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Heterogeneous price dynamics in U.S. regional electricity markets☆

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ABSTRACT

The U.S. electricity wholesale market is organized in several deregulated regional markets. This paper compares price dynamics of electricity in the U.S. wholesale markets and shows that electricity prices from the West and East coasts have different regime dynamics. Our methodology suggests that electricity prices are better parameterized by four regimes with different levels of volatility. Additionally, West and East coast markets differ in the time spent in each regime. The extremely high volatility regime describes West coast prices during the California electricity crisis, but East coast prices are also frequent in that regime. We find evidence of synchronization of price dynamics in the mean-reverting and highest volatility regimes, i.e., prices from the East and West coasts tend to be in the same regimes at the same time.

1. Introduction

In the late 1980s and 1990s, the United States (U.S.) electricity sector underwent a set of structural and regulatory reforms in which the creation of wholesale competitive markets was a major milestone. Although the technical features of transmission and distribution of electricity do not favor competition, at the generation level different participants can supply the electric grid (see a discussion in Haas and Auer, 2006). A set of rules was established to encourage the participation of independent generators. For instance, established transmission owners had to provide access to their networks at cost-based prices to end discriminatory practices against unaffiliated generators or to allow independent generators to sell power to the incumbent utility companies.[1]

The transition to a competitive market framework brought new dynamics to wholesale electricity prices. With deregulation, prices would inevitably oscillate as a result of interactions between demand and supply. As there are no electricity inventories to buffer shocks, prices absorb all demand and supply shocks (e.g., weather changes, outages), showing spikes that increase volatility.

The concerns about price spikes (and price increases in general) are exacerbated by the perceived potential for market power in the electricity sector (see a discussion in Borenstein, 1999). Factors such as economies of scale in generation or inefficiency of the duplication of grids favor imperfect competition, and ultimately deregulation could have adverse effects causing prices to soar. The concerns about market power were legitimated by the events in California in 2000–2001, where the exploitation of market design imperfections and market power triggered an explosion in wholesale prices. Moreover, the occurrence of blackouts caused severe economic losses.

Hadsell et al. (2004) and Park et al. (2006) study electricity prices in U.S. wholesale markets. Hadsell et al. (2004) analyze the volatility before and after the deregulation for the 1996–2001 period using a Thresholds Autoregressive Conditional Heteroskedasticity (TARCH) model. They document more unstable volatility and a change in persistence of volatility after the deregulation period. Their results indicate regional differences as volatility persistence was smaller in eastern markets. Park et al. (2006) use a vector autoregressive (VAR) model to study price discovery and contemporaneous and short-run interdependencies in U.S. regional markets in the 1998–2002 period. Their results suggest that shocks in eastern markets cause large and long lasting responses in the western markets.

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[1] For a comprehensive description of the changes in the U.S. electricity markets, we refer to Joskow (1997).

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Our paper analyzes price dynamics in U.S. wholesale electricity markets by regime-switching models (RSM, hereafter). These models, introduced by Hamilton (1989), allow the disclosure of states, or regimes, that reflect different interactions of demand and supply. They have been used to model electricity prices as they accommodate well electricity price features such as asymmetric volatility, jumps, and spikes (see, e.g., Bierbrauer et al., 2007; Haldrup et al., 2010; Huisman and Mahieu, 2003; Fong and See, 2002; Janczura and Weron, 2010). Their empirical application is hindered by the computational burden in model estimation, which increases with the number of time series, time points, and regimes. Seminal works set up two regimes a priori. Deng (2000) considered three models of spot price dynamics in a derivative pricing context. These included a two-regime switching specification for the log-prices in which the base regime is driven by an autoregressive (AR) process of order one, i.e., AR(1). Ethier and Mount (1998) propose a two-regime model with mean-reverting AR(1) processes for the log-prices to study electricity spot prices in a deregulated market. Strong empirical support for the existence of different means and variances in the two regimes was found for two U.S. and two Australian markets. Huisman and Mahieu (2003) were the first to propose a three-regime model, but with constraints: the initial jump regime is immediately followed by the mean-reversing regime and then moves back to the base regime. Using electricity price data from the Dutch, German and U.K. markets, they found that a regime-switching model performs better than a stochastic jump model specification for both mean-reversion and spikes. More recently, research has also specified a three-regime model (see, e.g., Bierbrauer et al.,2007 and Janczura and Weron, 2010). Our work departs from previous studies because we do not impose a priori the number of regimes that best captures the features of the electricity time series.

We propose a new approach that allows the study of the cyclical behavior of several electricity price time series in a parsimonious way, providing new insights into the existence of common regimes and synchronization between them. Moreover, the same framework is used for all the estimation allowing the investigation of regime synchronization and providing a comparison of the dynamics of different wholesale markets.

To study price dynamics in U.S. wholesale markets, we take the Dow Jones U.S. Electricity Price Indexes. These price indexes cover several geographical regions of the U.S. in the period from 1999 to June 2010.

We conclude that prices in the same U.S. region share the same regime dynamics, i.e., prices of the eastern (western) wholesale markets behave similarly.

The best model parametrization has four regimes. In addition to the common typification of base, spike and mean-reverting regimes (see, e.g., Huisman and Mahieu, 2003; Janczura and Weron, 2010; Mari, 2006), there is an extremely high volatility regime that describes West coast prices during the California electricity crisis. However, prices of the East coast markets are frequent in that regime as well.

Regional electricity markets seem to differ in the time spent in each regime. Western wholesale prices spend more time in the mean-reverting regime, while eastern markets spend more time in the spike regime; this may result from the introduction of mitigation procedures after the energy crisis in California (Moulton, 2005).

To address the question of whether wholesale prices of the East and West coasts are in the same regime at the same time, we compute synchronization measures between regimes. We find evidence of price synchronization in the highest volatility and in the mean-reverting regimes, i.e., prices from the East and West coasts tend to be in those regimes at the same time.

The re-estimation of the model for the post-California crisis period confirms that the dynamics of electricity wholesale prices are still better described by four regimes, but the crisis regime is very occasional in western markets. Consequently, regional regime synchronization decreases.

Results on regional differences are consistent with the findings of Hadsell et al. (2004) and Park et al. (2006). The results of Park et al. (2006) suggest that shocks in eastern markets cause large and long lasting responses in the western markets, which they interpret as western markets having access to price information from eastern markets because of time zone differences between the two regions.

Our paper extends the literature on the application of RSM to electricity markets by showing that relaxing the restriction on the number of regimes leads to a better characterization of regime dynamics. In particular, it is helpful to have more regimes so as to capture different types of imbalances in power markets.

Our paper offers insights not only for regulators who need to closely monitor price dynamics in markets due to natural hindrances to market competition, but also for the increasing number of participants in electricity markets. These participants, such as generation, distribution or transmission companies face enormous risks due to the high volatility that characterizes these markets (Huisman and Mahieu, 2003).

2. Data

To study electricity price dynamics in the U.S., we take the Dow Jones U.S. Electricity Price Indexes from Datastream as they cover different geographical regions of the U.S. From the West coast, and conditional on data availability, we use California Oregon Border Electricity Price Index (COB), Four Corners Electricity Price Index (4_CORNERS), Mid Columbia Electricity Price Index (MID_COLUMBIA), and Palo Verde Electricity Price Index (PALO_VERDE). From the East coast, we use prices from Cinergy Electricity Price Index (CINERGY) and PJM Electricity Price Index (PJM), which is the world's largest competitive wholesale electricity market.[2]

These indexes are volume-weighted averages of wholesale electricity transactions in different U.S. electricity markets and provide a clear spot market indication for over-the-counter trading in that region.

Prices are daily, nominal and in U.S. dollars. Our sample covers prices from January 6th 1999 through June 30th 2010, for a total of 2997 price observations. As is common in the literature, returns are computed as the change of the logarithm of the settlement prices. Let P_{it} be the observed daily closing price of market i on day t, $i = 1,\ldots,n$ and $t = 0,\ldots, T$. Daily rates of prices are defined as the log-rate percentage: $y_{it} = 100 \times \log(P_{it}/P_{i,t-1})$, $t = 1,\ldots,T$.

Fig. 1 plots the trend in electricity prices for the entire period. For the sake of comparability, the different time series are presented as indexes in which the first observation has the value of 100. Electricity prices show large spikes in 2000–2001, i.e., the period of California electricity crisis.[3] Fig. 2 depicts log-returns of electricity indexes. Prices from the eastern markets – CINERGY and PJM – tend to present frequent price spikes. We note the high levels of volatility and volatility persistence also reported in other studies (see, e.g., Hadsell et al., 2004).

Summary statistics of electricity price returns are reported in Panel A of Table 1. Firstly, mean returns (second column) are positive for all time series. As expected, electricity returns show high levels of dispersion (standard deviation), and are highest for CINERGY. In accordance with Hadsell et al. (2004), electricity prices tend to be positively skewed due to demand shocks. *4_CORNERS*, *MID_COLOMBIA* and *PALO_VERDE* have negative skewness. Kurtosis is also higher in western than eastern markets, probably inflated by the California electricity crisis. Not surprisingly, normality of price returns is rejected by the Jarque–Bera test (*p-value* < 0.001) for all time series.

[2] The corresponding geographical areas are as follows: COB from California and Oregon Border, 4_CORNERS from Utah, Colorado, New Mexico and Arizona, MID_COLUMBIA from Washington, PALO_VERDE from Arizona, CINERGY from Ohio, Indiana, and PJM from Pennsylvania–New Jersey–Maryland interconnection.

[3] A detailed account of the California electricity crisis can be found in Faruqui et al. (2001), Moulton (2005), and Woo (2001).