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Identifying regime shifts in the US electricity market based on price fluctuations ☆

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HIGHLIGHTS

- Researching correlations evolution of the U.S. electricity market based on RMT.
- Identifying four regime shifts with five periods among the three departments.
- Analysing the characteristics of cluster evolution and verifying the existence of regime shifts.
- Studying the electricity price level influences regime shifts.

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ABSTRACT

Electricity power is a basic industrial component which plays an important role in the economy of a nation. In this paper, the correlations evolution of electricity prices among 50 states and the District of Columbia are studied based on random matrix theory (RMT) Four regime shifts are identified from January 1990 to August 2014 in the U.S. residential, commercial and industrial electricity markets. Then, the genetic algorithm (GA) is applied to analyze the clusters of evolution. The results show that, the correlations of electricity prices increased continually in the three departments. However, it decreased in 2012 which further confirms its sensitivity to fuel market. Besides, four regime shifts exist in the three departments though the different times of occurrence caused by price level. And, the fluctuation of community evolution is consistent with four regime shifts. The final part is a summary of the research analyzed and results.

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1. Introduction

Electricity industry [1–5] is the foundation of national economy, and electricity price affects expenditure in other fields as well as the living standard of residents directly or indirectly. In the 1980s, the reform of electricity industry overtook the world [6–9]. Western countries lost the regulations to restructure and establish a competitive electricity market, which has spread in the global electricity market. In the U.S., most of electricity industries are privatized [10,11]. Electricity industry reforms mainly means reducing regulation while increasing competition in spite of the programs of reform being different for regions. The purpose is to fuse market mechanism into electricity industry, to optimize and improve the allocation and efficiency of resources using competition and privatization.

In recent years, one of the most important commodities for national development and people's life is the electricity market, and policy makers and researchers are increasingly concerned about. It should be mentioned that related surveys on electricity market have been conducted by a few researchers and organizations. Torrent-Fontbona et al. [12] proposed a new method that, given the demanded power of close consumers for a time window (power profile), electricity costs were reduced by reallocating the demanded power among consumers in order to keep all of them below or equal to their contracted power. Cappers et al. [13] summarized the existing contribution of Demand Response resources in the U.S. electricity markets, and concluded that competition is critical to the development of electricity markets. A more recent update was accomplished by Castagneto-Gissey et al. [14] in 2014 on European electricity market. They analyzed the interactions of a representative sample of 13 European electricity spot prices during the period 2007–2012 based on complex network theory. Their model establishes a time-varying network describing the evolving influences among the European electricity prices, and detects important changes in market integration. Similar surveys have also been

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conducted in other part of the world. For example, by using a fractional co-integration analysis, de Menezes Lilian et al. [15] showed that long memory for price shocks and co-integration exist only for a few markets, such as Germany, Netherlands and France. Subsequent survey, Pereira and Pronto [16] proposed a multistage stochastic optimization method for planning energy systems based on the approximation of the expected cost to go functions through the introduction of piecewise linear functions. Albadi and El-Saadany [17] applied an optimal power flow to economic dispatch including load forecast. The electricity prices for each period of the next day were calculated considering price elasticity. Ketter et al. [18] used an energy market simulator to study the dynamics of customer and retailer decision making. They introduced a coalition of customers and proposed a novel methodology to reduce electricity costs from the view of terminal consumer point. Wang and Li [19] reported a survey of Time-of-Use (TOU) pricing programs targeted industrial customers, and examined various industrial scenarios to predict electricity cost savings when customers were facing the transition from flat rates to TOU pricing.

The existing literatures has provided a solid empirical investigation and a good reference to understand the evolution of certain electricity markets around the world, but some studies of U.S. electricity market still needs to be further researched. The U.S. electricity market is one of the largest electricity markets in the world and the first country to reform. Two reasons supported the study of the U.S. electricity market. The first being its mature operation mechanism and supervision systems and the other are being the higher market competition. This paper researches the correlation coefficient of electricity price, and identifies the influencing factors whether they relate to policy, climate, geographical location, or distribution of coal resources. Our objective is to explore the principle of U.S. electricity market from the angle of electricity price and provide a reference for future research in the electricity market. We hope this research could be used to facilitate reforms in China's electricity market, as well as help energy investors to assess potential risk of the whole electricity market.

Motivated by these facts, this paper applies the RMT to the electricity market. First, the calculated parameters of electricity prices for 50 states and the District of Columbia are calculated by the method of RMT, with our focus on the correlations, eigenvalues and eigenvectors for the three departments. Secondly, we then proceed with the mechanisms of electricity market reform as well as the influencing factors. Then, the evolutionary characteristics of the electricity market are detected. Lastly, we identify and determine the important shift periods and some stylized facts of the actual electricity market the method of least-squares regression. This study reveals the main influencing factors in the regime shifts which are detected in the electricity market. Timely adjustment of policy in developing the electricity market would be given in accordance with the conclusions which are summarized from the analysis of the correlation between regime shifts and influencing factors.

The continuing parts of this paper is as follows: Section 2, the basic situation of the U.S. electricity market is introduced. Data sources and methods are showed in Section 3. In Section 4, the empirical study of the electricity prices for residential, commercial and industrial are presented. Section 5 provides concluding remarks.

2. Present situation of the U.S. electricity market

The U.S. has the largest and most advanced economies in the world with large total installed capacity and electricity consumption in the world. Coal-electricity is the main generating mode due to its rich coal resource. Therefore, the situation from the perspective of generation capacity, electric structure and electricity consumption is analyzed as follows.

2.1. Generation capacity and electricity structure

In the U.S., the generation capacity increased from 2000 to 2014. Data used in this part is downloaded from EIA [20]. In 2009, it decreased obviously as shown in Fig. 1(a and b). The electricity sources are mainly coal-electricity, gas-electricity and nuclear-electricity. However, the proportions of coal-electricity and gas-electricity have changed recently.

From the structure of generation capacity, the percentage of nuclear-electric varies between 19%–20%, while conventional hydroelectric is in the vicinity of 6–7%. However, the change in fuel oil-electricity is obvious declining from 3% to 0.7%, and will keep declining according to the national policy. Due to the adjustment in coal-electricity and gas-electricity in 2005, the percentage of coal-electricity declined from 52% to 38% while gas-electricity increased from 16% to 27%. However, coal-electricity has been recovering in 2012. In addition, conventional hydro-electricity and nuclear-electricity have remained in a stable level over a decade.

2.2. Electricity price

The U.S. is a federal country, and its electricity regulatory system also complies with federal and state government. It is therefore

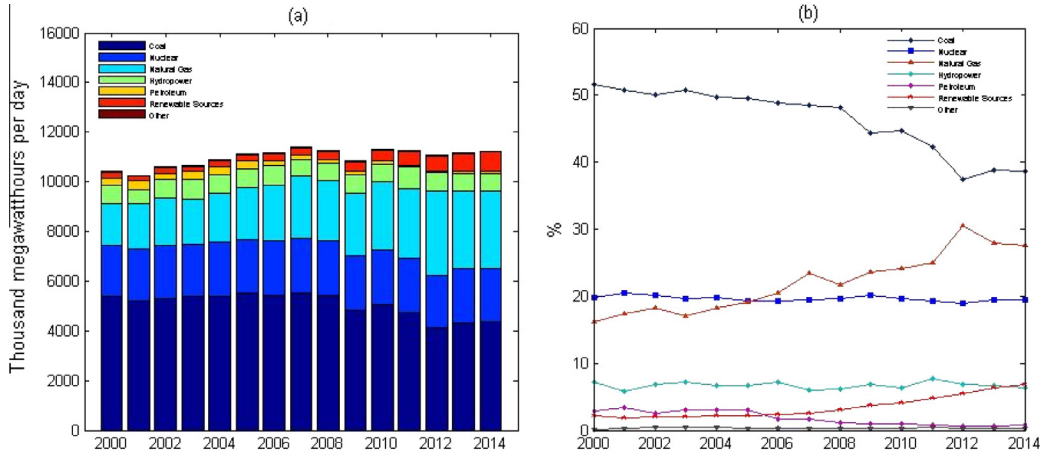

Fig. 1. Variation of electricity production in the U.S. *Note:* (a) Electricity production by energy resources. (b) Variation of electricity production percentage by energy resources.

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