. Klüppelberg et al., 2010; Bottazzi et al., 2005 and references therein).

The data studied in this paper consists of hourly real time pool electricity prices in Alberta, posted by the Alberta Electric System Operator (AESO), and Ontario, posted by the Independent Electricity System Operator (IESO). The data cover the period from May 1, 2002 to June 6, 2009. In addition to these Canadian markets, the Mid Columbia (Mid-C) market has been considered during the time interval 1 July, 2001 to 31 Oct, 2006. For each of the three hourly data sets, two secondary time series consisting of electricity prices during on- and off-peak hours have also been examined. Fig. 1 shows the time series under study, including the original data and their on- and off-subsets. Note that all plots contain numerous spikes with irregular timing and amplitude.

Alberta and Ontario are the only two Canadian provinces where wholesale electricity markets are fully deregulated (Alvarez-Ramirez and Escarela-Perez, 2010; Serletis and Shahmoradi, 2006). Alberta's market is dominated by fossil fuel generation and as such follows more closely the price of natural gas. Ontario's generation involves about 50% of nuclear and 25% of hydropower (Arciniegas and Arciniegas Rueda, 2008; S. Aggarwal et al., 2009) enabling a more stable price behavior (Zareipour et al., 2007). The average level of volatility of electricity prices in Alberta is about twice as high as in the Ontario market.

The Mid Columbia electricity market is not as deregulated as Alberta and Ontario are (Mjelde and Bessler, 2009). It is not a centralized power market, but it is a trading hub where power is bilaterally traded among utilities and marketers. The Mid-C price hub is a reference price for the Pacific NW region, which consists of Washington, Idaho, and Oregon. In this region, large utilities own generation and serve load under regulated rates. The generation is primarily hydro and the region typically exports to British Columbia and California (Uritskaya and Serletis, 2008; Deng and Oren, 2006). For these reasons, Mid-C prices are significantly less volatile than those in either Canadian market.

3. Statistical signatures and predictability

3.1. DFA and spectral signatures

For testing the informational efficiency of electricity price fluctuations, multiscale correlations of price dynamics were evaluated across different time scales. Two complementary approaches were used to achieve this goal — the scale-dependent DFA and the Fourier spectral analysis.

The former of the two approaches has been first introduced in Uritskaya and Serletis (2008). In contrast to previous methods manipulating with average scaling exponents characterizing broad scaling ranges, we investigated the distribution of local DFA exponents over all time scales involved. This approach was shown to be the only suitable when the signals under study encompass qualitatively different types of behavior including random price movements, cycles, and spikes. Using the DFA as the base algorithm is justified by the presence of multiscale trends in the electricity data (Uritskaya, 2005b; Serletis et al., 2008). The scale-dependent version of this algorithm presented in Uritskaya and Serletis (2008) enables the investigation of complex types of nonlinear behavior of financial and economic indicators by providing detailed information on the distribution of correlations over different scales, and is especially useful for quantitative analysis of market efficiency.

The DFA technique was applied to the time-integrated signal

$$y(k) = \sum_{t=1}^{k} (x(t) - \langle x \rangle), \tag{1}$$