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Industrial and residential electricity demand dynamics in Japan: How did price and income elasticities evolve from 1989 to 2014?

Nan Wang*, Gento Mogi

Department of Technology Management for Innovation, School of Engineering, the University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

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ABSTRACT

This study estimates the price and income elasticities of industrial and residential electricity demand in Japan with the annual data from 1989 to 2014. A time varying parameter (TVP) model with the Kalman filter is applied to monitor the evolution of consumer behaviors in the "post-bubble" period given the exogenous shock (financial crisis in 2008) and the structural breaks (electricity deregulation and Fukushima Daiichi crisis). The TVP model can provide a robust estimation of elasticities and can detect the outliers and the structural breaks. The results suggest that both industrial and residential consumers become less sensitive to price after the electricity deregulation and the financial crisis, and more sensitive to price after the Fukushima Daiichi crisis. Especially the industrial sector is less sensitive to price after the retail deregulation. By contrast, the income elasticities of industrial and residential sector consumers are stable during the examined period. Results also indicate that a negative relationship exists between the price elasticity of electricity demand and the price level of electricity after the electric sector deregulation. Some insights on the further electric sector reform and the environmental taxation in Japan are also provided.

1. Introduction

Electricity demand is of great importance to policymakers and electric companies. The insight of electricity demand dynamics is essential for regulators when planning for infrastructure and grid investment (Nakajima and Hamori, 2010). In order to properly model the demand-side behavior of the electricity market, electricity price and consumer income are widely accepted as potential explanatory variables (Dilaver and Hunt, 2011; Chang et al., 2014). Further, the price elasticity of electricity demand is also the determinate of tax revenue and effectiveness of environmental tax (Mori, 2012) and largely affects the consumer surplus. In Japan, the carbon tax was strongly opposed by Japan Business Federation (JBF) in 2003 claiming that price elasticity of energy demand is low that carbon tax cannot suppress carbon emission (JBF, 2003). The carbon tax has only been imposed upon the industrial sector in Japan as a consequence.

The growing literature on electricity demand modeling has offered different dimensions and choices in methodologies. Fixed coefficient models are among the most widely-used modeling approaches, ranging from Engle-Granger cointegration, Johansen cointegration, error correction model (ECM) to autoregressive distributed lag model (ARDL). Salisu and Ayinde (2016) provide a recent review of the methodologies on demand modeling. More recently, there is a growing trend of supporting time varying coefficients considering the parameter instability due to outliers and structural breaks (Inglesi-Lotz, 2011; Arisoy and Ozturk, 2014; Chang et al., 2014). An outlier can be captured by a dummy explanatory variable while a structural break can be modeled by a staircase intervention (Harvey et al., 1998). Time varying parameter models is also able to detect such structural change and outliers with drift in parameters and auxiliary residuals (Durbin and Koopman, 2001). In this research, financial crisis, together with the oil shock (the oil prices steepened sharply, sending the price to a high of $145/barrel on July 2008 and collapsed on December 2008 at the price of $32/barrel) in 2008 are viewed as the outliers while electricity deregulation and Fukushima crisis are regarded as the internal structural changes. The contribution of this study is not only to methodologically consider and capture the effects of structural breaks and outliers, but also to provide a more robust estimation of the evolution of price and income elasticities. Also, this work enhances the understanding of consumers' behaviors for the rationality of environmental policy making process and electricity market design.

1.1. Overview of electricity demand and supply in Japan

In Japan, despite the shortage of energy resources, electricity demand is generally met by the supply even after the Fukushima crisis

* Corresponding author.
E-mail addresses: wang1nan123@gmail.com (N. Wang), mogi@tmi.t.u-tokyo.ac.jp (G. Mogi).

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in 2011. Thus, in this research, it is possible to assume that the electricity demand is equal to the electricity consumption in Japan. Fig. 1 illustrates the electricity demand and supply in Japan from 1973 to 2013. From the supply side, several trends have been observed: Firstly, Japanese government tended to diversify power mix by increasing the portion of LNG and nuclear to decrease the proportion of oil power generation after the 1973 oil crisis. Secondly, electricity generation from coal increased in the 1990s. Thirdly, the proportion and volume of the privately generated power grew rapidly. Lastly, most of the nuclear power plants shut down after 2011 and the thermal power plants took over their share. From the demand side, the electricity consumption in Japan can be divided into three periods: 1973–1989, 1990–2007, and 2008–2014. Before the bubble burst[1] in 1989, the electricity demand was fast-growing due to the economic development and the population growth. From 1973–1989, the electricity consumption increased from 0.42 Trillion kWh to 0.72 trillion kWh. After 1989, during the second period, the electricity consumption growth slowed down. In 2007, the electricity consumption reached 1.07 trillion kWh as a peak. After 2008, in the third period, the electricity consumption in Japan has been declining. In 2014, electricity consumption fell to 0.99 trillion kWh.

This research focuses on the "post- bubble" period (electricity demand slow-growth period and declining period) in Japan. There are two reasons that the "post- bubble" period is examined. First, the post-bubble period is the so-called recession period in Japan and it may continue for the coming decades. Thus, monitoring consumer's behavior under recession economy might be meaningful for the future policy making. Second, the market structure is changed due to the electricity deregulation during the "post-bubble" period.

1.2. Electricity deregulation in Japan

Electricity deregulation began in Chile in 1982 and then spread across Latin America and Europe in the late 1980s. The general purposes of the electricity deregulation are introducing competition to power generation, reducing the public's financial burden, providing alternatives for consumers, and attracting private investment to the power sector. However, after more than 30 years, the understanding of the electricity deregulation and its impacts on consumers are still very limited.

Since 1951, the electric companies in Japan have improved the reliability of supply and the efficiency of the service. Even though the electricity price in Japan increased significantly after the oil shock in 1973, it dropped steadily after the shock and the power mix in Japan was diversified with more LNG power plants and nuclear power plants. However, after the bubble burst, industrial users became eager to further cut their cost in response to their severe financial status. The electricity price in Japan, which was the highest among the OECD countries, was criticized especially by the industrial users. It was widely accepted by the public that the regional monopoly and lack of competition were the main reasons of the relatively high price. This concern became the main social drive for the electricity deregulation in Japan.

Throughout its long history, Japanese electricity industry was highly regulated. The electricity system was designed on the premises of a vertical integrated structure, a regional monopoly, and rate of return (ROR) tariff regulation. Owing to the global trend of electricity deregulation and the evidence of declining economies of scale in the electricity industry, as explained by Nemoto et al. (1993), Goto and Sueyoshi (1998), and Kuwabara and Ida (2000), The Ministry of Economy, Trade and Industry (METI) partially deregulated the electricity industry. Electricity deregulation serves a part of the overall economic reform that aims to recover from the severe recession since the start of the bubble burst in 1989. The main targets of electricity deregulation are minimizing electricity rates, offering more choices for consumers, and opening new business opportunities for investors, under the premise of securing a stable supply of electricity. The process of the electricity deregulation started from 1995 when independent power producers (IPPs) were allowed to enter the power generation business and to compete in the bidding of the power supply contracts with the incumbent electric power utilities. In order to further encourage electricity trade and promote supplier competition, a wholesale market (Japan Electric Power Exchange, JPEX) was established in 2003. The retail deregulation was implemented step by step from ultra-high voltage users in 1999 to high voltage users in 2005. Consequently, hundreds of power producers and suppliers (PPSs) entered into the retail sector. The Japanese government further introduced regulation for third party access to transmission network with negotiation base tariff in 1999. Total retail deregulation was implemented in 2016. The Organization for Cross-regional Coordination of Transmission Operation was established as an independent regulator of the electric system in 2015 as an important milestone in the electricity deregulation. As for the next step of the reform, unbinding of the transmission and distribution sector is scheduled after 2018. Table 1 summarizes the electricity deregulation process.

Energy sector policymaking in Japan such as electricity deregulation is mostly drawn from the case studies of other pioneered countries such as the UK, the United States, and the Nordic nations. However, the quantitative analysis of the impact on consumers is still rare to our knowledge. Thus in this study, a time-varying parameter (TVP) approach is proposed using the state-space model based on the Kalman filter technique to estimate the evolving price elasticities and income elasticities of the industrial and residential sectors in Japan. This approach also enables the detection of the exogenous shocks and structural breaks. The remainder of the paper is organized as follows. Section 2 reviews the related literature on estimating electricity price and income elasticities. Section 3 gives an overview of the model and methodology of this study. Section 3 describes the data used for analysis. Section 4 presents the empirical results. Section 5 discusses and interprets the results. Section 6 summarizes this study and draws policy implications.

2. Literature review

During the past several decades, the electricity industry has received great attention globally. Restructuring the electricity industry by introducing competition, deregulation, and reform has been widely accepted by most governments. To understand the electricity market, a number of econometric methods have been applied to monitor the electricity sector, especially the electricity demand. In this section, both international and domestic studies are reviewed.

2.1. International studies

Autoregressive distribution lag (ARDL) method (e.g., Halicioglu, 2007; Ziramba, 2008; Amusa et al., 2009) and partial adjustment method (Kamerschen and Porter, 2004; Hosoe and Akiyama, 2009; Tanishita, 2009; Okajima and Okajima, 2013; Otsuka, 2015) are widely applied to estimate the sectoral or aggregate electricity demand. Okajima and Okajima (2013) suggest that ARDL approach works well with larger time series while partial adjustment works well with smaller time series. Except for the methods mentioned above, other regression techniques such as Johansen co-integration, generalized method of moments (GMM), dynamic ordinary least square (DOLS), and panel fully-modified ordinary least square (FMOLS) are also widely used.

Most recent studies on estimating electricity demand distinguish between short-run elasticities and long-run elasticities, the long-run

[1] Japan's equity and real estate bubbles in Japan started from 1986 to 1991 in which real estate and stock market prices were greatly inflated. The bubble burst began at the end of 1989 which represented the start of the lost decades due to its gradual effect. For more information please refer to Saxonhouse and Stern (2004) and Wood (2005).