博士論文

ECONOMIC ANALYSIS ON THE IMPACT OF JAPANESE ELECTRIC SECTOR DEREGULATION

（日本における電力自由化の影響に関する経済分析）

A dissertation submitted

to the University of Tokyo in

fulfillment of the requirements for the

degree of Doctor of Philosophy

by

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Feb, 2017

ABSTRCT

The late1980s marked the beginning of market driven reforms in the electricity sector. Most of the economies around the world have initiated power sector reforms since late 1980s irrespective of the sector size, resource endowments, institutional capacity and economic development. Japanese government also follows this great trend and deregulate electric sector step by step. However, the impacts of the reform have not yet been clear. In order to fill this gap, this dissertation qualitatively and quantitatively assesses the process and outcomes of market-based reforms on electricity sector both from demand and supply side. Thus, the most direct research questions of this dissertation are simplified as two research questions:

Does deregulation alter the behaviors of consumers? How did consumer behaviors change during the deregulation periods?

Does deregulation change the innovation behavors of the electric sector? How does deregulation change the R&D behaviors of electric utilities?

In chapter 2, the income and price elasticities of electricity demand in Japan have been estimated. Previous studies in Japan follow the implicit assumption that price elasticity and income elasticity are constant. However, this assumption may be unrealistic. This chapter estimates the price and income elasticities of electricity demand in the industrial and residential sectors in Japan with 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 structure breaks (electricity deregulation and Fukushima Daiichi crisis). Our model provides more robust results against the fixed coefficient model and is able to detect the outliers and structure breaks. The estimation results suggest that both industrial and residential consumers become less sensitive to price after electricity deregulation and the financial crisis, and more sensitive to price after the Fukushima Daiichi crisis. 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 electricity deregulation. Some insights on the further electric sector reform and the environmental taxation in Japan are also provided.

In chapter 3, the impact of the deregulation on utility R&D behavior has been analysed. Most previous studies in Japan only focus on the benefit of the static efficiency from the deregulation. However, in the long run, innovation is the source of continued efficiency and productivity improvements. The electricity deregulation started from the 1990s has altered the R&D behavior of electricity utilities remarkably. This chapter estimates both R&D input and R&D output of electric utilities in Japan with an econometric approach. Based on the empirical analysis of innovation activities of nine electric utilities in Japan, it is found that deregulation reduces the R&D investment of the incumbent electric utilities but increases the firm patent applications and patent citations/ average patent citations. In other words, deregulation will lead to better innovation productivity. We also try to estimate how incumbent electricity utilities change their R&D

strategy to adapt to new challenges during the transition a competition environment. The breakup of R&D expenditure from 1994 to 2005 implies that the R&D priority of the electric companies switch to cost-saving and business-oriented projects under the deregulation process. The declining R&D efforts may be detrimental to the reliability and dynamic efficiency of the electricity system especially more renewable energy has been incorporated, as well as the innovation maintenance of introducing smart grid and environmental concerns.

In chapter 4, the contributions and limitations of this paper are concluded. This study contributes to the international efforts to estimate the impacts of electricity deregulation on consumer behaviors and R&D behaviors of the electric utilities with econometric approaches. The policy makers may need to consider the changing behaviors of consumers as well as utility R&D when designing the future reform scheme and agenda.

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CHAPTER 1 **Introduction**

1.1 **Industrial policy, a paradox?**

The post-war Japanese "miracle" draws attentions of economists for the expansion of demand, high manufacturing productivity, huge international trade revenue and high GDP growth rate in Japan. The "miracle" is believed to be caused by the successful industrial policy (Johnson, 1982). But the position of government and the effectiveness of industrial policy are ambiguous among economic researchers (伊藤等, 1988; Buigues and Sekkat, 2009; Stiglitz and Lin, 2013).

Also, the definition of industrial policy is ambiguous in economic textbooks. It is sometimes defined as a government's strategic effort to encourage the development and growth of part or all of the manufacturing sector as well as other sectors of the economy. In this dissertation, the structural reform and deregulation of electricity sector are also viewed as one kind of industrial policy. This definition of industrial policy can also be seen in 大橋 (2015).

According to Porter (1990), government should play a supportive role for national competitiveness through encouraging change, promoting domestic rivalry and stimulating innovation. However, whether industrial policy is beneficial is always arguable. The failure of market and the failure of governance exist simultaneously and lead to much debate on which one of them is more pervasive and severe.

1.2 Reform in electric sector in a liberalized age

Public utility regulation started in the nineteenth century for network industries like gas, water, railways, telegraph, electricity, and telecommunication. These networks need access rights from the community or government while costly and large sunk cost of the network raises a fear that competition on prices will prevent the investor to gain a fair return on the investment. Regulation, applied in these industries usually is designed to balance the interests of investors and consumer. If a satisfactory balance could be achieved, regulated utilities with private ownership are more likely to exist. If the regulation is badly designed, private investors are less motivated due to increasing possible risk, uncertainty and less return or lack the financial ability to invest. In this case, utilities with public ownership will occur more likely. The essence of a network sector reform starts from a simple question: who can do better, the government (public sector) or the private sector?

In the beginning of the 1970s, regulatory action and legislation performed a trend of deregulation in most industries which previously subjected to government interference and regulation. The industries include: 1. Transportation: airlines and railroads; 2. Energy: natural gas, oil, coal and electricity; 3. Broadcast and communication: postal service, cable

TV and telecommunication; 4. Health: hospitals and medicines; 5. Banking and financial sector. The fundamental change in supply and demand in these industries, led by the technological advancements, is the primary source of the deregulation trend. Also, political interests of stakeholders and the political process always play central roles in the reform process. The dynamics of political interest also shape the reform direction, sequence and possible output.

Electric systems around the world are physically and operationally very similar. The physical functions or sectors of the industry are generation, system operation, transmission, and distribution. The electricity selling is either through wholesaling or retailing. The typical organization of the industry prior to deregulation is usually composed of one vertically integrated company or several regional vertically integrated companies, incorporating all these functions that mentioned above. These companies build their own generating plants and coordinated the planning of generation with the planning of transmission and distribution. These companies are obligated to supply electricity to consumer customers and other small-scale electricity users in the area at the public prices and contractual terms.

1.3 Standard textbook reform in electric sector

Pioneered by Chile (1982) and UK (1990), the "standard textbook reform" became widely accepted by the major OECD economies which targets at improving the operational efficiency of electric sector utility. The basic ideas of the reform are promoting competition and utilizing market mechanism to achieve a better allocation of resources, through the implementation of cost-reflective pricing; establishment of competitive environment for generation market, wholesale market and retail market, and the effective operation of transmission networks by an independent system operator (Pollitt, 2004).

The "standard textbook reform" includes sequenced measures as follows: 1. Modification of electricity related legislation; 2. partially or overall privatization of the electric sector; 3.opening up of the sector to private generation companies or Independent Power Producers (IPPs); 4. unbundling and corporatization of vertically integrated state-owned utilities; 5. commercialization of competitive sector (generation, distribution and retailing) and monopoly sectors (distribution, transmission and system operation); 6. establishment of independent regulation authority. Deregulation is also embraced by developing countries due to their urgent needs to confront the problems like unbalanced supply and demand, bad performance of utilities and financial deficits.

The vertical separation or unbundling of electric industry mainly focus on the function based separation. The unbundling mainly divides the electric industry into the potentially competitive segments (generation, distribution and retail) from the natural monopoly segments (the transmission and distribution networks). The model assumed that not all aspects of the electricity supply industry are monopolistic and electricity can also be generated and supplied by private and competitive firms apart from the state.

Privatization is another component of electric sector reform. It is based on the implicit assumption that private sectors could better allocate the scarce capital resources and ensure efficient management of the system with market mechanism.

According to North (1990), institutions are humanly devised constraints that structure human interaction at the political, economic and social levels, provide an incentive structure of an economy, create order and reduce uncertainty in exchange. As Stiglitz (1998) suggests regulation may become a tool of self-interest within the government or ruling elite. Jean- Jacques Laffont, who is credited as the father of modern regulation economics, provide theoretical research framework on regulation of network industry (Laffont, J. J., 2005). In his book, Laffont emphasizes the effectiveness of regulation is constrained by weak institutional environment and information asymmetrices. The institutional challenge is mainly because: 1. regulators are generally short of human resources and financial budget; 2. auditing system is incomplete; 3. the judiciary lacks in experience. The information asymmetry between regulator and operator, as well as the inability of regulator, usually degrades the regulation output. The outputs of regulatory designs are usually limited by these institutional constraints. The Laffont theory is based on agency model and incomplete contract theory and is workable when information asymmetries dominate and the multi-agency problem is severe.

Thus, the standard model also emphasizes the need to create powerful and effective new institutions in the form of independent regulators and regulatory agencies. An independent regulator would act as the representative of public interests (Armstrong et al., 1994). According to the understanding of most scholars, an independent regulatory authority with adequate capacities like staff, powers and information about the costs, service quality and performance of the utilities will ensure proper conduct in the industry by effectively implementing the incentive regulation of the monopoly segments in terms of market entry, network charges and network access. As an extension of this idea, many scholars assume that incentive regulation of monopoly electricity networks will, to some extent, replace a competitive market (Littlechild, 1992).

The standard textbook reform also includes other measures: restructuring generation segment to create adequate number of competing generators and suppliers, designation of an independent system operator to maintain network stability and facilitate competition, creation of wholesale market application of regulatory rules to promote access to the transmission networks, unbundling of retail tariffs and rules to enable access to distribution networks (Joskow, 2000).

1.4 **Purpose of this study**

The purpose of this empirical research is not to assess or promote deregulation. It is rather intended to understand the impact and consequence of such "institutional change" in developed countries based on the example of Japan electric sector. The major contribution of the current work remains in deriving relevant reform options and policy recommendations for the electricity sector based on the lessons learnt after more than two decades of reforms in the global electricity industries.

1.5 **Research questions and the structure of the dissertation**

Good empirical research in industrial organization should start with some basic questions about firms, consumers, markets, policies and institutions and the interaction between them (Joscow, 2005). In this research, the statement of Joscow is followed by touching upon basic questions on the interactions within players in electricity market. The research questions are:

Does deregulation alter the behavior of consumers? How do consumer behaviors change during the deregulation periods?

Does deregulation change the innovation behavors of the electric sector? How does deregulation change the R&D behavior of electric utilities?

This paper focuses on electricity sector and analyses the connection of consumer, market and government (chapter 2); supplier, market and government (chapter 3). Policy and market are the cores in this dissertation. In chapter 2, the traditional market framework is applied and electricity is considered as a commodity. The hypothesis that electricity demand equals to electricity consumption is only consistent in developed countries, where electricity supply is abundant. However, in developing countries, where they have a chronic shortage of electricity under a fixed price, it is not appropriate to estimate the electricity demand with the electricity consumption data. In chapter 3, electricity is regarded as a commodity with externalities.

The structure of this dissertation is as follow. Chapter 2 presents the demand side analysis which estimates the price elasticity and income elasticity of electricity demand for Japanese industrial consumers and residential consumers with time varying parameter models. It utilizes the Kalman filter approach to obtain the evolution of consumer behaviors. It provides a robust estimation of elasticities while highlight the evolution of elasticities under structure breaks and outliers. The process of deregulation is considered as a structure break in the estimation. Chapter 3 presents the supply side analysis, especially on firm-level R&D. The impacts of deregulation on R&D input and output of Japanese electric utilities are examined. The firm-level evidences suggest that electric sector deregulation negatively affect utility innovation input while positively affect utility innovation outputs. Chapter 4 concludes the overall dissertation and provides overall policy recommendations and discusses the limitations and future works.

CHAPTER 2 **Industrial and residential electricity demand dynamics in Japan**

2.1 **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). 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 JBF (Japan Business Federation) 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 on industrial sector in Japan as a consequence.

The growing literature on electricity demand modelling has offered different dimensions and choices in methodologies. Fixed coefficient models are among the most widely-used modelling 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 modelling. More recently, there is a growing trend of supporting time varying coefficients considering the parameter instability due to outliers and structure breaks (Inglesi-Lotz, 2011; Arisoy and Ozturk, 2014; Chang et al., 2014). An outlier is usually captured by a dummy explanatory variable while a structure break is modelled by a staircase intervention (Harvey et al., 1998). Time varying parameter is able to detect such structure change and outliers with drift in parameters and auxiliary residuals (Durbin and Koopman, 2001). In our case, financial crisis/ oil shock in 2008 is the outlier while deregulation and Fukushima Daiichi are the internal structure changes. The contribution of this study is methodologically not only to consider and capture the effects of structure 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.

2.1.1 **Overview of electricity demand and supply in Japan**

In Japan, despite the shortage of resources, electricity demand is generally met by the supply even after the Fukushima crisis in 2011. Thus, in this research, it is assumed that the electricity demand is equal to the electricity consumption in Japan. Fig. 2.1 illustrates the electricity demand and supply in Japan from 1973 to 2013.

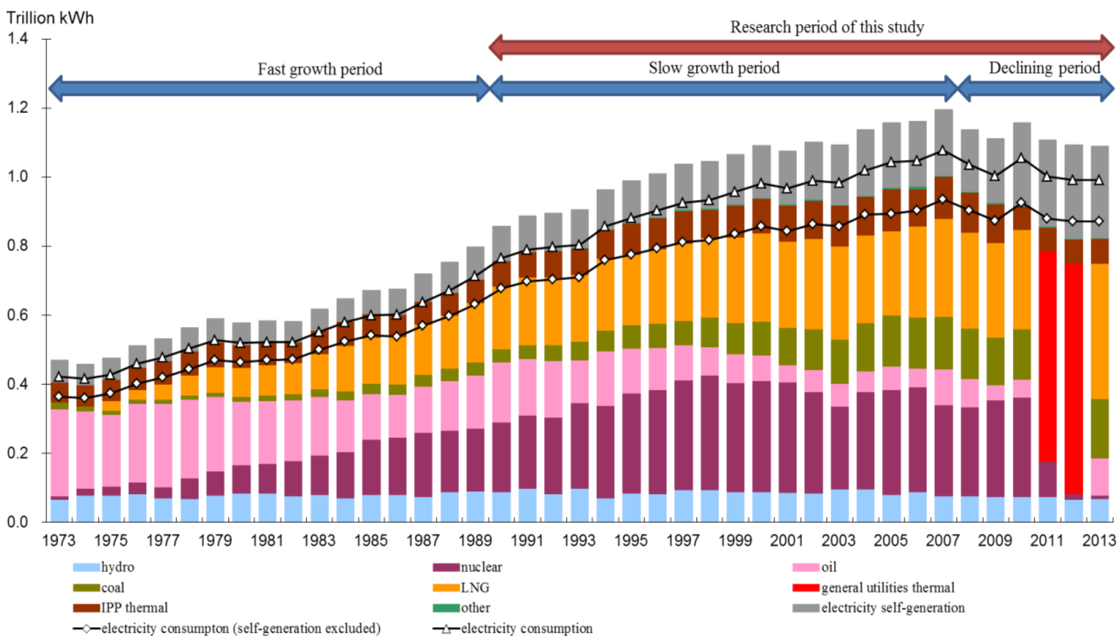

Figure 2.1 Electricity generation and demand in Japan Source: Compiled by the author and IEEJ/EDMC based on the METI and the FEPC database (IEEJ: the Institute of Energy Economics, Japan; EDMC: the Energy Data and Modeling Center; METI: Ministry of Economy, Trade and Industry; FEPC: the Federation of Electric Power Companies of Japan)

From the supply side, several trends can be observed: 1. 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. 2. Electricity generation from coal increased in the 1990s. 3. The share and capacity of privately-generated power grew rapidly. 4. Most of the nuclear power plants shut down after 2011 and the thermal power plants took over their share. From the demand side, we can generally divide the electricity consumption in Japan into three periods. Before the bubble burst[1] in 1989, the electricity demand was fast-growing due to the economic development and the population growth. From 1973 to 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. We focus on the period for three reasons: 1. Data availability. 2. Post-bubble period is the so-called recession period in Japan and it may continue for the coming decades. Monitoring consumers' behaviors under recession economy will be meaningful for the future policy making. 3. Market structure is changed due to the electricity deregulation during the "post-bubble" period.

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)

2.1.2 **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 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, our understanding of the electricity reform and its impacts on consumers are still very limited.

Since 1951, the electric companies in Japan have continuously reduced the cost of electricity supply. In addition, they have improved the reliability of supply and achieved universal services. Even though the electricity price in Japan increased significantly after the oil shock in 1973, it dropped steadily after the shock when the power mix was diversified introduced with the LNG and the nuclear power. However, after the bubble burst, industrial users became eager to further cut their cost in response to the falling revenue. The electricity price in Japan, which was still the highest among the OECD countries, was criticized by industrial consumers. It was widely accepted that the regional monopoly and lack of competition were the main reasons of the relatively high price. This concern became the social driving force for the electricity deregulation in Japan.

Throughout its long history of monopoly, Japan's electricity industry was highly regulated. The regulatory authority applied the rate of return regulation in this industry and approved regional monopoly and vertical integration for the 10 major electricity companies by creating entry barriers to the industry. 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), METI partially deregulated the electricity industry. Electricity deregulation is a part of the 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 compete in the bidding of the supply contract with electric companies. 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 (PPS) 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 reform. As for the next step of the reform, unbinding of the transmission and distribution sector is scheduled after 2018. Table 2.1 summarizes the electricity deregulation process in Japan.

Table 2.1 Milestones of electricity sector regulation reform in Japan

Year	Electricity reform milestone
1995	Amendment of the Electricity Utility Industry Law, opening access for independent power producers (IPP).
1999	Introduced partial retail deregulation on industrial sector (over 2,000kW in 2000 [26%]).
2003	Establishment of the wholesale power exchange market (JEPX).
2004	Expanded retail deregulation, (over 500kW in 2004 [40%]).
2005	Expanded retail competition (over 50kW [62%]).
2008	Improvement of the competition and strengthening of JPEX, modification of the rule of wheeling rates.
2015	Establishing the Organization for Cross-regional Coordination of Transmission Operation, Japan.
2016	Retail deregulation for residential users (total retail deregulation).
2018-2020	Revision of business license and unbinding of the transmission and distribution sector.

Energy sector policymaking in Japan such as electricity deregulation is mostly drawn from the case studies of other developed countries such as England, the United States, and the Nordic nations. However, the quantitative analysis of the impact on consumers is still rare to our knowledge. In addition, price and income elasticity are widely accepted as the key parameters to understanding electricity demand. Thus, the evolving price and income elasticities during the 26-year period highlight the changing electricity demand dynamics and consumer behavior under exogenous shocks and structural breaks.

In this study, a time-varying parameter (TVP) approach using the state-space model based on the Kalman filter technique is proposed to estimate the evolving price elasticity of the industrial and residential sectors in Japan. This method is supposed to capture the behaviors change of industrial and residential consumers respond to price and income under the circumstance of electricity deregulation or other exogenous shocks and structural breaks. The remainder of the chapter 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.

2.2 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, various statistical methods have been applied to monitor the electricity sector, especially electricity demand. We review the major methods used to estimate the electricity demand function from an international perspective and then turn to the literature on Japanese electricity demand.

Electricity demand is extensively investigated by scholars using different econometric approaches. Most recently, 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. Comparison of these two methods is reported in Okajima and Okajima (2013). Except for the methods mentioned above, other regression techniques such as Johansen co-integration, GMM, DOLS, three-stage LS, and FOLS are also widely used.

Most recent studies on estimating electricity demand distinguish between short-run elasticities and long-run elasticities, the long-run elasticities can be easily calculated with ARDL or partial adjustment model. For a necessary good like electricity, the long-run elasticities are usually larger than the short-run (Paul et al., 2009). However, most studies still follow a common hypothesis that coefficients are constant over time.

It has been recognized that variation in estimated price elasticities is substantial across the existing literature. One possible reason for this variation is the examined period difference within studies (Miller and Alberini, 2016). In addition, demand elasticity is unlikely to remain constant over time as the nature of demand and also the tastes of consumers are time varying (Arisoy and Ozturk, 2014). Chang and Hsing (1991) test generalized functional form to examine the demand for residential electricity and provide evidence on time-varying elasticities. Based on these reasons, we may suspect that the relationship between electricity demand and income or electricity price is constant. To deal with the shortcomings of fixed coefficient assumption, time varying parameter (TVP) model is an alternative to estimate electricity demand. For example, Fan and Hyndman (2011) use half-hourly data of the South Australian electricity system to utilize TVP model; Inglesi-Lotz (2011) models South African electricity demand with aggregate annual data and Arisoy and Ozturk (2014) build the TVP model using annual Turkish sectoral electricity demand data. Because the coefficients are allowed to change over the estimation period, TVP approach is capable of capturing the dynamics of the electricity demand and the evolution of price and income elasticities. However, most studies end up with proving "elasticity is time varying" without providing further in-depth analysis. In this research, we provide possible explanations by considering the impact of structure breaks and outliers and argue that electric sector deregulation, financial crisis, and Fukushima Daiichi crisis can lead to change in elasticities.

To the best of our knowledge, Nakajima and Hamori (2010) is the only study that evaluates how retail deregulation affects residential electricity demand through estimating the change in price and income elasticity before and after deregulation. They apply the panel cointegration technique to estimate state-level residential price and income elasticity by using quarterly data on US residential electricity demand. The estimation results indicate that price elasticity has decreased and income elasticity has increased for both regulated and deregulated states.

The estimation of electricity demand price elasticity in Japan started from Matsukawa et al. (1993), which reports that industrial electricity price elasticity is -0.63

using pooled data from 1980 to 1988. Since then, electricity demand has been investigated by scholars as well as Japanese government (Cabinet Office of Japan, 2007; Hosoe and Akiyama, 2009; Tanishita, 2009; Nakajima, 2010; Okajima, 2013; Tamechika, 2014; Otsuka, 2015). Domestic studies and international studies with Kalman filter approach are presented in Table 2.2. It is obvious that the variances of the estimation results are substantial. Thus, it is meaningful to provide a more robust estimation of price elasticity and income elasticity with latest data.

Table 2.2 Selected empirical studies on electricity demand income elasticity and price elasticity

Author	Period	Country	Sector	Methodology	Income elasticity	Price elasticity
Studies with Kalman filter						
Arisoy and Ozturk (2014)	1960-2008	Turkey	Residential and industrial	Kalman filter	S:Residential:0.979 Indutrial:0.955	S:Residential:-0.014 Industrial:-0.023
Inglesi-Lotz (2011)	1986-2005	South Africa	Aggregate	Kalman filter	S:0.794	S:-0.075
Studies on Japan						
Matsukawa et al. (1993)	1980-1988	Regional	Industrial	Pooled regression		-0.63
Tamechika	1996-	Prefecture	Residential	GMM	S: 0.41to 0.50	S: -0.26 to -

(2014)	2009				L: 0.60 to 0.75	0.35 L: -0.49 to -0.40
Hosoe and Akiyama (2009)	1976-2006	Regional	Industrial and commercial	Partial adjustment	S: 0.36-0.53	S:-0.105 to -0.300 L:-0.190 to -0.552
Okajima and Okajima (2013)	1990-2007	Regional	Residential	GMM		S: -0.397 L: -0.487
Otsuka (2015)	1990-2010	Regional	Industrial and Commercial	Partial adjustment	S:0.274 L:1.169	S: -0.034 L:-0.146
Tanishita (2009)	1986-2006	Regional	Residential	Partial adjustment	S: 0.25	S: -0.60 to -0.92
Cabinet office of Japan (2007)	1986-2005	Regional	Residential	OLS	0.911	-0.373

Note: S stands for short run, L stands for long run.

This study attempts to combine the ideas that deregulation may change the behavior of consumers, which can be monitored by the change in elasticities (Nakajima and Hamori, 2010), and that electricity demand elasticities are time varying, as shown by Inglesi-Lotz (2011), Arisoy and Ozturk (2014), and Chang et al. (2014). We develop these ideas in three aspects. First, Nakajima and Hamori (2010) find that retail deregulation affects residential electricity demand. We extend this idea from residential consumers to industrial consumers for the case of Japan, where retail deregulation is implemented gradually to industrial consumers. Second, considering the non-stationarity of the variables, TVP models coupled with Kalman filter techniques are able to estimate the dynamics of electricity demand in the industrial and residential sectors. The dynamics of the price and income elasticities has been captured to understand how elasticities have evolved in the past 26 years and the impacts of structure breaks and outliers have been successfully observed from the shifting of parameters using the TVP model. Finally, latest data is utilized, which enables monitoring the effect of Fukushima Daiichi crisis.

2.3 Model and methodology

2.3.1 Time varying model, state-space model, and the Kalman filter

The time varying parameter model is most conveniently estimated and analyzed using the state space methods (Zivot, 2005). The time varying coefficients can be handled straightforwardly in the state space framework by modeling them by random walks (Durbin and Koopman, 2001). State-space models are firstly introduced to describe a system that comprises a set of inputs, outputs, and state variables related by first-order differential equations. The state of a system can be represented as a vector within a space to characterize a linear system. This model has been applied in the econometrics literature to model unobserved variables such as rational expectations, measurement errors, missing observations, permanent income, unobserved components, and the non-accelerating rate of unemployment. Extensive surveys of the applications of state-space models in econometrics can be found in Hamilton (1994) and Harvey (1989).

The main benefit to representing a dynamic system in state-space form is that state-space models can be analyzed by using the Kalman filter. The Kalman filter is considered to be the simplest dynamic Bayesian network in which the true state is assumed to be an unobserved Markov process. In economics, the Kalman filter algorithm has been used, among other things, to compute Gaussian ARMA models, multivariate (vector) ARMA models, MIMIC (multiple indicators and multiple causes) models, Markov switching models, and time-varying (random) coefficient models. The Kalman filter recursively calculates the true values of states by using incoming measurements and a mathematical process model for a linear system (Zhe, 2003).

The state-space model consists of two equations: the measurement equation describes the relationship between the observed and unobserved variables (Eq. 2-1) and the transition equation describes the dynamics of the unobserved variable (Eq. 2-2). Following Durbin and Koopman (2001), the general linear Gaussian state-space model is presented as follows:

$$\boldsymbol{y_t = \beta_t x_t + e_t} \qquad \textbf{2-1}$$

$$\boldsymbol{\beta_t = \gamma + F\beta_{t-1} + \mu_t} \qquad \textbf{2-2}$$

In Eq. 2-1, y_t is the objective variable vector or observation vector, x_t is the vector of the explanatory variables, β_t is the vector of time varying state, and e_t is a vector considered to be a random error. In Eq. 2-2, β_t is the vector of the state F is the covariance matrix, γ is the constant, and μ_t considered to be the random error of the state. In a linear system, the disturbances $\mathrm{e_t}$ and $\mathrm{\mu_t}$ are assumed to be independent white noise: $e_t = N(0, \sigma_e^2)$, $\mu_t = N(0, \sigma_\mu^2)$ and also $E(e_t, \mu_t) = 0$.

To explain how the Kalman filter adapts to estimate electricity demand, a brief introduction is described. . The algorithm and calculation process can also be found in Grewal (2011). $\beta_{t/(t-1)}$ stands for the estimated state vector from the information up to t-1 and $\beta_{t/(t-1)}$ denotes the estimated state vector from the information up to t. $C_{t/(t-1)}$ stands for the covariance of the state from the information up to t-1 and $C_{t/(t-1)}$ denotes the covariance of the state from the information up to t. $y_{t/(t-1)}$ stands for the forecasted measurement variable from the information up to t-1. $\eta_{t/(t-1)}$ denotes the prediction error. $\eta_{t/(t-1)} = y_{t-} y_{t/(t-1)}$ and $f_{t/(t-1)}$ stands for the variance of the predicted error. K_t stands for the Kalman gain. The Kalman filter estimates the following three steps recursively: 1. Identify the initial states $\beta_{0/0}$ and $C_{0/0}$ at time 0; 2. Predict $y_{1/0}$ by using estimated value $\beta_{1/0}$; 3. Calculate the prediction error $\eta_{1/0} = y_1 - y_{1/0}$ and update the state vector by $\beta_{1/1} = \beta_{1/0} + K_t \eta_{1/0}$. The basic methodology of Kalman filter is shown in Fig.2.2. The process follows a recursive process from step1 to setp3.

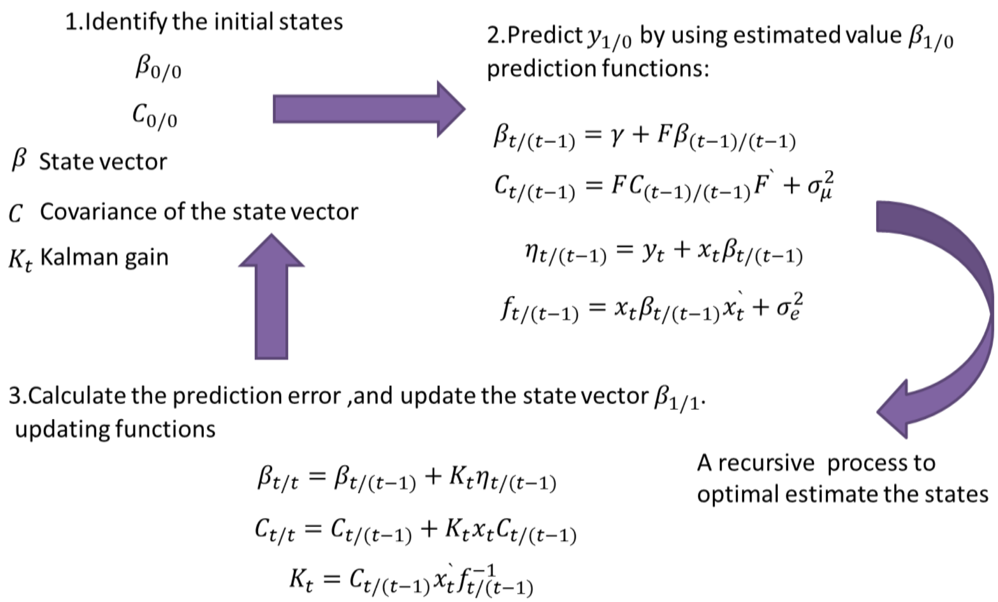

Figure 2.2 Kalman filter calculation process

The prediction functions are as follows:

$$\boldsymbol{\beta_{t/(t-1)} = \gamma + F\beta_{(t-1)/(t-1)}} \tag{2-3}$$

$$\boldsymbol{C_{t/(t-1)} = FC_{(t-1)/(t-1)}F^{`} + \sigma_{\mu}^2} \tag{2-4}$$

$$\boldsymbol{\eta_{t/(t-1)} = y_t + x_t\beta_{t/(t-1)}} \tag{2-5}$$

$$\boldsymbol{f_{t/(t-1)} = x_t\beta_{t/(t-1)}x_t^{`} + \sigma_e^2} \tag{2-6}$$

The updating functions are as follows:

$$\boldsymbol{\beta_{t/t} = \beta_{t/(t-1)} + K_t\eta_{t/(t-1)}} \tag{2-7}$$

$$\boldsymbol{C_{t/t} = C_{t/(t-1)} + K_t x_t C_{t/(t-1)}} \tag{2-8}$$

$$K_t = C_{t/(t-1)} x_t^{`} f_{t/(t-1)}^{-1} \qquad \text{2-9}$$

The determination of the initial state of the Kalman filter is another important topic. In system engineering, this is usually calibrated by the measurement of the system. However, in economics, the initial state is usually determined by using the maximum likelihood approach (Durbin and Koopman, 2001).The following likelihood function is used for the maximization:

$$LnL = -\frac{1}{2} * \sum_{t=1}^{T} Ln\left(2\pi^n \, det\left(f_{\frac{t}{t-1}}\right)\right) - \frac{1}{2} * \sum_{t=1}^{T} \eta_{t/(t-1)}^{`} f_{t/(t-1)}^{-1} \, \eta_{t/(t-1)} \qquad \text{2-10}$$

2.3.2 Estimation of electricity demand

A number of determinants for electricity demand have been considered in the previous research. The potential determinants of electricity demand are the electricity price, the income of consumer, the price of substitutions, such as the price of oil and the price of natural gas, and the weather indicators like the heating days and the cooling days. Some authors also include instrumental variables when correlation between the explanatory variables and the error term is suspected and lagged dependent variable in order to consider a dynamic adjustment process.

In the specification stage of our analysis, the prices of gas and oil and the weather indicators are dropped due to the insignificance in the regression. According to the existing literature, the demand function is either in the double-log form or in the linear form. The comparison of these two function forms can be found in Chang and Hsing (1991). Following the previous literature (Nakajima and Hamori, 2010; Dilaver and Hunt, 2010; Inglesi-Lotz, 2011; Arisoy and Ozturk, 2014), electricity demand in this study is explained by electricity price and aggregate income in double-log form. Then, our model function is specified as follows:

$$\boldsymbol{LnQ = \alpha LnP + \beta LnY + \gamma + \varepsilon_t} \qquad \textbf{2-11}$$

In Eq. 2-11, LnQ is the natural logarithm of electricity consumption. LnP is the natural logarithm of the real electricity price. LnY denotes the natural logarithm of real income. γ is the constant and ε_t is the random walk error. α and β represents price elasticity and income elasticity, respectively. TVP model is applied to the estimation allowing price elasticity and income elasticity time-varying. Combining the state space model with the estimation, Eq. 2-11 is considered to be the measurement function. The transition equation is assumed to follow random walk assumption. The random walk hypothesis allows for frequent changes in parameters. Also, the parameter changes are assumed to be independent from each other. The overall TVP model in the state-space function is shown below:

$$LnQ = \alpha_t LnP + \beta_t LnY + \gamma + \varepsilon_t \quad \varepsilon_t = iid\ N(0, \sigma_e^2) \qquad \text{2-12}$$

$$\alpha_t = \alpha_{t-1} + \mu_t \quad \mu_t = iid\ N(0, \sigma_{\mu 1}^2) \qquad \text{2-13}$$

$$\beta_t = \beta_{t-1} + v_t \quad v_t \sim iid\ N(0, \sigma_{\mu 2}^2) \qquad \text{2-14}$$

The initial state of this model is calculated by applying several of the observation results in Eq. 2-10. After the initialization Kalman filter, price and income elasticity of electricity demand can be obtained by recursive calculation of state vector.

2.4 **Data**

To apply the Kalman filter technique with the TVP in the elasticity estimation, empirical data on industrial electricity demand and residential electricity demand from 1989 to 2014 are used in our analysis. The electricity demand is approximated by the electricity consumption. The consumption data is obtained from the database of FEPC. For the income variable, annual real industrial output (constant price 2005) and annual real household final expenditure (constant price 2005) are derived from the database of the Cabinet Office of Japan.

The electricity price shall be treated carefully. First, macro-analysis uses averaged price within a certain period (quarterly or yearly). This kind of aggregation may create aggregate bias (Blundell and Stocker, 2005; Miller and Alberini, 2016). Second, in economic theory, firms and consumers are optimized with the marginal price. Consumers face "real price" or marginal price rather than average price. Following this idea, the price elasticity is estimated with marginal price data by Kamerschen (2004). However, Shin (1985) and Ito (2014) find strong evidence that residential consumers respond to average electricity price rather than marginal or expected marginal electricity price using the USA micro panel data. Thus, in this study, average price rather than marginal price is calculated and used.

As mentioned in the introduction sector, Japanese industrial electricity retailing is partially deregulated after 1999 and totally deregulated in 2005. New entrants took over a substantial market share as a result. Fig. 2.3 implies the increasing market share of PPS. This phenomenon biased our estimation of industrial sector electricity price as PPS contracts are not yet open to the public. Thus in our estimation of electricity price, we only the data from 10 regional-monopolized electric utilities, assuming PPS electricity price is equal to that of incumbent firms. For the price variable, the price of residential electricity is calculated by dividing the sales revenue of the residential sector by the electricity consumption of the corresponding sector. The industrial price is calculated with the same method. The sectoral electricity sales revenue is obtained from the annual report of the 10 utilities

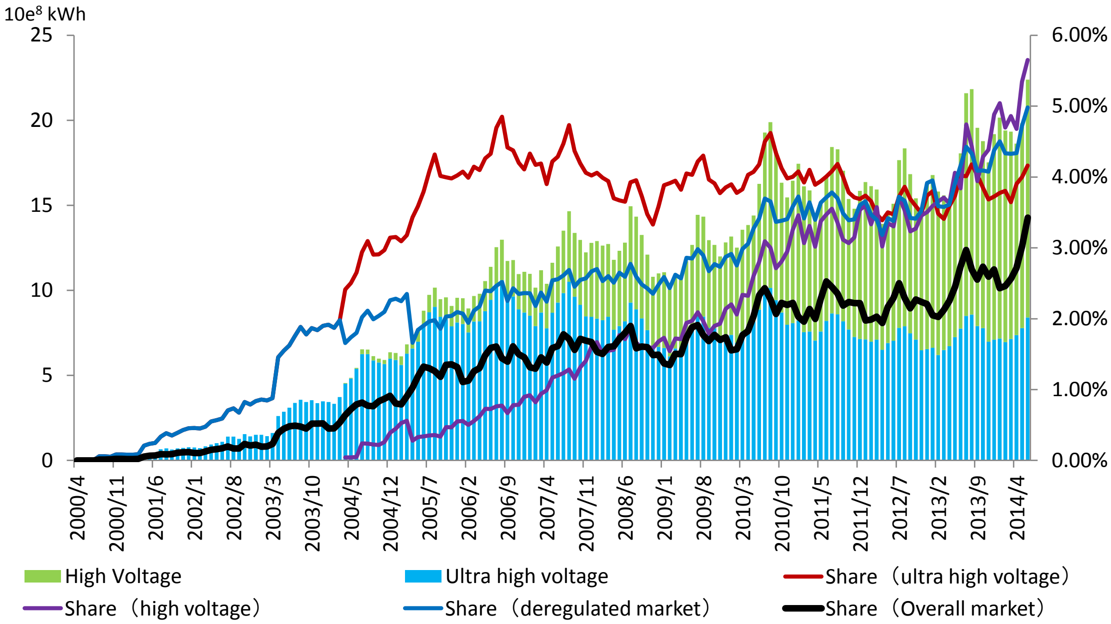

Figure 2.3 PPS sales and market share Source: compiled by IEEJ/EDMC with based on METI and FEPC database

To eliminate the inflation/deflation impact on our calculations, residential and industrial electricity prices are deflated with consumer price index (CPI) (constant price 2005) and corporate goods price index (CGPI) (constant price 2005). CPI is obtained from the Statistics Bureau of Japan and CGPI is from the database of the Bank of Japan. For the unit of measurement, electricity consumption unit is kWh. The unit for income is yen. The industrial and residential electricity prices are measured in yen/kWh.

2.5 **Results**

As the TVP approach does not require the data to be stationary before model estimation (Smeral and Song, 2015), it is more convenient to estimate electricity demand by using the TVP model to detect the dynamic factors. When the estimated parameters are unstable, rather than increasing the estimation complexity by adding more explanatory factors, the TVP model is another solution (Isaiah et al., 2015). However, the statistical test of TVP is challenging. Thus most TVP models with Kalman filter do not provide statistical tests (Pindyck, 1999; Inglesi-lotz, 2011, Arisoy and Ozturk, 2014). Bernard, (2012) applies the maximized Monte Carlo (MMC) test technique to test the model of Pindyck (1999) and enables more diagnostic tests to be implemented to TVP model.

Except for the hypothesis testing, in-sample test and out-of-sample test are two possible diagnostic methods. Because there is limited annual data available, we could not use out-of-sample tests for variable selection. Among the in-sample model fit method, AIC, is widely adopted to provide model fit statistics. In order to prove the robustness and fitness, our results are tested against fixed-coefficient models based on Equation 2-11, such as the OLS, the OLS with time tend, the OLS with external shock dummy and the partial adjustment model. We display the regression results of industrial sector and residential sector in Table 2.3 and Table 2.4. The estimation results of the Kalman filter are the final state of the price elasticities and income elasticities are statistically significant at 1% level. The S. E. value, log likelihood and Akaike information criterion (AIC) suggest that Kalman filter provides a more robust estimation of price elasticity and income elasticity than OLS and the partial adjustment model.

Table 2.3 Comparison of the estimation results (industrial sector)

	Kalman filter	OLS	OLS with trend	OLS with dummy	Partial adjustment
LnP	-0.160***	-0.341***	-0.342***	-0.351***	--0.229***
	(0.049)	(0.058)	(0.056)	(0.062)	(0.060)
LnY	1.025***	0.955***	1.271***	0.947***	0.430**
	(0.071)	(0.103)	(0.206)	(0.106)	(0.162)
Constant	-16.353***	-13.297**	-24.626***	-12.985**	-2.497
	(3.491)	(3.801)	(7.417)	(3.906)	(4.170)
Time trend			-0.003*		
			(0.002)		
Dummy				-0.015	
				(0.028)	
LnQ(-1)					0.388***
					(0.118)
R^2		0.909	0.920	0.911	0.927
S.E.	0.017	0.026	0.025	0.026	0.021
Log likelihood	71.792	59.716	61.416	59.883	63.576
AIC	-4.991	-4.363	-4.417	-4.299	-4.766

Note: The values in parentheses are standard errors. The symbols *, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively. The coefficients of Kalman filter are the final values of the state vectors. The OLS with trend includes a linear time trend component. The OLS with dummy includes a year dummy in 2008 to detect the shock in 2008 financial crisis. The partial adjustment model includes a one-year lag component of the dependent variable (Chang and Hsing, 1991; Hosoe and Akiyama, 2009).

Table 2.4 Comparison of the estimation results (residential sector)

	Kalman filter	OLS	OLS with trend	OLS with dummy	Partial adjustment
LnP	-0.511***	-0.681***	-0.682***	-0.670***	--0.463***
	(0.067)	(0.075)	(0.078)	(0.072)	(0.105)
LnY	1.450***	1.585***	1.565***	1.583***	0.826***
	(0.009)	(0.082)	(0.262)	(0.079)	(0.290)
Constant	-30.285***	-34.876***	-34.174**	-34.843***	-16.013**
	(3.011)	(3.075)	(9.384)	(2.973)	(7.540)
Time trend			-0.001		
			(0.002)		
Dummy				-0.036	
				(0.022)	
LnQ(-1)					0.385**
					(0.142)
R^2		0.984	0.985	0.986	0.985
S.E.	0.016	0.022	0.023	0.022	0.020
Log likelihood	72.792	63.608	63.611	65.066	64.457
AIC	-5.011	-4.662	-4.585	-4.697	-4.837

Note: The values in parentheses are standard errors. The symbols *, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively. The coefficients of Kalman filter are the final values of the state vectors. The OLS with trend includes a linear time trend component. The OLS with dummy includes a year dummy in 2008 to detect the shock in 2008 financial crisis. The partial adjustment model includes a one-year lag component of the dependent variable (Chang and Hsing, 1991; Hosoe and Akiyama, 2009).

To justify to application of Kalman filter, we also compare the results of Kalman filter with OLS and rolling regression results with the same data. The OLS and rolling regression are also based on Equation 11. In rolling regression model, the window size is 10 observations, thus the elasticities start from the year 1999. Fig. 2.4 implies the elasticities estimated by the three models. From the rolling regression, parameter instability and non-constancy can be easily noticed. Fig. 2.5 indicates the residuals comparison of the three models. From the results, we may conclude that Kalman filter fit the data better than the other two models considering that residuals of Kalman filter are considerably smaller than those of OLS and rolling regression in both industrial sector and residential sector.

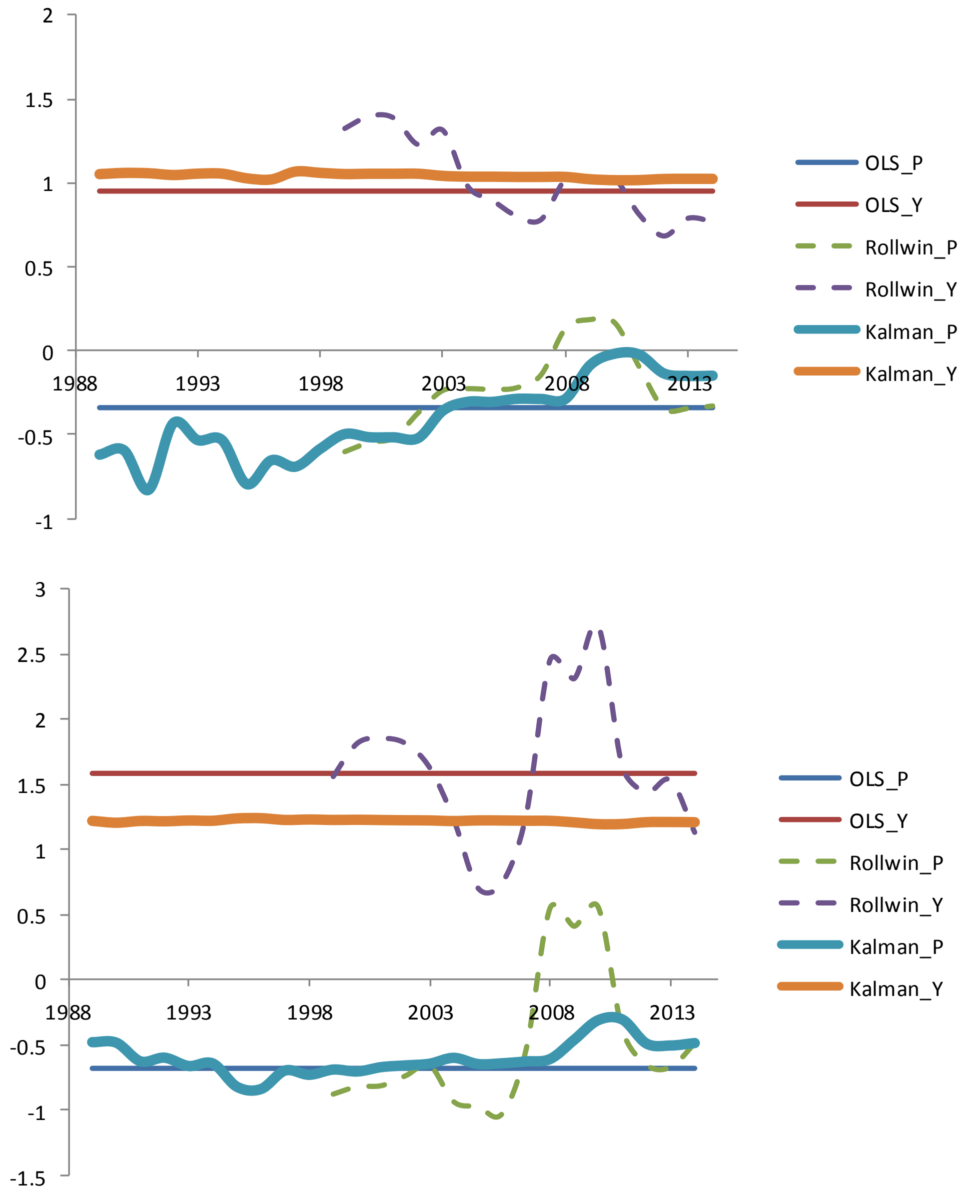

Figure 2.4 The comparison of elasticities from Kalman filter, OLS and Rolling regression

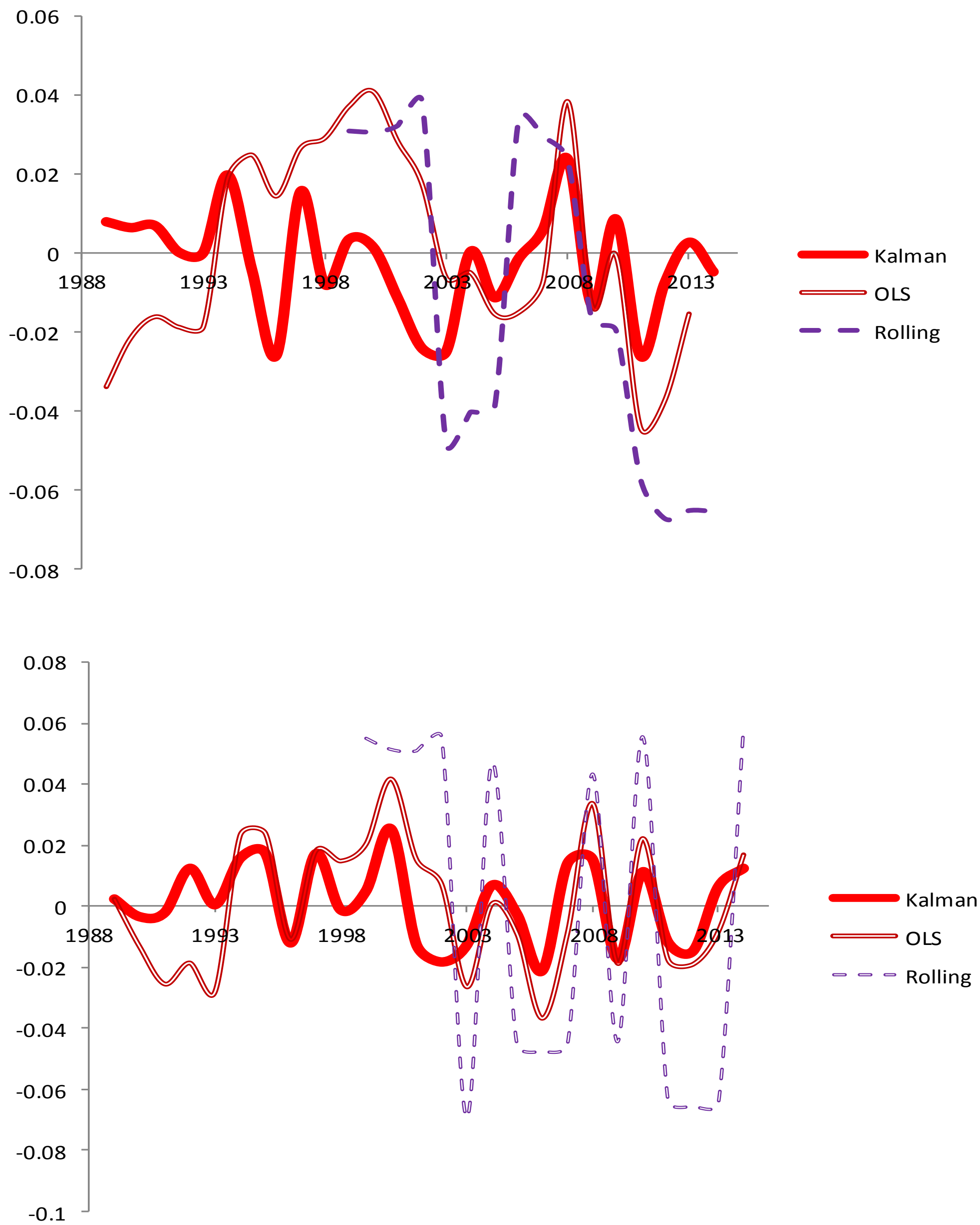

Figure 2.5 The comparison of residuals from Kalman filter, OLS and Rolling regression

2.5.1 **Industrial sector**

Fig.2.6 illustrates the evolving price and income elasticities of industrial electricity demand from 1989 to 2014. Income elasticity is 1.024 in 2014 and it barely changes during the examined period. From 1989 to 1994, the structural adjustment of the industrial sector after the bubble burst led to the fluctuation of price elasticity. The industrial sector price elasticity declines from-0.797 in 1995 to -0.289 in 2007 during the deregulation. After the financial crisis in 2008, price elasticity declines further, falling to -0.020 in 2010, the lowest of estimated period. After the Fukushima Daiichi crisis, price elasticity starts to recover and reach -0.160 in 2014.

2.5.2 **Residential sector**

Residential electricity demand has not experienced deregulation during the research period. Fig.2.6 illustrates that income elasticity of residential demand is stable from 1989 to 2014 (1.206 in 1989 and 1.219 in 2014), while the price elasticity of the residential sector increased from -0.48 in 1989 to -0.64 in 1994. Since the electricity reform in 1995, price elasticity decreased a little: from -0.72 to -0.61 in 2007. From 2008 to 2010, it further declined, similar to the case of the industrial sector, dropping to -0.3107 in 2010. Price elasticity also recovered after the Fukushima Daiichi crisis in 2011 and reached -0.611 in 2014.

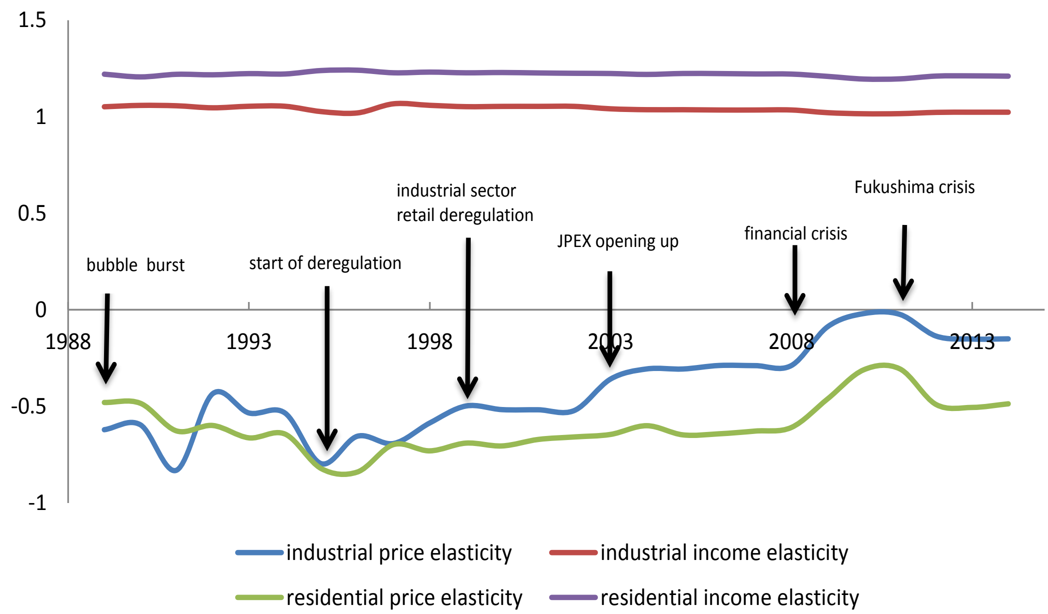

Figure 2.6 The evolution of price and income elasticities of residential and industrial sector electricity demands

Even though residential and industrial sector electricity price elasticities are inelastic, residential users are more sensitive to price during most of the time according to the estimation. This conclusion can be verified by comparing other studies on residential sector or industrial sector in Japan respectively (Hosoe and Akiyama, 2009; Tanishita, 2009; Okajima and Okajima, 2013; Otsuka, 2015). Base on the results, it is possible to infer that the rebound effect of industrial sector electricity consumption is larger than that of residential sector electricity consumption as rebound effect is equal to one minus the negative of the price elasticity (Sorrell and Dimitropoulos, 2008).

2.5.3 **Detection of outliers and structure breaks**

As stated in the model and method section, disturbances associated with the measurement equation and transition equation can be used to identify outliers and structure breaks. The procedure for detecting outliers and structure break can be found in Durbin and Koopman, (2001) and Harvey et al., (1998). In TVP model, the residuals associated with the states or the signals are called auxiliary residuals which are the indicators of outliers and structure breaks. The basic detection procedure starts with calculating and plotting the standardized auxiliary residuals. In a Gaussian model, indication of outliers and structure changes are the points with larger value than the absolute value of 2. When either state auxiliary residual or signal auxiliary residuals are larger the absolute value of 2, it is a weak sign of structure break or outliers. When both state auxiliary residual and signal auxiliary residuals are larger than the absolute value of 2, it is a strong sign of structure break or outliers. We apply this method to our model and the plot standardized auxiliary residuals in Fig. 2.7 and Fig. 2.8. Combining the results of states and signal, we are able to observe the structure breaks or outliers. From Fig. 2.7, we detect evidence of structure breaks or outliers in the industrial sector in 1995, 2003, 2008 and 2011. From Fig. 2.8, we detect evidence of structure breaks or outliers in the residential sector in 1995, 2008 and 2011. These results are compatible with the shift in elasticities shown in Fig. 2.6.

The detection successfully captures the start of electric deregulation in 1995, 2008 financial crisis and 2011Fukushima Daiichi crisis. Especially, for the industrial sector, retail deregulation and open up wholesale market are also captured due to the change in market structure in 2003. Thus in return prove the shifts in coefficient are mainly due to these structure breaks and outliers in the time series.

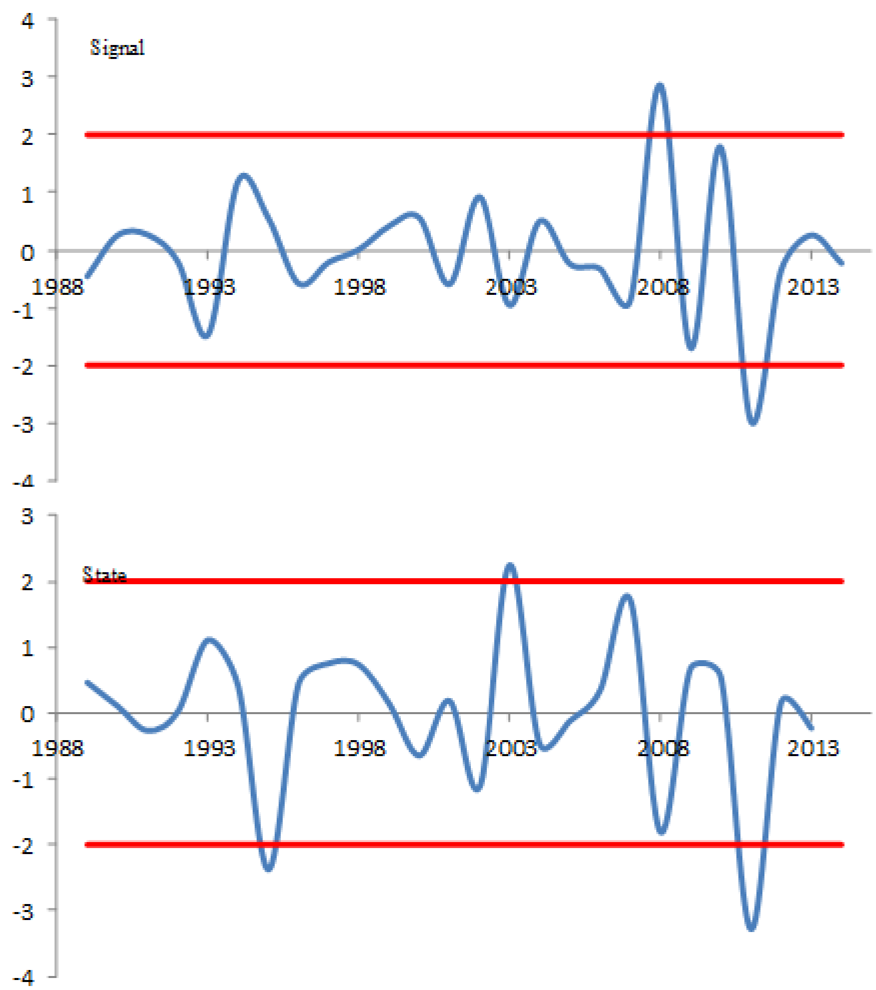

Figure 2.7 Standardized auxiliary residuals of signal and state (industrial sector)

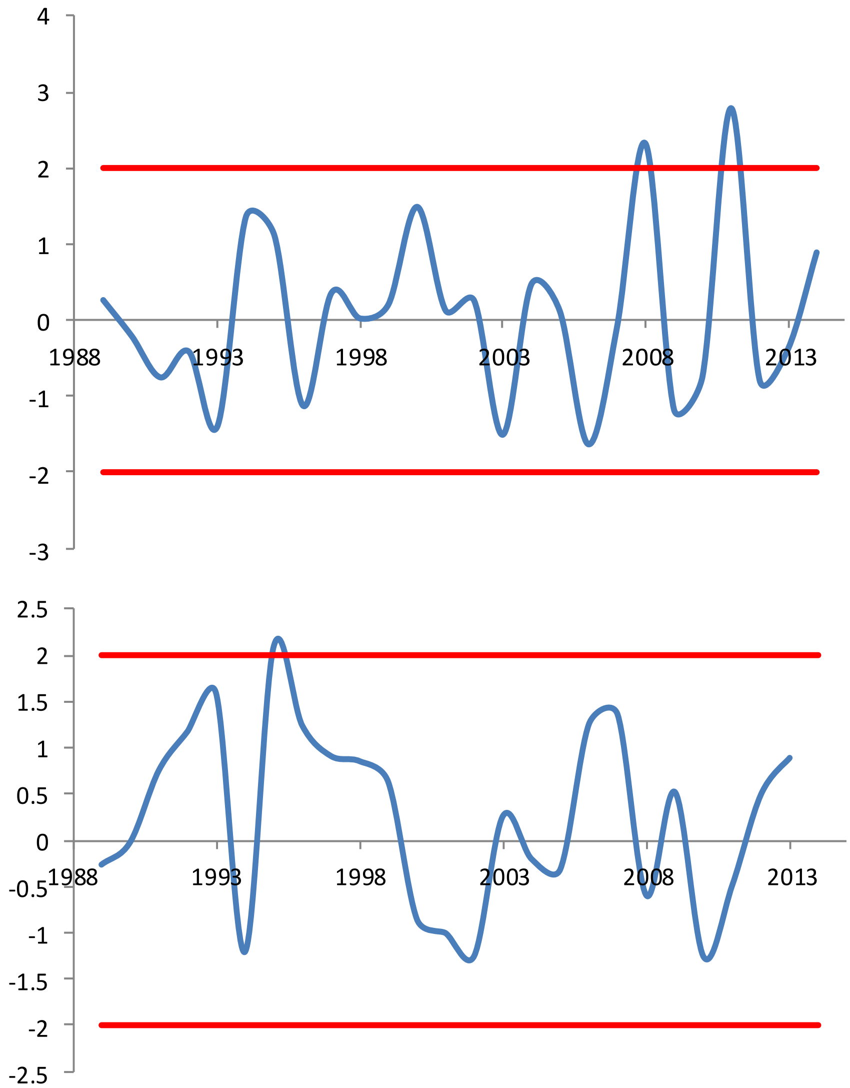

Figure 2.8 Standardized auxiliary residuals of signal and state (residential sector)

2.6 Discussion

2.6.1 Price level and price elasticity

Using aggregate data of South Africa electricity related data, Inglesi-Lotz (2011) reports that the sensitivity of consumers to price fluctuations becomes lower when the real prices of electricity decline. In addition, Inglesi-Lotz (2014), using aggregate data of the industrial sector, drew the similar conclusion. More recently, Miller and Alberini (2016) report similar results with US residential panel dataset. Their result implies that negative relationship exists between the price elasticity and the average price at that year. This simulation results are in line with previous studies, implying that there is a reverse relationship between electricity price elasticity and electricity annual average price in both residential sector and industrial sector.

Fig.2.9 illustrates the negative relationship between industrial electricity price elasticity and industrial electricity price after the electricity reform since 1995. Especially, after 2011, because of the shutting down nuclear power plant and the implementation of FIT, the electricity price grew rapidly. The consumer price elasticity recovers as a response.

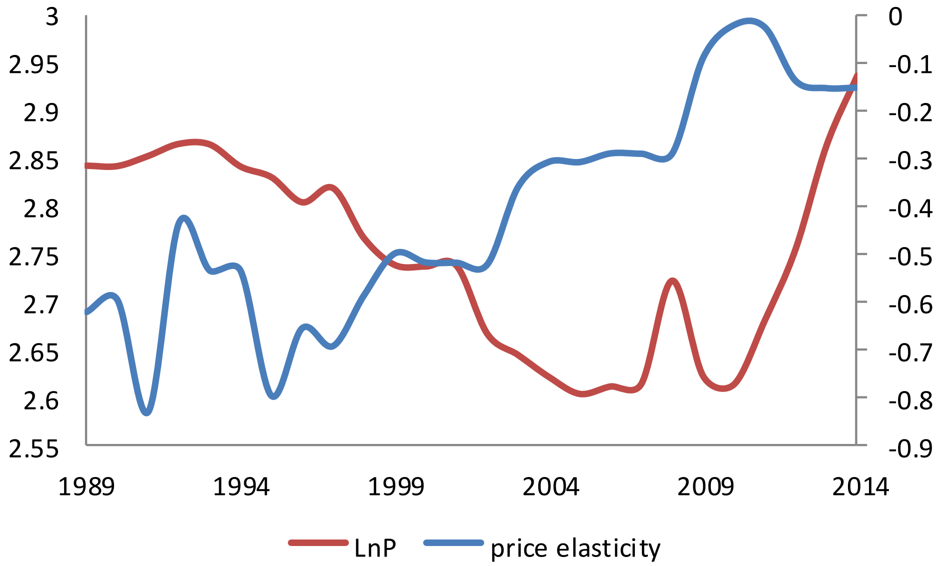

Figure 2.9 Electricity price and estimated price elasticity of the industrial sector

Fig.2.10 illustrates the relationship between residential price elasticity and residential electricity price. A negative relationship between residential electricity price elasticity and residential electricity price can be observed from the start of the electricity reform in 1995. Similar to industrial sector, price elasticity recovered after Fukushima crisis, when electricity price became higher.

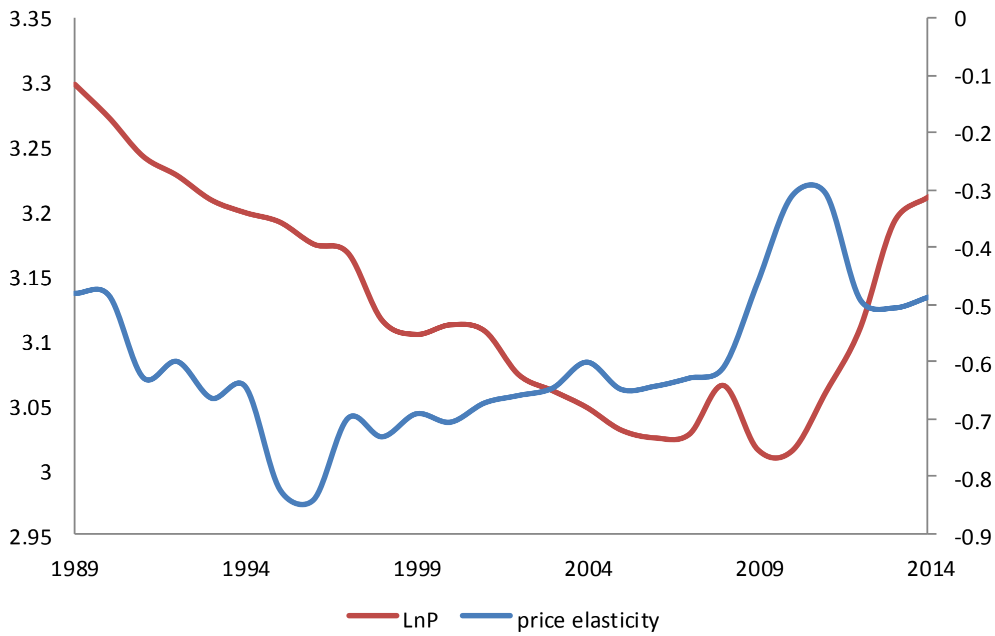

Figure 2.10 Electricity price and estimated price elasticity of the residential sector

2.6.2 **Price elasticity from 1995-2007**

Nakajima and Hamori (2010) report that retail deregulation in the United States do not make residential users more sensitive to the price as government expected. On the contrary, they find a decline in price elasticity after deregulation. Similar results for the industrial sector electricity consumption in Japan is found in this study, considering the fact that, industrial sector electricity market was deregulated step by step from 1995 to 2005. In their research, income elasticity becomes larger after the deregulation, but in this research, income elasticity is stable during the examined period. Another fact worth mentioning is that the electricity price increased continuously in the United States after the deregulation, but in Japan, electricity price declined after deregulation in both regulated (residential) and deregulated (industrial) sector. Comparing the estimation results of industrial sector and residential sector in Japan, it is obvious that the industrial sector price elasticity declines much more than that of the residential sector, as Fig. 2.6 indicates. Thus, price elasticity declining during the deregulation period in industrial sector cannot be fully explained by the declining electricity price. This difference may possibly be considered due to the retail deregulation.

The deregulation affects consumer sensitivity of price through two channels:1. Deregulation process brings down the electricity price. Ito et al. (2004) find that deregulation leads to 7.5% of generation cost reduction. The average cost of electricity in Japan has decreased 15% to 20% from the year 1995 to 2005. Electricity deregulation leads to 5% cost reduction due to the appropriation of capital investment, reduction of operation cost and improvement of management efforts according to Kanio (2005). Hattoti (2009) also suggests that the potential competition which is caused by deregulation has led to a decline of electricity price. 2. Deregulation process alters the electricity market and institutions. Deregulation changes the mean of electricity transaction like spot market, length of contract etc. These factors also affect the consumers' sensitivity to price. However, the mechanism of how deregulation can change consumer behavior need further study based on microdata. We leave this to future research.

Although deregulation tends to improve the operational efficiency of electricity companies according to Nakano (2008), Hattori (2009), Ito et al. (2004), and Kaino (2005), there is growing concern about the cost of deregulation (Woo et al., 2006) and the negative impact on utility R&D (Jamasb and Pollitt, 2008; Sanyal and Cohen, 2009; Kim et al., 2012; Jamasb and Pollitt, 2015). Also, how to transfer reform benefit to consumers become more and more important due to recent deregulated residential sector. Electricity reform is an evolving process and it changes the structure and behavior of all players in electricity market. We would like to emphasize that researchers should not neglect the possible impacts of electricity reform on consumers. As an extension to this study, it would be interesting to examine how elasticities evolve after residential retail deregulation in Japan.

2.6.3 Price elasticity from 2008 to 2014

Japan heavily depends on importing oil and natural gas. As an external shock, the 2008 financial crisis and the oil price spike push the domestic electricity price higher. However, after 2009, the electricity price drops even lower than that before the financial crisis. Both residential and industrial price elasticities decline dramatically from 2008 to 2010 as a response. From Fig. 2.6, we find that the price elasticities from 2009 to 2010 are the lowest in our examined period. Recovery from the crisis and the low electricity price lead to the low price elasticity during that period.

As an inner structure change, the Fukushima Daiichi crisis in 2011 forces the Japanese government to close all nuclear power plants. The subsequent electricity generation shortage is covered by the thermal power stations, which also lead to a rapid increase in the electricity cost and electricity price. Also, Japanese government further introduces FIT to most renewable energies. This policy further pushes up the electricity price. Consumers thus become more sensitive to price because of the rising electricity prices and the energy saving policies. However, owing to the limitation of data, it is still too early to identify the full effects of the Fukushima crisis. Nonetheless, we still find that price elasticity increase in the industrial and residential sectors. This finding may be a further proof that higher price level leads to higher electricity price elasticity. We may also predict that when prices continue to increase, consumers will become more sensitive to price.

2.7 **Conclusion and Policy Implication**

The analysis of the elasticity of the electricity demand is a long lasting research for decades due to the importance to monitor and forecast electricity demand. Also, understanding how consumers may respond to price change provides policy makers and regulators useful tools when designing deregulation process or making environmental policy. This study employs the TVP model using the Kalman filter to capture outliers and structure breaks and provide a robust estimation of the evolving price elasticity and income elasticity. Our paper contributes to the existing literature arguing that the price elasticity is time varying. Our estimation also finds that income elasticity is generally stable in both the residential and the industrial sectors and that price elasticity is time varying from 1989 to 2014. The dynamics of consumer behavior are explained by combining price level changes, external shocks and structure breaks. The estimation results also indicate the negative relationship between price elasticity and price level in both the residential sector and the industrial sector since the electricity reform.

In Japan, METI tends to further reform the electricity sector as a part of the social reform. Policymakers will definitely need to understand the impacts of the reform on consumers and this approach may applicable to the evaluation of the reform impacts. The low and declining price elasticity in industrial sector during the process of deregulation can partially explain why the rate of switching to new suppliers is low for industrial users. The relatively higher residential price elasticity suggests that the retail deregulation in the residential sector in 2016 may achieve higher switching rate. The ongoing process of residential sector deregulation also provides possibility to clarify whether price elasticity will also decline during the process of retail deregulation as US residential sector (Nakajima and Hamori, 2010) and as Japanese industrial sector. As we mentioned in the introduction section, the environmental tax was opposed by JBF and thus has been only imposed upon the industry sector in Japan. Our results contradict the assumption of JBF in 2003 claiming that energy price of elasticity is low that carbon tax cannot suppress carbon emission. As residential sector is much more elastic than industrial sector, price and environmental tax can be a better tool in the residential sector.

The analysis in this work should be interpreted cautiously. There are several drawbacks in the analysis. Statistical test of TVP is challenging at the present stage (Bernard, 2012). Studies which utilize TVP with Kalman filter approach scarcely provide any diagnostic statistical test (Pindyck, 1999; Arisoy and Ozturk, 2014; Inglesi-Lotz, 2011; Ozturk and Arisoy, 2016) as a result. In this work, we compare the elasticities and residuals of TVP approach with OLS and rolling regression and find that TVP approach exhibit better estimation results considering residuals, log likelihood and AIC. Utilizing more advanced statistical test is beyond this study's capacity. I leave this to future research.

Further research should focus on estimations in other developed and developing countries which implemented deregulation. Investigating the electricity demand dynamics in these countries may help us to understand the consumer behavior in different conditions and at different stages of economic development. However, in developing countries, we should be aware that price elasticity may be greatly interrupted by the theft of electricity. Also, as natural gas retail deregulation is scheduled in 2017 in Japan, it will be interesting to analysis the dynamics of gas demand as a comparative study.

CHAPTER 3 **Analysis of the deregulation and the electric utility innovation in Japan**

3.1 **Introduction**

Over the last two decades, deregulation has been implemented in Japan electric sector with the aim of stimulating competition, increasing efficiency, and reducing electricity price following the great trend of worldwide deregulation. Adapted to the overall economic reform, which aims at activating the economy in Japan, together with gas deregulation scheduled in 2017, electric deregulation has been changing the electricity industry in Japan. Recently, residential electricity retailing in Japan was deregulated in April 2016. Gas companies, oil companies, and even telecommunication companies rushed into electricity retailing. Fierce competition and restructuring are expected to activate the electric industry.

The liberalization process in the electric sector was originally designed to create a new institutional framework to foster social welfare and transfer reform benefit to consumers. As Joskow (2008) argues, these benefits can be realized by relying on competitive wholesale markets for power to provide better incentives for controlling the construction and operating costs of new and existing generating capacity, to encourage innovation in power supply technologies and to provide incentives for network operators to deliver appropriate levels of service quality. With retail competition, suppliers are expected to offer various retail service products, risk management, demand management, new opportunities for service quality and differentiation to better match the consumer preferences.

The deregulation process, in theory, should produce an increased alignment of managerial incentives with firm financial performance, ultimately promoting a more efficient use of resources. Indeed, most of the studies on the economic consequences of deregulation in electric sector generally show consistent efficiency gains and improvements in productivity (Goto and Tsutsui, 2008; Goto and Sueyoshi, 2009). There is a large body of literature on evaluating the effectiveness of the electricity reform in Japan. Hattori and Tsutsui (2004) explain the relationship of deregulation and electricity price using panel data of OECD. Kaino (2005) evaluate the impacts of electricity reform and gas reform based on the firm-level financial statistics. He finds that deregulation leads to a reduction in capital investment and labor expenditure of the electric companies which lead to a reduction in total cost and increasing efficiency. Nakano and Managi (2008) and Tanaka et al. (2012) also examine the efficiency of the electric companies using DEA approach with Luenberger indicator implying that deregulation brings in increasing efficiency but may also lead to investment uncertainty and blackouts. Deregulation resulted in important structure change in electric sector and achieved technical efficiency improvements.

Joscow (2005), in his keynote speech given at 2004 International Industrial Organization Conference, claims that "research in industrial organization and related public policy prescription has placed too much emphasis on static efficiency gain or loss and not enough emphasis on the factors influencing the rate and direction of product and process innovation which are likely to have much larger consumer welfare effects". Most previous studies in Japan only focus on the benefit of static efficiency from the reform. However, in the long run, innovation is the source of continued efficiency and productivity improvements. Thus, the impact of deregulation on electric sector innovation should not be neglected.

The electric industry and energy industry, despite their crucial importance in economy and society, are under the low level of R&D (GEA, 2012). Fig.3.1 shows the R&D level of all industries in Japan. Comparing R&D intensity of each industry in 2014, electric and gas utilities (0.19%) as well as oil and coal industries (0.19%) are among the lowest R&D level industry in Japan, slightly higher than the broadcast industry (0.10%). In a deregulated environment, R&D decisions of firms are largely different from those in the period before the reform. As energy and electricity are homogenous products, competitive strategies adopted by firms mostly focus on two topics: 1. Efficiency in process to reduce cost and increase margins. 2. Differentiation in contracts (Jamasb and Pollitt, 2008).

表12　産業別売上高に対する研究費の比率

産業	平成25年度 (%)	26年度 (%)	対前年度差 (ポイント)
全産業	3.33	3.28	−0.05
農林水産業	2.29	2.10	−0.19
鉱業，採石業，砂利採取業	0.38	0.39	0.01
建設業	0.41	0.36	−0.05
製造業	4.15	4.11	−0.04
食料品製造業	1.14	0.87	−0.27
繊維工業	4.07	4.18	0.11
パルプ・紙・紙加工品製造業	0.61	0.87	0.26
印刷・同関連業	0.71	0.91	0.20
医薬品製造業	11.70	12.21	0.51
化学工業	3.64	3.59	−0.05
総合化学工業	3.16	3.27	0.11
油脂・塗料製造業	4.28	3.70	−0.58
その他の化学工業	4.54	4.51	−0.03
石油製品・石炭製品製造業	0.19	0.19	0.00
プラスチック製品製造業	2.92	3.08	0.16
ゴム製品製造業	3.93	3.94	0.01
窯業・土石製品製造業	3.09	2.71	−0.38
鉄鋼業	1.19	1.24	0.05
非鉄金属製造業	1.93	1.73	−0.20
金属製品製造業	1.33	1.31	−0.02
はん用機械器具製造業	3.77	3.07	−0.70
生産用機械器具製造業	3.92	3.53	−0.39
業務用機械器具製造業	8.81	8.77	−0.04
電子部品・デバイス・電子回路製造業	5.49	5.34	−0.15
電気機械器具製造業	6.21	6.01	−0.20
電子応用・電気計測器製造業	8.54	6.29	−2.25
その他の電気機械器具製造業	5.87	5.95	0.08
情報通信機械器具製造業	6.29	6.26	−0.03
輸送用機械器具製造業	4.77	5.08	0.31
自動車・同附属品製造業	4.91	5.25	0.34
その他の輸送用機械器具製造業	2.60	2.63	0.03
その他の製造業	2.75	2.01	−0.74
電気・ガス・熱供給・水道業	0.22	0.19	−0.03
情報通信業	1.87	2.17	0.30
通信業	2.03	3.25	1.22
放送業	0.17	0.10	−0.07
情報サービス業	1.82	1.62	−0.20
インターネット附随・その他の情報通信業	0.67	0.67	0.00
運輸業，郵便業	0.41	0.39	−0.02
卸売業	0.32	0.30	−0.02
学術研究，専門・技術サービス業	17.43	20.13	2.70
学術・開発研究機関	75.17	86.44	11.27
専門サービス業（他に分類されないもの）	3.16	2.00	−1.16
技術サービス業（他に分類されないもの）	1.61	2.46	0.85
サービス業（他に分類されないもの）	0.35	0.38	0.03

Figure 3.1 Sectoral R&D intensity Source: report of science and technology research (http://www.stat.go.jp/data/kagaku/)

Some researchers have raised the concern regarding the “unintended consequence” even at the beginning of the reform (Dooley, 1998). A lot of studies report the declining R&D effort phenomenon after the deregulation (GAO, 1996; Bell and Seden, 1998; Margolis and Kammen, 1999; Bell and Schneider, 1999). Recently, more scholars argue that increase in static efficiency may at the expense of dynamic R&D by monitoring the activities of the companies related to electric industry under deregulation in US and EU (Sanyal and Cohen, 2009; Jamasb and Pollitt, 2008; Sterlacchini,2012; Kim et al., 2012). A similar result is also found in some other energy sectors (Olivier and Benoît, 2013). It is widely recognized that deregulation will reduce R&D outlays and these impacts will have profound implication for the future reliability of the electricity system (Joscow, 2006).

In Japan, this topic is scarcely investigated. To our best knowledge, only Hattori (2005) reports an initial observation of the R&D investment and patent activities of the electric sector in Japan. Also, empirical work on the relationship between innovation and deregulation measures is largely missing.

Thus in this chapter, the impacts of electricity deregulation on both firm-level innovation input and output are intensively investigated. This study intends to fill this gap to expand the understanding of Japanese electric utility R&D activities under the process of deregulation using data of nine vertically-integrated, monopoly utilities in Japan. This study intends to fill this gap to explore the factors in driving electric utility innovation and to expand the understanding of the impact of deregulation on utility innovation input as well as innovation output.

This work also contributes to existing literature: to our knowledge, it is the first analysis that investigates the effect of regulation reform on innovation which measures both innovation input and output with econometric approach. Most studies in the literature only focus on the effect of deregulation on R&D input. In this paper, we take a step forward by providing a complete picture of the impacts of deregulation on firm innovation. The two aspects of innovation may provide policy makers better understandings on utility innovation behaviors. We use R&D expenditure as a proxy for innovation input and patents as proxy for innovation output. Based on our estimation, electric sector deregulation has negative impact on utility R&D input while positively affect utility R&D output quantity and quality.

This chapter proceeds as follows: In Section 2, hypothesis is built based on economic theory and literature review. Section 3 outlines the research methodology and model specifications. Two models are established to estimate the impacts of deregulation on the innovation behaviors of the electric utilities Section 4 explains data and variables. Section 5 reports the results of the analysis. Section 6 draws conclusion of this chapter and provides discussion on policy implications.

3.2 Economic theory and literature review

3.2.1 Market structure, competition and firm innovation: from Schumpeter hypothesis to inverted-U theory

What kind of market structure promotes rapid technology progress? This question can be traced back to the book named “Theory of Economic Development” by Joseph Schumpeter in 1911. In the book named “Capitalism, Socialism and Democracy” which is published in 1943, he further developed his theory that large firm with market power accelerates the rate of innovation. In that book, Schumpeter says, “a market involving large firms with a considerable degree of market power is the price that society must pay for rapid technological progress”. He argues that monopolies favor innovation because they face less market uncertainty and have larger and stable cash flow to fund innovation activities. Also, monopolies have a stronger incentive to innovate.

According to the Solow’s growth model, technology advancement is crucial to economic growth. How to balance the social gains from Schumpeter innovation and social loss from high monopoly price becomes a recurrent topic of regulation economics.

However, even though a large variety of empirical tests of Schumpeter hypothesis have been implemented, the hypothesis is still controversial. Adolf and Gardiner (1932) argue that the effectiveness of R&D in large firms may be low because of agency problems and the large incumbent companies may be resistant to radical innovation due to organizational inertia. Arrows (1962) claims that competition pressure is the main driving force of innovation.

After that, a large number of studies focus on uncovering the relationship between competition and innovation (Kamien and Schwarzt, 1975; Cohen and Levin, 1989; Gilbert, 2006). However, the findings are always diverse and sometimes conflicting. More recently, Aghion et al. (2005) suggest that product market competition and innovation follows an inverted-U shape based on Schumpeter model and agency model. The authors use UK industry data (17 industry over the period from 1973 to 1994) to support the results. Thus, it is difficult to find strong theoretical support to describe the behaviors of the firms under transition from a regulated and protected market to a competitive and liberalized market.

3.2.2 **Deregulation and electric sector firm innovation**

In the electric sector, innovation behaviors of firms are altered due to regulatory change and policy-induced market structure change in both power generation market and the power selling market. Before the deregulation, the Japanese electric market is immune from competition. Nine regional vertically-integrated monopolies generate and supply electricity to residential, commercial and industrial users under the rate of return (ROR) based price regulation. It is assumed that deregulation affect utility R&D behavior through two channels: 1. Direct impact: deregulation policy increase the R&D risks and the market uncertainty also, it reduces the possible return from R&D input. 2. Indirect impact: deregulation policy fosters competition pressure through market mechanism. Incumbent utilities face increasing challenge on their market share.

Theoretically, the effect of competition on firm R&D is ambiguous. On one hand, a firm may increase their research spending, especially on those projects that will increase their profits or directly related to gaining the market share. On the other hand, in order to get a short-term cost reduction, a firm may cut off R&D investment if it does not contribute to gaining a competitive advantage.

Economic theory suggests that competition and profit incentive should somehow provide a firm efficiency gain and cost saving that can be passed to consumers by lowering the prices. Thus, in a competitive environment, in order to achieve competition advantage, R&D activities should play a more crucial role than that in a regulated environment.

However, we should not neglect the public aspect of the electric utilities in the regulated environment, in which R&D, focused on grid efficiency, environment issues, and energy efficiency, do not necessarily relate to increasing firm financial benefit. In ROR regulated electric market, the R&D investment of the electric sector utility has been regarded as part of their ordinary cost, which should be transferred to the consumers. In this way, the risk of R&D is transferred to consumers simultaneously. In addition, expectations of the spillover effect of R&D further limited the incentives to pursue on direct return from R&D due to the nature of network industry.

After the deregulation, firms are no more obligated to act for the interest of the public welfare or for the overall industry. The firms may less intended to carry out research programs which may go far beyond their own immediate business needs. Electricity turned out to be a commodity rather than public service after the deregulation. Shor-term cost saving and an increase in profitability can be achieved though cut off R&D expenditures.

In sum, hypothesis is built as:

Hypothesis 1: The expected overall effect of deregulation on utility innovation input is negative.

Under a deregulated environment, a tighter control of the investors and shareholders is expected. Thus, the managers of the utilities tend to reduce investment in long-term, high-risk and public-oriented R&D projects and to focus on short-term, cost-reduction and business-oriented results (Jamasb and Pollitt, 2008). “This should push the management to reconsider the scope of R&D projects undertaken, by focusing on those most closely linked to the needs of the core business” (Munari. et al., 2002). As the result of changed research priority, deregulation may also affect R&D outcomes. The shift from a regulated market to a competitive market influences significantly firms' patent behavior.

Deregulation alters patent production in three ways. First, it is likely that, under regulated environment, utility R&D pay less attention to control mechanisms against information leakage and know-how spill over, as a consequence of their status as mission to maximize social returns to R&D activities. On the contrary, after deregulation the company has no more obligations to act for the interest of public welfare and should focus on the maximization of firm profit. Therefore, patent number will increase to gain competitive advantage. Second, the increase in patenting may also reflect a shift of research portfolio towards more applied work. Utilities tend to give the priority to focus on research projects which offering more direct and faster commercial application. Third, after deregulation, electric utilities manage R&D activities in a more efficient way due to a tighter R&D budget. In this sense, an increase in the number of patents issued should be attributed to higher productivity of research efforts. These three interrelated explanations support the expectancy of a rise in patent production following to the deregulation.

However, patent production cannot be immune from the decreasing R&D input from utilities. This negative impact will decrease patent application due to less R&D effort on innovation. A large fall in utility patenting in the 1990s is mainly because the impact of the declined R&D input overwhelmed that of the positive impact like increased R&D efficiency (Jamasb and Pollitt, 2015). Fortunately, Japan electric utility did not experience such "collapse" until now. Jacquier-Roux and Bourgeois (2002) examine the effect of deregulation on patenting activities of large utilities and equipment suppliers in electric and petroleum industry. They conclude that both industries increase patenting despite the evidence of less R&D investment. Also, Nesta et al. (2014) find a positive correlation between deregulation and patent count using panels of 25 countries from 1978 to 2003. Their results also imply that promoting policies for renewable energy is more effective in a more competitive market.

In our study, utility innovation output is measured by two dependent variables: patent quantity (the number of patent applications of a utility) and patent quality (the number of citations of the utilities' patents and patent average citations of a utility). We use a patent's application year instead of granted year because the application year better captures the actual time of innovation (Cornaggiaa, et.al, 2015).

The reason we also use patent average citation is to compensate the bias that patent citation may include. In the years that utilities are getting more (fewer) patents, total citation of the utility may increase (decrease) simply because there are more patents granted or because there are more (fewer) citing patents exist which does not reflect change in patent quality. Thus the total patent may not be a good indicator of patent quality. Average patent citation, on the other hand will change when and only when the rate the change in citation is larger/smaller than the rate of change in the number of patents. Thus we use both as indicators to measure the effect of deregulation on patent quality.

Thus, second hypothesis is built:

Hypothesis 2: The expected overall effect of deregulation on utility innovation output (both quantity and quality) is positive.

3.2.3 **Government R&D effort and utility innovation**

Recent literature highlights that high interdependence exists between public and private R&D. Government intervention in electric sector R&D investment is required to allocate enough resources for innovation. There are two policy tools available for government to inventive private R&D: 1, provide favorable tax treatment for those firms undertaking R&D; 2.directly subsidize private R&D projects. According to Becker and Pain (2003), weak macroeconomic growth and declining government efforts are the main reasons for the drop in private sector R&D investment in 1990s in the UK. Magrolis and Kammen (1999) argue the crucial role of government effort on energy sector R&D using US energy sector R&D input and patent data. Jamasb (2007) shows that the cost reduction effect of learning-by-research is stronger than that of the learning-by-doing. Thus public support on electric sector R&D is a very strong policy instrument to promote electric sector innovation. Jamasb and Pollitt (2015) also emphasize the effectiveness of regulatory interventions to stimulate innovation. They point out that the UK's Low Carbon Networks Fund successfully created a new institutional arrangement aiming at an improvement in the energy sector social technology. Government funding can encourage firms to engage in R&D projects. Empirical results also show that government funding accelerated the completion of business R&D projects, expanded their scale and scope, and encouraged firms to conduct more challenging research (OECD, 2006). From previous literature on US and EU, one phenomenon is obvious: during the deregulation process, the government energy sector R&D budget decreases together with the private sector. Thus, the following hypotheses are formulated:

Hypothesis 3: The impact of government R&D funding on utility innovation input is positive.

Hypothesis 4: Government R&D funding will promote utility innovation output.

3.2.4 **Firm size and utility innovation**

Following the Schumpeter hypothesis, the size of the internal fund and financial accessibility will increase with the firm size. Even though cross-industry studies suggest that this hypothesis may not be consistent (Kamien and Schwarzt, 1975; Cohen and Levin, 1989), studies on the electric sector suggest that R&D spending is positively correlated with firm size. But the choice between sales and assets as the proxy of size is not determined. Sanyal and Cohen (2009) find R&D expenditure elasticity with respect to real operation revenue is 1.039 using 195 firms for the period 1990-2000. Kim et. al (2012) report R&D expenditure elasticity with respect to total asset is within 1.118 to 1.382 using 70 electricity-generating utilities across 15 OECD countries from 1990 to 2008. Salies (2010) tests the Schumpeter hypothesis with panel data of 22 European electric utilities from 1980 through 2007 and find that elasticity of size is 1.064.

Murari and Soberero (2003) examine the effect of privatization on R&D and patent activities for 35 European companies in 11 industries. They find that R&D expenditure and

R&D intensity are positively correlated with size and leverage but negatively correlated with privatization. Further, they find that firm size and privatization positively correlates with firm level patent activities.

Hence:

Hypothesis 5: Larger firm may spend more on R&D.

Hypothesis 6: Larger firm may be more active in applying for patent and high-quality patent.

3.2.5 **Other factors related to firm innovation**

According to Mokyr (1992), "technology change and innovations financed by the extension of credit", financial constraint (leverage, liquidity constraints and cash-flow) is another possible explanatory variable to estimate firm-level innovation activities in most industries following the Schumpeter hypothesis. However, this argument may not hold in the regulated sector like the energy sector. More recently, Costa- Campi, et.al (2014) analyze the incentives and barriers related to the access to knowledge and the market structure in energy sector. The results suggest that financial barriers are not the determinant in explaining R&D investment in energy sector. The financial barrier is also checked in this analysis using net income of each utility. However, financial constraint is finally dropped in the regressions due to its insignificance.

The consideration of technology of energy generation affects utility R&D and innovation is motivated by Sanyal (2007) who find a positive correlation between the "fossil fuel in total generation" and the firm environmental R&D spending. Sanyal and Cohen (2009) also report similar results that generation mix will affect utility R&D investment. Sterlacchini, (2012) also suggest that in electricity sector, some technological trajectories are more R&D intensive than others and can significantly affect the amount of research expenditures of electric utilities. Salies (2010) implies that for a firm like EdF (Électricité de France), which produce electricity essentially from nuclear and hydro plants, these variables will have positive effect on R&D. In Japan, nuclear power is especially a dominant research priority in electric sector before the 2011 Fukushima crisis. Also, nuclear R&D projects are usually supported by utility-joint research with support from consortia, public agencies and government fund. Thus nuclear generation share is adopted as an indicator of the impact of generation mix on utility R&D expenditure. A utility with larger share of nuclear generation will invest more in joint nuclear R&D projects

Hence:

Hypothesis 7: Nuclear share of the electricity generation of a utility is positively related to its R&D expenditure.

Finally, the macroeconomic condition and the demand pull effect on R&D outlays are also considered. Sanyal and Cohen (2009) use gross state product to test the effect of increasing demand on R&D expenditure. Kim et.al (2012) use GDP growth rate to control macroeconomic condition. We may also expect that the growth in demand will be positively correlated with the firm-level R&D input.

Hence:

Hypothesis 8: High GDP growth rate will encourage firms to invest more in R&D.

3.3 Methodology

3.3.1 Basic model

The methodology part begins with the basic model expressed by Eq. 3-1 to estimate the overall effect of deregulation on firm-level R&D expenditure. Econometric approach like pooled OLS, fixed effect model, and random effect model are utilized to measure the coefficients.

$$\boldsymbol{LnRD_{i,t} = \alpha + \beta DEREG_{1995} + \sum_{r=1}^{m} \delta_r F_{i,t} + \sum_{k=1}^{n} \theta_k P_{i,t} + \gamma gdprate + \varepsilon_{i,t}} \quad 3\text{-}1$$

The dependent variable is the nature logarithms of R&D expenditure where i denotes the firm and t denotes the year. α is constant. $DEREG_{1995}$ is the deregulation dummy which implies the effect of deregulation. $F_{i,t}$ is the vector of firm character variables and $P_{i,t}$ stands for the vector of policy variables. The $gdprate$ is the GDP growth rate which represents the macroeconomics conditions.

Different from many countries, Japanese electric utilities are all private companies. Thus, ownership shift (privatization) is not considered in this model. Japanese electric utilities follow very similar organization structure, business pattern and ownership (regional monopoly, vertically integrated, and privately owned). Thus, firm character variable vector is simplified as two variables in my analysis: the firm size and the nuclear share of the total generation. In the basic model, deregulation policy is simplified as deregulation dummy. The policy vector is simplified as: government energy R&D expenditure, which proxies the government emphasis on the energy R&D that may stimulate the private sector R&D;

Tobit model, Poisson regression, negative binominal model and logit model are usually applied to estimate patent count, especially for those datasets with many observations which censored to zero. Considering the dataset, each Japanese electric utility patent number is strictly positive during the examined period. Thus, log transformation is applied to estimate the patent count with Eq. 3-2.

$$Lnpatent_{i,t} = \alpha + \beta DEREG_{1995} + \sum_{r=1}^{m} \delta_r F_{i,t} + \sum_{k=1}^{n} \theta_k P_{i,t} + \varepsilon_{i,t} \qquad \textbf{3-2}$$

Firm character variable vector is simplified as two variables in the analysis: the firm size and the R&D intensity. As Margolis and Kammen (1999) indicate, there is always a positive correlation between R&D expenditure and patent output. It can be assumed that R&D expenditure will positively affect patent count in the model. Considering about the endogeneity of R&D expenditure in the model, firm size and R&D intensity are applied to replace R&D expenditure. In fact, it is possible to exclude R&D input in the explanatory variables as Munari and Sobero (2002) indicates. However, this greatly decreases the estimation significance. The policy vector is similar with Eq.3-1.

Next, we estimate the effect of deregulation on patent quality with by replacing the dependent variables with our innovation quality proxy, the patent citations and patent average citations, and estimate the following model:

$$\boldsymbol{Lncitation_{i,t}(Lnacitation_{i,t}) = \alpha + \beta DEREG_{1995} + \sum_{r=1}^{m} \delta_r F_{i,t} + \sum_{k=1}^{n} \theta_k P_{i,t} + \varepsilon_{i,t}} \quad \textbf{3-3}$$

3.3.2 **Extended model**

We consider deregulation alter the behavior of firm R&D from two channels: the effect of policy and regulation and the effect of the market mechanism through competition. Both effects are supposed to exist in generation sector, distribution sector, and retailing sector. However, the Japanese government did not fully implement the "standard textbook reform". Thus, electricity distribution is not privatized during the examined period. In this part, an extended model is built to calculate the impacts of deregulation from retail market and power generation market by replacing the general deregulation dummy with policy variables and competition variables.

The R&D expenditure is automatically transferred to consumers based on ROR regulation. Deregulation is supposed to cancel this mechanism but in fact utility R&D expenditure is fully included in the cost calculation. However, after 2011, there is a growing concern on the increasing electricity tariff. Thus, utility R&D projects is under severe scrutiny and it is required that utility R&D expenditure shall be controlled below 0.2 percent of sales revenue of residential sector (regulated sector) in the previous year. We consider this cost recovery mechanism is included in the deregulation. Thus we use the cost recovery dummy to capture this effect. The other control variables are in line with the basic model. The following Eq. 3-4 is the function of the extended model:

$$\boldsymbol{LnRD_{i,t} = \alpha + \sum_{r=1}^{m} \delta_r F_{i,t} + \sum_{k=1}^{n} \theta_k P_{i,t} + \sum_{j=1}^{l} \rho_j M_{i,t} + \gamma gdprate + \varepsilon_{i,t}} \qquad \textbf{3-4}$$

where $M_{i,t}$ represents the vector of market competition. $F_{i,t}$ is the vector of firm character variables and $P_{i,t}$ stands for the vector of policy and macroeconomic variables. Fixed effect regression is applied for the analysis of extended model for two reasons: 1.Hausman test rejected the null hypothesis and support fixed effect regression 2. Pooled OLS is criticized for neglecting heteroscedasticity.

In the extended model, the simplification of the control variables is similar with that in the basic model. The independent effects of R&D cost recovery policy, generation deregulation, and retail deregulation are included in the policy variable vector. Generation market competition and retailing market competition are included in the vector of market competition variables..

Eq.3-5 is the regression function to estimate patent count data. Firm character variable vector is simplified as two variables in the analysis: firm size and R&D intensity. The policy variable vector and the market variable vector remain the same.

$$\boldsymbol{Lnpatent_{i,t} = \alpha + \sum_{r=1}^{m} \delta_r F_{i,t} + \sum_{k=1}^{n} \theta_k P_{i,t} + \sum_{j=1}^{l} \rho_j M_{i,t} + \varepsilon_{i,t}} \qquad \textbf{3-5}$$

Eq.3-6 is the regression function to estimate patent quality. We estimate the patent quality based on firm patent citation number and average patent citation . The explanatory variables are the same with Eq. 3-5.

$$\boldsymbol{Lncitation_{i,t}(Lnacitation_{i,t}) = \alpha + \sum_{r=1}^{m} \delta_r F_{i,t} + \sum_{k=1}^{n} \theta_k P_{i,t} + \sum_{j=1}^{l} \rho_j M_{i,t} + \varepsilon_{i,t}} \ \textbf{3-6}$$

3.3.3 **Does deregulation really change utility R&D behavior?**

To answer whether deregulation is responsible for the decline of the R&D spending, the difference in difference model is usually a good choice. However, it is usually extremely difficult to find a good control group in most regulated industries due to the small number of samples. Gas industry is possibly a good control group. However, gas industry is deregulated even earlier than the electric sector in Japan.

However, even though, an econometric approach is unavailable, it is possible to observe the impact of retail deregulation on R&D expenditure by comparing general utilities (vertically integrated) with wholesale utilities (utilities only evolve in electricity generation) as retail deregulation should not affect the wholesale utility. Fig.3.2 is to compare the R&D expenditure of Hokuriku Electric Power Company, Hokkaido Electric Power Company, and Electric Power Development Company (J-Power, the largest wholesale utility in Japan). Both Hokuriku Electric Power Company, Hokkaido Electric Power Company cut off their R&D investment after retail deregulation while Electric Power Development Company even increased their R&D investment. It may be inferred that the gap after the retail deregulation in 2000 is partially due to retail deregulation policy and the competition pressure from the retailing market.

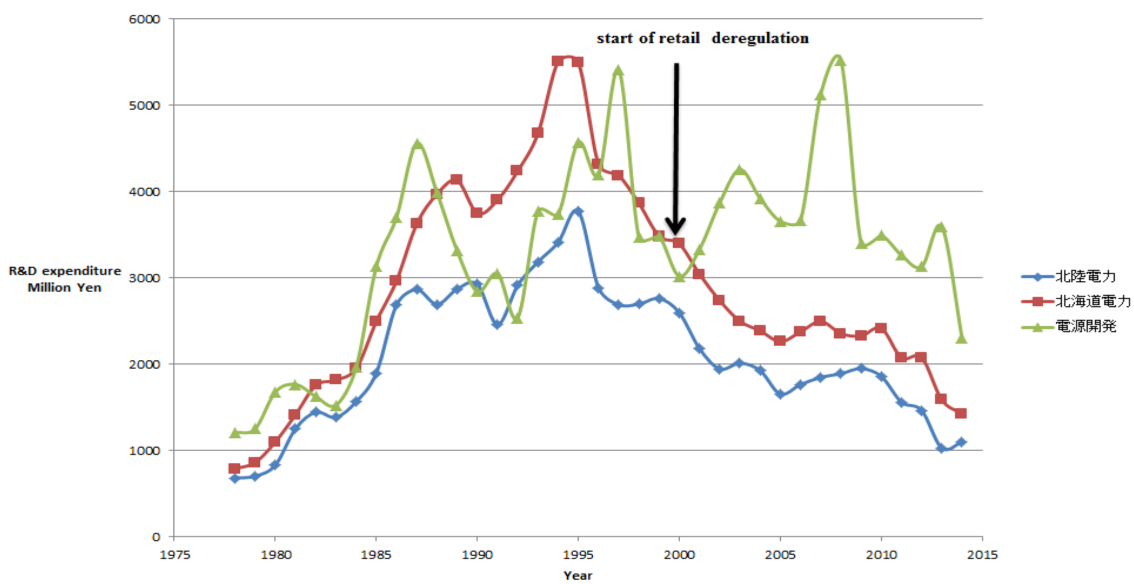

Figure 3.2 R&D expenditure comparison of Hokuriku Electric Power Company, Hokkaido Electric Power Company and Electric Power Development Company (J-Power)

Fig. 3.3 implies the shift in the share of Japanese electric utilities among the total patent application in Japan. It is clear that there is a boost in patent application of electric utilities after the electric deregulation, especially after the retail deregulation.

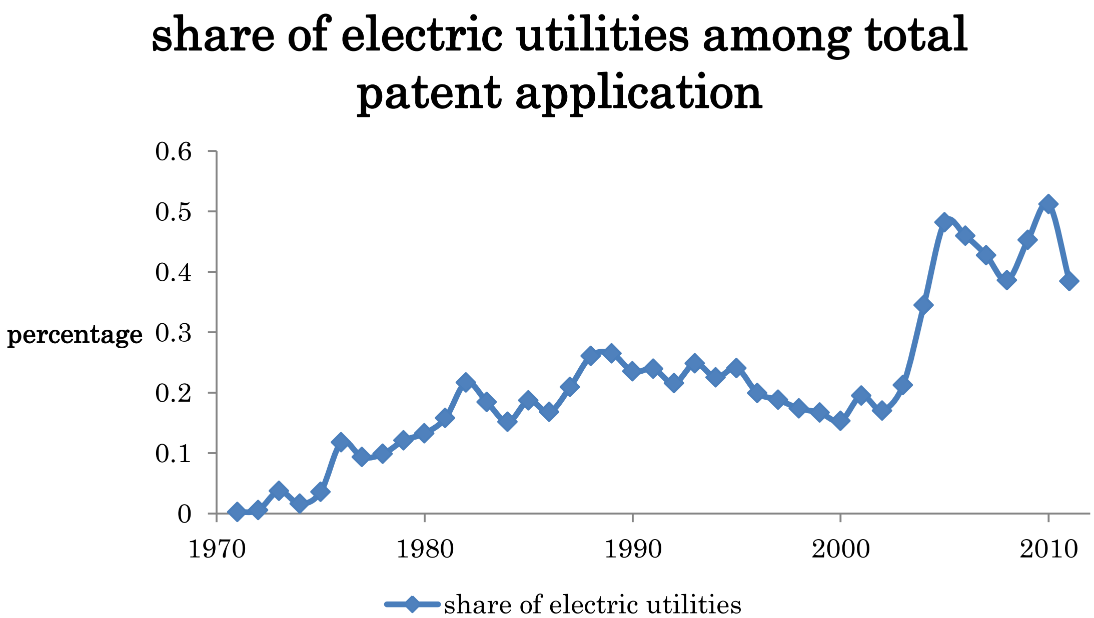

Figure 3.3 Share of electric utilities among total patent application

3.4 Data and variables

3.4.1 Dependent variables

In Japan, the electricity market is divided up into 10 companies:

- Chugoku Electric Power Company

- Chubu Electric Power
- Hokuriku Electric Power Company
- Hokkaido Electric Power Company
- Kyushu Electric Power
- Kansai Electric Power Company
- Okinawa Electric Power Company
- Tokyo Electric Power Company
- Tohoku Electric Power Company
- Shikoku Electric Power Company

Okinawa Electric Power Company is excluded in the datasets due to its short history, small size and relatively independent status in the electricity market comparing with the other electric utility companies in mainland Japan. The first dependent variable is R&D expenditure, expressed as natural logarithms of R&D input. The database consists of a balanced panel of the nine electricity utilities of Japan from 1978 to 2014. The nine electricity utilities are so-called general electric utilities which are regional monopolies and vertically integrated since the 1950s.

This panel is believed to be relevant to the analysis because little R&D seems to occur for smaller firms in the same industry (Sterlacchini, 2012). It is trustworthy that the R&D behaviors of incumbent utilities can represent the overall R&D behavior in the electric sector. R&D expenditures are compiled with the annual report of each utility and are deflated at the 2005 constant price using CPI provided by the Bureau of Statistics of Japan.

Patent application count, patent citations and patent average citations are the proxies to analyze innovation output. In this analysis, patent application count of the nine utilities in Japan is included from 1978 to 2011. The data for the patent count is compiled from IIP-DB (The Institute of Intellectual Property Patent Database) by Goto and Motohashi (2007). The database includes patent application data, patent registration data, application data, rights holder data, citation information and inventor data. IIP-DB covers 12706640 patent applications from 1964 to 2012. The patent application count from 1978 to 2011 has been extracted as there is 1.5 years' lag between the patent application and the publication to public. The reason that I use patent application data not the patent-granted data is obvious. According to Popp (2006), patent-granted count is mainly used for the diffusion of technologies. However, unsuccessful patent application which reflects the firm R&D strategy is not included in patent granted count. According to Fujii and Managi (2016), the advantage of using patent application to evaluate the firm-level R&D is that it reflects investors' R&D strategy more accurately than patent-granted count. As this research focuses more on strategic R&D change during the deregulation rather than technology diffusion, patent application data count is applied in this analysis.

Similarly the patent citations and average patent citations are also compiled from IIP-DB using the number of backward citation received. However, when search for citations, it is obvious that old patents have larger chance to be cited than newer patents. To avoid this bias, only citations within 5 years after being granted are considered in our analysis. Thus both citations and average citations are from 1978 to 2006.

3.4.2 **Explanatory variables**

Table 3.1 summarizes the description of dependent variables and explanatory variables. Japanese electric utilities share very similar organizational structure, thus heterogeneity of firms is controlled by their firm size and the share of nuclear in the total generation of the utility.

Deregulation and Competition

In order to capture the overall effect of deregulation, this research follows the approach of Sanyal and Cohen (2007) and Salies (2010). The overall impact is captured through a deregulation dummy that equals to 1 since the start of deregulation. To see the separate impact of each process of the deregulation, Kim et. al provide an approach that separates the process of the deregulation as “Entry liberalization”, “vertical integration”, and “privatization”, and each process is represented by dummy indicator. However their results are polluted by multicollinearity, thus they report separated estimation of each measure. This research also follows the same idea to separately estimate the deregulation impact on R&D input through five indicators. In Japan, the process of privatization, vertical unbundling and horizontal splitting cannot be observed. The indicators of deregulation and competition are built with: 1. Cost recovery policy dummy (1when cost recovery of R&D can be achieved, 0 when cost recovery cannot be achieved). The reason to use this variable is that under ROR regulation, utility R&D expenditure is generally viewed as cost and automatically transferred to consumers without any risk. During the deregulation, this mechanism is partially cancelled, thus firm R&D become risky and uncertain which will lead to less motivation to invest in R&D. However, this indicator is not included in the analysis on patent as it is irrelevant to patent application. 2. Power generation market deregulation indicator (0 when generation market is regulated, 1 when generation market is deregulated, and 2 when a wholesale market is established). 3. Retailing market deregulation indicator (the share of retailing deregulated market in the overall market). 4. Generation market competition indicator (the share of IPP generation in overall generation market). Generation competition pressure will alter the behavior of R&F since a large portion of R&D is usually connected to electricity generation where competition is often the greatest (Salies, 2010). 5. Retailing market competition indicator (the share of PPS generation in overall generation market). The greater share of PPS means the greater competitive threats to the incumbent utilities.

There are other indicators to measure market competition, such as number of firms, market share, concentration ratio, Herfindahl-Hirschman index, Hannah and Kay index and Lerner index. However, due to data limitation, we choose market share to proxy market competition.

Deregulation dummy and separate measures of the deregulation process such as R&D cost recovery, generation deregulation variable, retail deregulation variable and retail competition variable are compiled from the Ministry of Economy, Trade and Industry (METI) database.

Government incentive, firm size, macroeconomic condition and technological incentive

To estimate R&D input, firm revenue is used to proxy the firm size which is widely applied in previous literature (Sanyal and Cohen, 2007; Munari and Sobrero, 2002). Firm revenue is also in the natural logarithm form. As mentioned in Section 2, generation technology may also affect R&D investment. The share of nuclear in power generation is applied as the proxy of the generation technology due to nuclear technology is the first priority in the R&D investment of Japanese utilities during the examined period. The government energy R&D spending is adopted as a proxy for the government efforts that stimulate private R&D. GDP growth rate is also adopted as a controlling variable which aims at controlling the macroeconomic conditions during the examined period.

For innovation output, as discussed in Section 3, firm assets and R&D intensity are chosen as explanatory variables to avoid endogeneity problems. Firm assets indicate the impact of firm size and R&D intensity stands for the R&D investment effort of each utility. Similar with the case of R&D input, the government energy R&D spending is adopted as a proxy for the government incentive to stimulate private R&D output.

R&D intensity, firm asset and revenue are compiled with the annual report of each utility and are deflated at the 2005 constant price using CPI provided by the Bureau of Statistics of Japan. Nuclear share and generation competition indicator are calculated with the database of the Federation of Electric Power Companies of Japan (FEPC). Government energy R&D expenditure is obtained from the International Energy Agency (IEA) database. GDP growth rate is from the Cabinet Office, Government of Japan.

Table 3.1 Variable description and statistics

Variable	Description	Data source	Min/Max	Mean(S.D.)
Dependent Variable				
Ln(RD)	Nature logarithm of real R&D expenditure (constant price 2005)	Annual report	20.705 /24.913	22.711 (0.983)
Ln(patent)	Nature logarithm of patent application count	IIP-DB	0/7.057	3.766 (1.346)
Ln(citation)	Nature logarithm of patent citation count (within 5 years)	IIP-DB	0/6.518	3.523 (1.405)
Ln(acitation)	Nature logarithm of average patent citation count (within 5 years)	IIP-DB	-2.564/ 1.204	-.2904 (0.571)
Firm Variables				
Ln(revenue)	Natural logarithm of real revenue (constant price 2005)	Annual report	25.421/29.479	27.793 (0.772)
Nuclear share	Share of nuclear generation in total power generation	FEPC	0 /0 .654	0.243 (0.177)
Ln(RDIntensity)	Natural logarithm of firm R&D intensity	Annual report	-6.113/ -4.056	-5.016 (0.444)
Ln(assets)	Natural logarithm of real assets(constant price 2005)	Annual report	30.421/33.539	32.234 (0.923)
Policy and macroeconomic variables				
Deregulation dummy	Overall indicator of deregulation	METI	0 /1	0.541 (0.499)

R&D cost recovery	Indicator of the R&D recovery under ROR regulation	METI	0 /1	0.919 (0.273)
Ln(govRD)	Nature logarithm of real government energy R&D expenditure (constant price 2005)	IEA	12.401 /13.145	12.882 (0.139)
GDP growth rate	Percentage of real GDP growth rate of Japan *100 (constant price 2005)	Cabinet Office	-3.7/6.4	2.119 (2.372)
Generation deregulation	Generation dummy (0 for regulated, 1 for deregulated, 2 for wholesale market)	METI	0/2	0.868 (0.878)
Retail deregulation	deregulated retail market/total electricity market	METI	0/0 .62	0.206 (0.270)
Competition variables				
Generation competition	Electricity bought by utility*100/ (Total electricity generation of each utility)	FEPC	10.958 /20.285	14.026 (2.548)
Retail competition	Regional market share of PPS*100	Compiled from METI	0/9.8	0.555 (1.312)

3.4.3 **Endogeneity**

It is possible that firm size may introduce the endogeneity problem. However, firm size of utility is more likely to respond to domestic electricity demand due to the demand matching obligation of the utilities, even though this obligation is cancelled by deregulation process. As electric sector is quite different from other technology-intensive industries like IT and communication, it is reasonable to assume that size factor is exogenous.

As explained in Section 2, deregulation dummy is applied to capture the overall deregulation effect in the basic model. In the extended model, deregulation is estimated with policy variables including R&D cost recovery policy, generation deregulation policy, retail deregulation policy and market competition variables including generation competition variable and retail competition variable. Variables on deregulation policy and competition are highly correlated as Table 3.2 indicates. Therefore, it is difficult to estimate the independent effect of each of the variable simultaneously. Separated models are built to estimate the separated effect of generation deregulation and retail deregulation.

Table 3.2 Correlation of explanatory variables for the estimation of R&D expenditure

Variables	Ln(revenue)	Nuclear share	R&D cost recovery	Ln(govRD)	GDP rate	Retail deregulation	Retail competition	Generation deregulation	Generation competition
Ln(revenue)	1.000								
Nuclear share	0.208	1.000							
R&D cost recovery	-0.069	0.394	1.000						
Ln(govRD)	0.078	0.355	0.316	1.000					
GDP rate	-0.085	-0.143	0.186	-0.282	1.000				
Retail deregulation	0.084	-0.034	-0.455	-0.090	-0.457	1.000			
Retail competition	0.412	-0.077	-0.441	-0.155	-0.268	0.588	1.000		
Generation deregulation	0.098	0.188	-0.274	0.250	-0.590	0.705	0.391	1.000	
Generation competition	0.065	-0.241	-0.673	-0.230	-0.308	0.879	0.593	0.548	1.000

For patent count, similar approach is adopted as the analysis of R&D expenditure. Other explanatory variables include Ln(asset) to capture the firm size effect, Ln(RD intensity) to capture the effect of R&D input, and Ln(govRD) to capture the government incentive. Considering the fact that there will be a time lag between the R&D input and the R&D output, further regression is examined with lag effect. Literature has suggested that there is a lag effect in relationships between R&D input and patent applications, but only a one-year lag is consistently significant in different models (Wang and Hagedoorn, 2014, Dang and Motohashi, 2015). Also, using more lagged variables will decrease the sample significantly. For these reasons, in the regression, patent count is estimated with one year lag in R&D input as well as the case of without lag in R&D input. Therefore, the estimation only includes one-year lag R&D expenditures as an explanatory variable. Similar with R&D expenditure estimation, variables on deregulation policy and competition are highly correlated as Table 3.3 indicates. Separated models are built to estimate the separated effect of generation deregulation and retail deregulation in line with the analysis of R&D expenditure.

Table 3.3 The correlation of explanatory variables for the estimation of patent data

Variables	Ln(asset)	Ln(RD intensity)	Ln(gov RD)	Retail deregulation	Retail competition	Generation deregulation	Generation competition
Ln(asset)	1.000						
Ln(RD intensity)	0.213	1.000					
Ln(govRD)	0.078	0.170	1.000				
Retail	0.084	-0.090	-0.457	1.000			

deregulation							
Retail competition	0.412	-0.155	-0.268	0.588	1.000		
Generation deregulation	0.098	0.250	-0.590	0.705	0.391	1.000	
Generation competition	0.065	-0.230	-0.308	0.879	0.593	0.548	1.000

3.5 Estimation results

3.5.1 The effect of deregulation on R&D input

Table 3.4 implies the regression results of the simulation. The coefficient of deregulation dummy is negative and significant in model 1 (-0.295), model 2 (-0.252) and model 3 (-0.289). These coefficients are consistent with Hypothesis 1 which implies that the overall impact of deregulation on R&D expenditure is negative. The effect of R&D cost recovery is positive which indicates that under ROR regulation, utility R&D investment is encouraged as R&D is non-risky. However, in a deregulated market, as R&D investment become risky and uncertain, R&D investment is reduced. The effects of generation deregulation policy, retailing deregulation policy are negative and significant. These results are in line with the previous analysis that direct impact of deregulation is negative. Also, coefficients of market competition (generation market competition and retailing market competition) are negative and significant. Comparing the absolute value of coefficients, we also find that the impacts of retail market deregulation and competition on R&D investment are stronger than those of generation market deregulation and competition.

In line with existing literature, the elasticity of R&D spending with respect to the size of the electric utilities and government energy R&D is positive and significant. Thus Hypothesis 3 and Hypothesis 5 are confirmed by the regression results. In line with the Schumpeter hypothesis, size advantage in R&D is proved to be an important factor that affects the amount of resources allocated to technology and innovation. Government R&D efforts also tend to encourage private R&D investment based on regression results. This expresses the positive role of the government technological innovation policy and investment, especially in a deregulated market. The share of nuclear power positively affects the R&D expenditure and is elastic except for Model 7. A strong impact from technology of energy generation can be observed. This result supports Hypothesis 7. GDP growth rate is significantly positive, however, the coefficient value is relatively small. This result supports Hypothesis 8, but the low significance rates indicate that the impact of the macroeconomic on the electric utility R&D investment is relatively weak.

Table 3.4 Regression results of innovation input * p=0.1, **p=0.05, ***p=0.01

	Dependent variable : ln(RD)							
	Basic Model			Extended Model				
Explanatory variable	Model1 OLS	Model2 FE	Model3 RE	Model4	Model5	Model6	Model7	Model8
Ln(revenue)	1.043***	0.674***	0.990***	0.581***	0.674***	1.011***	1.174***	0.758***

	(0.025)	(0.184)	(0.073)	(0.224)	(0.184)	(0.180)	(0.159)	(0.180)
Nuclear share	1.668*** (0.117)	1.576*** (0.163)	1.653*** (0.152)	1.120*** (0.199)	1.571*** (0.164)	1.417*** (0.150)	0.862*** (0.141)	1.095*** (0.161)
Ln(govRD)	0.743*** (0.150)	0.891*** (0.161)	0.765*** (0.146)	0.840*** (0.185)	0.891*** (0.162)	0.455*** (0.165)	0.331** (0.146)	0.717*** (0.162)
GDP growth rate	0.019* (0.010)	0.015* (0.009)	0.018** (0.009)	0.033** (0.009)	0.015* (0.009)	0.012 (0.008)	0.012* (0.007)	0.024*** (0.008)
Deregulation dummy	-0.295*** (0.047)	-0.252*** (0.048)	-0.289*** (0.044)					
R&D cost recovery				0.251*** (0.110)				
Generation deregulation					-0.285*** (0.044)			
Retail deregulation						-0.676*** (0.080)		
Generation competition							-0.096*** (0.007)	
Retail competition								-0.116*** (0.018)
Constant	-15.539*** (1.964)	-12.278*** (2.498)	-15.082*** (1.983)	-10.628*** (2.658)	-12.278*** (2.498)	-11.323*** (2.276)	-10.944*** (2.044)	-11.187*** (2.376)
R-square	0.877	0.858	0.879	0.838	0.859	0.890	0.895	0.860
Observations	333	333	333	333	333	333	333	333

3.5.2 **The effect of deregulation on R&D output**

Patent quantity

Table 3.5 implies the regression results on patent count without considering the lag effect of R&D input. Table 3.6 implies the regression results on patent count with one-year lag effect of R&D input. The coefficient of deregulation dummy is positive and significant in model1 (0.238), model2 0.191), model3 (0.247), model8 (0.300), model9 (0.300), model 10 (0.327). These coefficients are consistent with Hypothesis 2 which implies that the deregulation positively correlated with electric utility patent application. The effect of generation deregulation policy and retailing deregulation policy are positive and significant. These results are also in line with the previous literature that direct impact of deregulation is positive. The coefficients of market competition are positive and significant. Comparing the absolute value of coefficients, it is reasonable to infer that the impacts of retail market deregulation and competition on patent application are much stronger than those of the power generation market deregulation and competition, this result is quite similar to the case of R&D input.

Table 3.5 Regression results of innovation output (patent quantity) (without R&D lag) * p=0.1, **p=0.05, ***p=0.01

	Dependent variable : ln(patent)						
	Basic Model			Extended Model			
Explanatory variable	Model1 OLS	Model2 FE	Model3 RE	Model4 FE	Model5 FE	Model6 FE	Model7 FE
Ln(RD intensity)	0.585*** (0.114)	0.668*** (0.136)	0.658*** (0.130)	0.668*** (0.136)	0.914*** (0.144)	1.012*** (0.163)	0.873*** (0.138)
Ln(asset)	1.179*** (0.065)	1.969*** (0.611)	1.208*** (0.148)	1.969*** (0.611)	0.827 (0.637)	1.678*** (0.570)	1.372** (0.574)
Ln(govRD)	1.512*** (0.400)	1.016** (0.509)	1.447** (0.382)	1.016** (0.509)	1.765*** (0.520)	1.299** (0.503)	1.574*** (0.505)
Deregulation dummy	0.238** (0.104)	0.191* (0.110)	0.247** (0.100)				
Generation deregulation				0.191* (0.110)			
Retail deregulation					1.041*** (0.226)		
Generation competition						0.117*** (0.294)	

Retail competition							0.273*** (0.056)
Constant	-29.373*** (5.388)	-33.571*** (6.802)	-28.583*** (5.362)	-33.572*** (6.802)	-26.134*** (6.246)	-32.919*** (5.789)	-31.412*** (5.719)
R-square	0.629	0.614	0.629	0.614	0.627	0.636	0.645
Observations	306	306	306	306	306	306	306

Hypothesis 4 and Hypothesis 6 also are supported by regression results. The coefficients of patent application with respect to the assets of the electric utilities and government energy R&D are positive and significant. Positive and elastic government R&D efforts coefficient further suggests that government support incentive private sector patent application.

Robustness for the results has been checked by comparing the results of the case of without lag and the case with one year lag. There is no obvious difference on the estimation results.

Table 3.6 Regression results of innovation output (patent quantity) (one year R&D lag) * p=0.1, **p=0.05, ***p=0.01

	Dependent variable : ln(patent)						
	Basic Model			Extended Model			
Explanatory variable	Model8 OLS	Model9 FE	Model10 RE	Model11 FE	Model12 FE	Model13 FE	Model14 FE
Ln(RD intensity)(lag 1)	0.623*** (0.121)	0.714*** (0.153)	0.703*** (0.141)	0.714*** (0.153)	0.975*** (0.159)	1.026*** (0.182)	0.869*** (0.148)
Ln(asset)	1.177*** (0.117)	1.626** (0.646)	1.183*** (0.137)	1.626** (0.646)	0.595 (0.665)	1.679*** (0.587)	1.271** (0.601)

Ln(govRD)	1.328*** (0.411)	0.980* (0.533)	1.247*** (0.410)	0.980* (0.533)	1.735*** (0.533)	1.156** (0.524)	1.522*** (0.522)
Deregulation dummy	0.307*** (0.109)	0.300** (0.119)	0.327*** (0.107)				
Generation deregulation				0.300** (0.119)			
Retail deregulation					1.205*** (0.244)		
Generation competition						0.127*** (0.032)	
Retail competition							0.324*** (0.064)
Constant	-26.826*** (5.619)	-28.154*** (7.437)	-25.490*** (5.721)	-28.154*** (7.437)	-22.225*** (6.663)	-31.160** (6.123)	-29.371*** (5.983)
R-square	0.637	0.630	0.636	0.630	0.590	0.634	0.651
Observations	297	297	297	297	297	297	297

Patent quality

Table 3.7 implies the regression results on patent citation. Table 3.8 implies the regression results on average patent citations. The coefficient of deregulation dummy is positive and significant for both variables. The effect of the process of deregulation and the market competition are in line with the results in patent quantity. These coefficients are consistent with Hypothesis 2 which implies that the deregulation positively correlated with electric utility patent quality. Hypothesis 6 is also supported by regression results. The coefficient of patent quality with respect to the assets of the electric utilities is positive and significant. The variable of government R&D efforts is dropped due to its insignificance. It seems that government R&D efforts are less relevant with utility patent quality.

The extended models are estimated with fixed effect model. The choice is made based on the results of Hausman test.

To sum it up, deregulation positively affects utility patent quality.

Table 3.7 Regression results of patent citation (one year R&D lag) * p=0.1, **p=0.05, ***p=0.01

	Dependent variable : ln(citation)						
	Basic Model			Extended Model			
Explanatory variable	Model15 OLS	Model16 FE	Model17 RE	Model18 FE	Model19 FE	Mode20 FE	Model21 FE
Ln(RD intensity)(lag 1)	1.024*** (0.111)	1.111*** (0.135)	1.074*** (0.122)	1.198*** (0.119)	1.445*** (0.134)	1.591*** (0.161)	1.418*** (0.148)
Ln(asset)	1.104*** (0.064)	1.127*** (0.623)	1.100*** (0.098)	1.090*** (0.099)	1,131*** (0.109)	1.146*** (0.115)	1.020** (0.115)
Deregulation dummy	0.774*** (0.096)	0.728** (0.110)	0.771*** (0.094)				
Generation deregulation				0.554** (0.119)			
Retail deregulation					2.341*** (0.272)		
Generation competition						0.197*** (0.036)	
Retail competition							0.853*** (0.115)
Constant	-7.105*** (1.180)	-6.6065 (1.845)	-6.839*** (1.168)	-6.060*** (1.614)	-5.356*** (1.803)	-7.184*** (1.874)	-3.845** (1.906)
R-square	0.707	0.698	0.708	0.717	0.683	0.632	0.661
Observations	252	252	252	252	252	252	252

Table 3.8 Regression results of average patent citation (one year R&D lag) * p=0.1, **p=0.05, ***p=0.01

	Dependent variable : ln(acitation)					
	Basic Model		Extended Model			
Explanatory variable	Model22 FE	Model23 RE	Model24 FE	Model25 FE	Mode26 FE	Model27 FE
Ln(RD intensity)(lag 1)	0.513*** (0.082)	0.414*** (0.066)	0.594*** (0.084)	0.630*** (0.092)	0.721*** (0.101)	0.627*** (0.092)
Ln(asset)	0.305 (0.376)	0.017 (0.038)	0.728* (0.371)	1.373*** (0.371)	1.761*** (0.359)	1.599** (0.362)
Deregulation dummy	0.563* (0.066)	0.604*** (0.057)				
Generation deregulation			0.325*** (0.119)			
Retail deregulation				0.855*** (0.176)		
Generation competition					0.084*** (0.021)	
Retail competition						0.319*** (0.701)
Constant	-2.260 (5.332)	1.251 (0.704)	-7.717 (1.614)	-16.452*** (5.329)	-22.432*** (5.150)	-19.587** (1.906)
R-square	0.321	0.314	0.389	0.319	0.304	0.307
Observations	252	252	252	252	252	252

3.6 Conclusions and policy implications

This paper explores the determinants that drives utility innovation and investigates how deregulation affects R&D input and output of the incumbent electric utilities in Japan This paper also investigates how electricity deregulation affects R&D input and output of the incumbent electric utilities in Japan. This work seeks to contribute to the understanding of the impact of deregulation in terms of private utility innovation behavior. In this study, the overall impact of deregulation, as well as the separate effects of cost recovery policy, generation deregulation, retail deregulation, generation competition and retail competition are examined based on firm-level empirical evidence. We find that electric deregulation has a negative impact on utility R&D input while positively affects utility R&D output. In line with previous studies on this topic (Dooley, 1998; Jamasb and Pollitt, 2006; Sanyal and Cohen, 2009; Salies, 2010; Kim et.al.2012; Sterlacchini, 2012; Costa-Campi et. al, 2014), evidences are found that deregulation reduces incumbent utility R&D investment but increases firm patent applications and patent average citations, by utilizing Japanese data. Thus, it can be inferred that deregulation will boost utility R&D productivity (see Appendix.B.3). This is supposed to be the short-term benefit of deregulation. The increase in innovation productivity can be explained by three possible reasons. 1. There is a certain degree of inefficiency of utility R&D before deregulation. 2. The electric utilities are becoming more commercialized. Growing competition encourages utility in patenting to get competition advantage. 3. The utilities have changed their research priorities to short-term, business oriented/consumer-oriented research projects which can increase patenting. However, in the long run, the lasting declining R&D investment may eventually lead to a reduction in patent and innovation which has been observed in the US (Sanyal and Ghosh, 2008) and the UK (Jamasb and Pollitt, 2011).

It can be inferred government energy R&D fund can promote private sector innovation input as well as output. The collapse in the UK energy sector R&D provided good lessons on the importance of government interference when market failure occurs (Jamasb and Pollitt, 2015). It will be more and more demanding on governance ability to achieve environmental and renewable energy target in a deregulated market. Jamasb and Pollitt (2015) emphasize that importance of technology push and market pull to promote renewable energy. Popp et al. (2011) even find that R&D expenditure (technology) push and not the installed capacity of the renewable energy (market/demand) pull the renewable energy technology. Thus, government R&D effort on renewable energy will be emphasized together with the renewable energy promoting policy like feed-in tariff policy which started in 2009.

As for the firm size, the Schumpeter hypothesis is applicable in Japanese electric sector. Large firms exhibit much stronger R&D ability and willingness. It may possibly infer that the forthcoming unbinding of transmission and distribution which is scheduled during 2018 to 2020 may further reduce innovation activities in electric sector.

The innovation in electricity industry exhibits strong path dependence. The innovation of incumbent utilities is more of an incremental type which builds high barriers for radical change. Markard and Truffer (2006) argue that market liberalization induced a shift from incremental, technology-oriented innovation to more radical, customer-oriented product innovations as well as organizational innovation. Also, they conclude that market liberalization is a drive for the overall level of innovation activities as competition challenges incumbent electric utilities and newcomers. Even though their results mainly based on surveys on EU utilities, similar things happened in Japan during the process of deregulation.

Except for the decrease in the amount of total R&D investment, Table 3.9 indicates the change in R&D expenditure breakups after the deregulation. It can be observed that the input of public-oriented R&D projects including nuclear power, environmental technology, energy efficiency, and power system is greatly reduced. The projects that are business oriented and related to cost saving, such as power generation efficiency, information technology are less affected. Public-oriented research may hardly provide any short-term incentive to utilities under deregulated market. However, environmental related technology, energy efficiency, and power system are among the top priority of the Japanese energy policy. In order to achieve government target in deregulated market, further market and institutional reforms are needed (Newbery, 2012).

Table 3.9 Change in private sector R&D expenditure by technology type from 1994 to 2005 (compiled by author with data from Central Electric Power Council)

Category	Research topic	Change
Overall R&D expenditure		-41.9%
Public-oriented	Nuclear	-50.8%
	Environmental technology	-46.5%

	Energy efficiency	-42.7%
	Power system	-63.5%
Cost-saving	Power generation efficiency	-18%
	Information technology	-23%
	other	-27.7%

The results do not necessarily imply that utilities should simply increase or decrease R&D investment. It is impossible to determine current R&D investment is above or below the “optimal level” (if it does exist).

The declining R&D effort may be detrimental to the reliability and dynamic efficiency of the electricity system, especially if more renewable energy has been incorporated, as well as the innovation maintenance in introducing smart grid and dealing with environmental concerns. Gugler et.al (2013) state that there is inherent trade-off between static and dynamic efficiency in high sunk-cost network industry based on the dynamic panel regression with the data of 16 European countries over the period 1998-2008. We also emphasize that trade-offs between static and dynamic efficiency also exist from the perspective of firm innovation. Less incentive for electric sector capital investment may be preferable considering the current electricity capacity in Japan. However, less motivation in technological R&D investment will in long term negatively affect the efficiency of the electric sector. How to deal with this “unintended consequence” remains as the further policy design during the implementation of deregulation. For example, the deregulation pioneer, UK set up mechanisms to support energy R&D as a response to the collapse of electricity deregulation (Jamasb and Pollitt, 2015). According to the results, government role is becoming more important to maintain research on the future long-term, public-oriented project in the electric sector.

For the future study, it will be interesting to check the impact of deregulation of electric sector on the upstream innovations as well as downstream innovation. During the process of deregulation, it might be drift and rebalance in the R&D within electric sector (equipment manufacturers, generators, operators, retailers). The innovation behavior of other players will provide a bigger picture of the electric sector innovation.

CHAPTER 4 **Conclusion**

Electricity is indispensable goods for households and a key input for industry in almost every economy. The three decades of electricity sector reforms all over the world exhibit a general trend towards liberalization of the economy in general as well as energy industry. In this process, the motivation, target extent and output of reforms have been largely determined by country specific conditions and political preferences. This dissertation contributes to the international efforts to estimate the impact of electricity deregulation on consumer behavior and electric utility R&D behavior in Japan with an econometric approach.

This concluding chapter is composed of three sections. First of all, the main research questions in this research are examined the answers are summarized. Then, key policy implications of the results from the studies are presented. The last section of this chapter discusses the limitations of the research and future work.

4.1 **Research question and answers**

In this section, we answer the research question of this study based on the empirical results from Chapter 2 and Chapter 3

Does deregulation alter the behavior of consumers? How do consumer behaviors change during the deregulation periods?

The analysis in chapter 2 shows that deregulation alters the behavior of the consumers. The empirical study of Japan residential and industrial sector suggests that income elasticities are stable during 1989-2014, while the price elasticities are time-varying. The analysis also proves that electricity price elasticity could be altered by price level, deregulation process, economic crisis and the structural change. During the deregulation period, price elasticities of residential sector and industrial sector gradually decline.

Does deregulation change the innovation behavors of the electric sector? How does deregulation change the R&D behavior of electric utilities?

Chapter 3 answers this question: deregulation is negatively correlated with R&D expenditures of electric utilities while positively correlated with electric utilities patent quantity and patent quality .Deregulation process as well as market competition altogether affect the electric utility innovation. Also, deregulation motivates electric utilities to change their research priority to short-term and business-oriented research projects.

Except for deregulation, firm size, government R&D efforts and R&D-intensive generation technology also positively correlated with R&D input of electric utilities. Firm size, R&D intensity and government R&D efforts are positively correlated with utility patent applications while firm size and utility R&D intensity are positively correlated with patent citations,.

4.2 Policy implication

In developed economies, electricity reforms have reached advanced stages with major elements of the standard reform model being already implemented. Many developed economies like EU, US and Japan, have already established wholesale spot markets for electricity. However, developed economies also face a major challenge and need of balancing economic efficiency and social equity as in less developed and developing countries during the process of implementing electric sector reform. Except for this, growing attention on environment, promoting renewable energy and long term development of electric sector also bring new challenge as well as opportunities on electric sector reform and industry policy of the government. This work empirically examines electric sector demand and supply while estimates of impact of electric deregulation on both sides.

On demand side, the results suggest that price elasticity is negative and is time varying. Time varying parameter model with Kalman filter provide a more robust estimation on price elasticity and income elasticity with the possibility to detect structure breaks and outliers. Also, during the process of deregulation, we find that price elasticities of industrial sector and residential sector both decline. The results cast doubt that offering consumers more choices will make consumers more elastic to price. Estimating time-varying electricity demand enables policymakers to capture the changing dynamics of consumer behavior in response to structural breaks, price levels, and deregulation. The results indicate that more emphasis should be placed on estimating consumer behavior in a liberalized market not only for policy makers but also for other players in the electricity market.

On supply side, even though electric utilities are proved to have increased their efficiency and have worked hard for cost-cutting, the unintended consequence of declining R&D efforts calls for government intervention. The increase in static efficiency is at the expense of dynamic efficiency. Also, even though deregulation has proved to be positively affecting utility innovation output which is measured by patent quantity and quality. This may simply because more commercializing of the electric utility. The electric utilities are focusing more on applicable, business oriented R&D with declining R&D investment. In contrast to airline deregulation and communication sector deregulation, regulation and government intervention become necessary and urgent in order to achieve global environmental goal and promote renewable energy. Relying on market turns out impossible to achieve either target.

Further, it is necessary to draw out relevant lessons and policy implications of reforms in terms of "what needs to be done" and "what needs to be avoided" based on the reform discourse observed from different reforming countries at varying stages of the market-oriented reform process and economic development.

4.3 **Limitation and future works**

On demand side, as retail deregulation in Japan was implemented in the residential sector in 2016, there is currently no available data to estimate the change of price and income elasticities. Further research will be interesting when enough time passes to see the impact of residential retail deregulation. The results indicate that consumers become less sensitive during the process of deregulation. However, a cross-country research is the future work to better estimate deregulation impact on consumer behavior.

On supply side, more works can be done on innovation output. We use patent application number and patent citation proxy the output of innovation in chapter 3. More complex indicators may better represent the innovation output, such as patent citation, patent claims, patent generality, patent technological categories, patent family size, scientific publications etc. More detailed indicators for patent quality can also be found in Squicciarini et.al (2013). In order to fully assess the impact of deregulation, there is a need to check upstream innovations in manufacturing companies and the possible innovation activities of the newcomers.

Political interest always plays a central role in the dramatic changes such as electric sector reform. “Based on reality” and “think politically” should be emphasized when scholars try to understand the mechanism behind the change in these sectors. Analysis of policy reform remains a great challenge. Newer frameworks like political economy analysis have been introduced. Such an approach provides insights into the underlying interests and incentives of stakeholders and the ensuing political settlements among them (Dixit, 2004; Drazen, 2000). However, the political discussion of incentives of stakeholders and process of the reform is not included in this research. This may lead to misinterpretations and misunderstandings on the choices that developing countries made. The use of CBA in analysing the effectiveness of electricity reforms is also limited in existing literature.

Electricity reform process remains a work in progress and an evolving process across all countries. A majority of the less-developed and developing countries are still at some stages of the standard reform menu. Some developed countries have established a well-functioning wholesale spot market for electricity but are suffering from chronic market power concerns coupled with the inability to sustain competition and lack of investment in the networks. Climate change and security of supply issues in the face of regulatory uncertainty have raised new problems and concerns in advanced economies such as the EU, US and Japan.

This dissertation reveals that electricity sector reforms remain a major economic, political and social challenge across all reforming countries in the world. This is because electricity reforms require coordinated progress on all aspects of the development process, namely political, macroeconomic, sectoral, and financial to be successful. The interplays between the economic, social and political factors complicate the reform process. Thereby, any qualitative and quantitative evaluation of the success or failure of the reform process is difficult irrespective of the evaluation of reforms being a matter of empirical testing or theoretical debate. Further, new economic, political and technological challenges will also change the electricity sector as market-based reforms continue to progress across all countries. These factors lead to a unanimous conclusion that electricity sector reform is and will remain a complex process across each economy.

The reliance on market-based models and the fact that most economies in this world have adopted market-oriented reform have reflected a general political belief in the efficacy of markets. However, competitive markets with independent regulatory bodies have exhibited significant market and regulatory failures in both developed countries and developing countries. The current electricity market model has demonstrated considerable stress in delivering the large scale investment required for electricity infrastructure expansion to meet global climate targets and course uncertainty in the security of supply. This indicates that future electricity sector reform should be coupled with government intervention rather than a complete reliance on market mechanism.

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ACKNOWLEDGEMENT

I would like to take this opportunity to thank people and institutions without whose extremely generous support this thesis would have hardly been prepared. First of all, I would like to thank my advisor, Prof. Gento Mogi for his helpful comments and suggestions on my research and my career. I am fortunate and grateful to have him as my PhD supervisor. His personality and I would also thank two secretaries in Mogi lab for their support on the general affairs. I would also thank all members in Mogi lab for discussion and wonderful time together.

I would also thank my examiners, Prof. Zhidong Li, Prof. Hisashi Yoshikawa, Prof. Ichiro Sakata and Prof. Kazuo Furuta for their time spent on my dissertation and constructive comments that made the dissertation much better.

I would also thank researchers in IEEJ for their kind support during my internship. Special thanks to Mr. Junichi Ogasawara, Dr.Zheng Lv, Mr.Yu Nagatomi, Mrs. Yukari Yamashita Prof. Zhidong Li for their input on my first paper.

My research has benefited greatly throughout the years from comments and suggestions by many participants of the conferences or seminars such as 5th IAEE Asian Conference, 8th International Conference on Applied Energy, 35th Japan Society of Energy and Resources Annual Conference and various workshop in PARI and Chulalonkorn University. Their contributions are sincerely appreciated. I thank all the anonymous reviewers for my papers. Without their strict comments, improvements in my research cannot be made.

I am grateful to Prof. Toshiro Matsumura and Prof. Masahiro Sugiyama from the University of Tokyo; Prof. Nobuhiro Hosoe and Prof. Makoto Tanaka from National Graduate Institute for Policy Studies; Dr. Toru Hattori and Prof. Hiroshi Asano from Central Research Institute of Electric Power Industry; Prof. Daniel Kammen from University of California, Berkeley.

I am also grateful to GSDM (Global Leader Program for Social Design and Management) for the financial support during my Doctoral course and three wonderful secondary advisors: Prof. Nobuo Tanaka, Prof. Hisashi Yoshikawa and Prof. Naoki Shikazono.

Last but not least, I owe many thanks to my parents, my sister and loving girlfriend, Miss Meng. They have been by my side through all my ups and downs and have supported me during the entire PhD journey, Without them, things would not be the same.

APPENDIX A

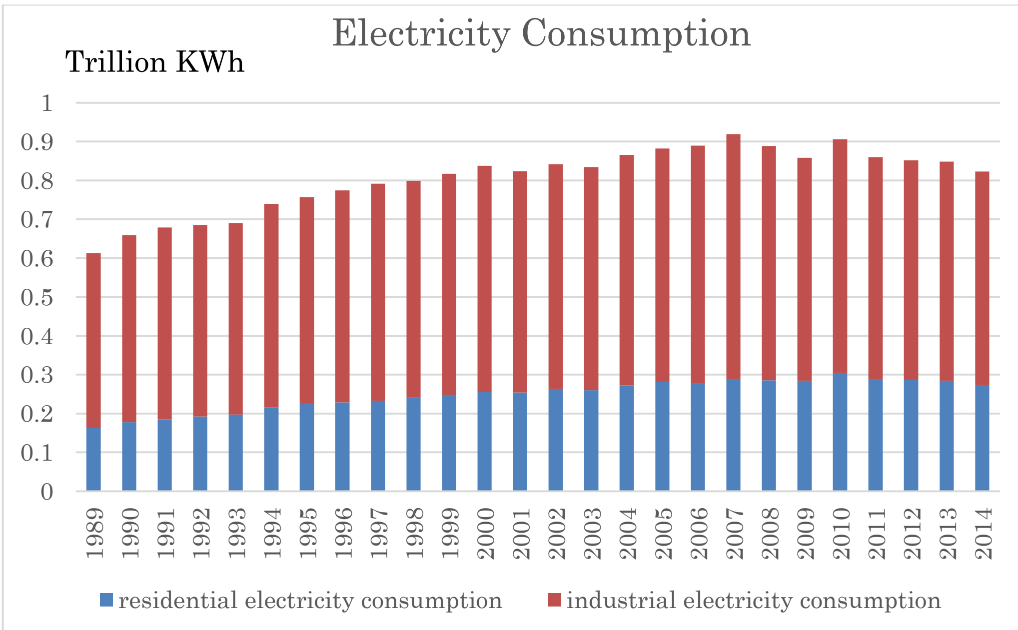

Fig. A.1 Restructured residential and industrial electricity consumption.

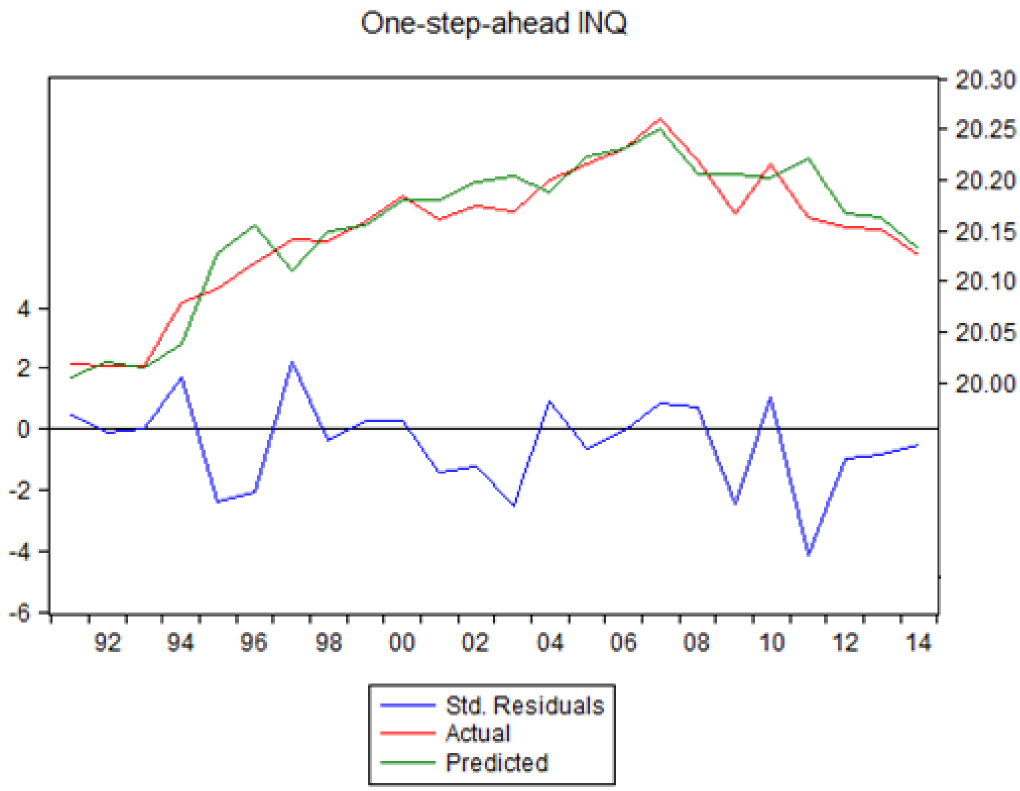

Fig.A.2 Industrial sector actual signal, predicted signal and residuals.

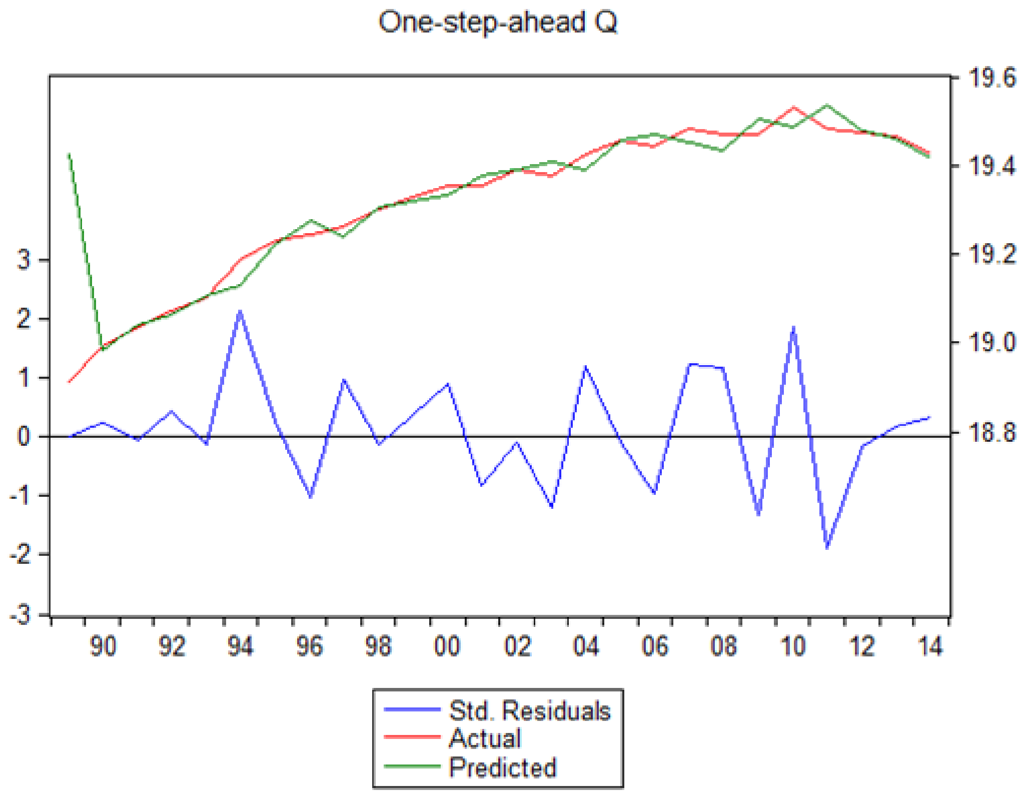

Fig.A.3 Residential sector actual signal, predicted signal and residuals.

APPENDIX B

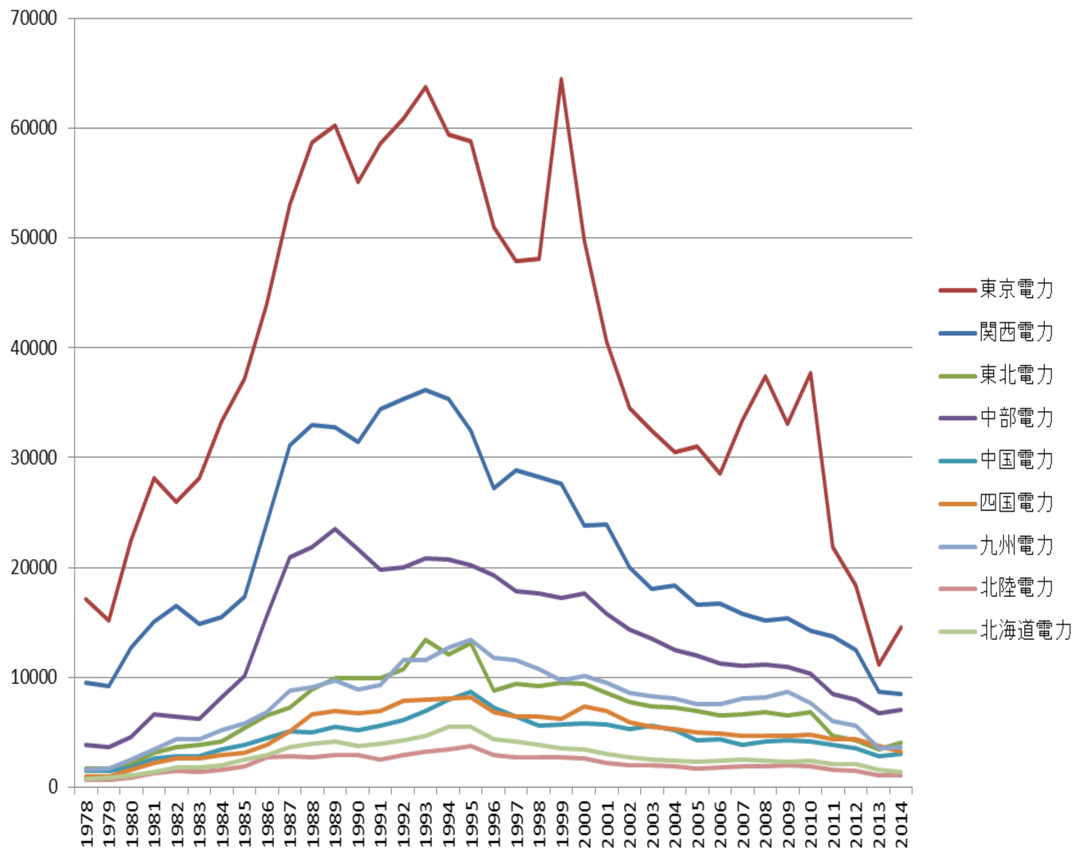

Fig..B.1 R&D expenditure of the nine electric utilities in Japan, 1978-2014.

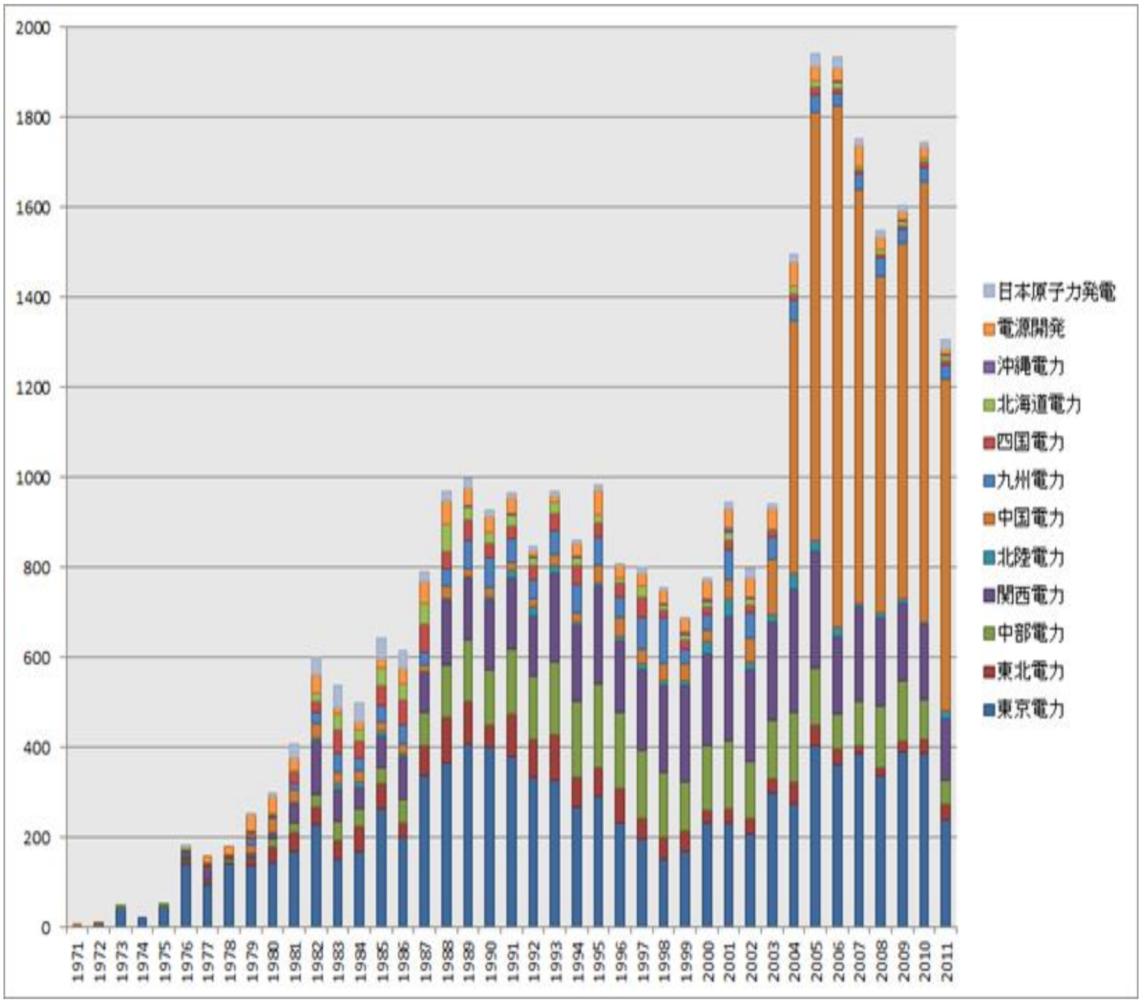

Fig.B.2. Patent application count of the nine utilities and the two main wholesale utilities (The Japan Atomic Power Company and Electric Power Development Co.,Ltd.).

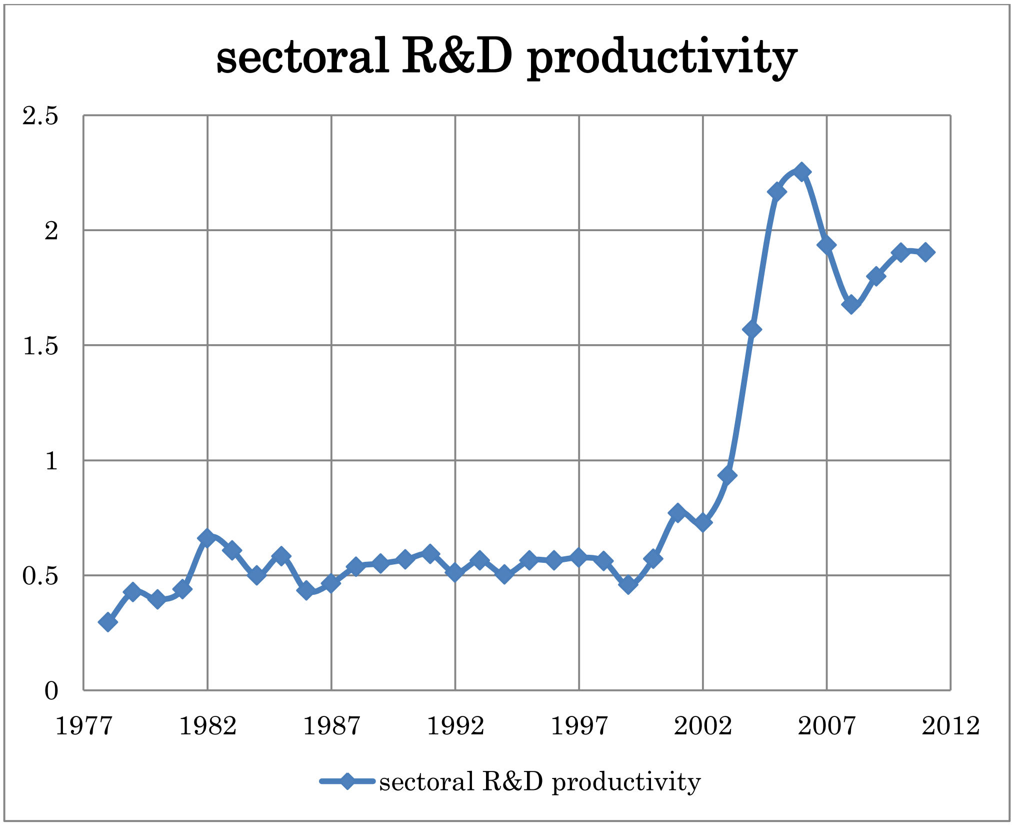

Fig.B.3. R&D productivity of Japanese electric utilities (1978-2011).

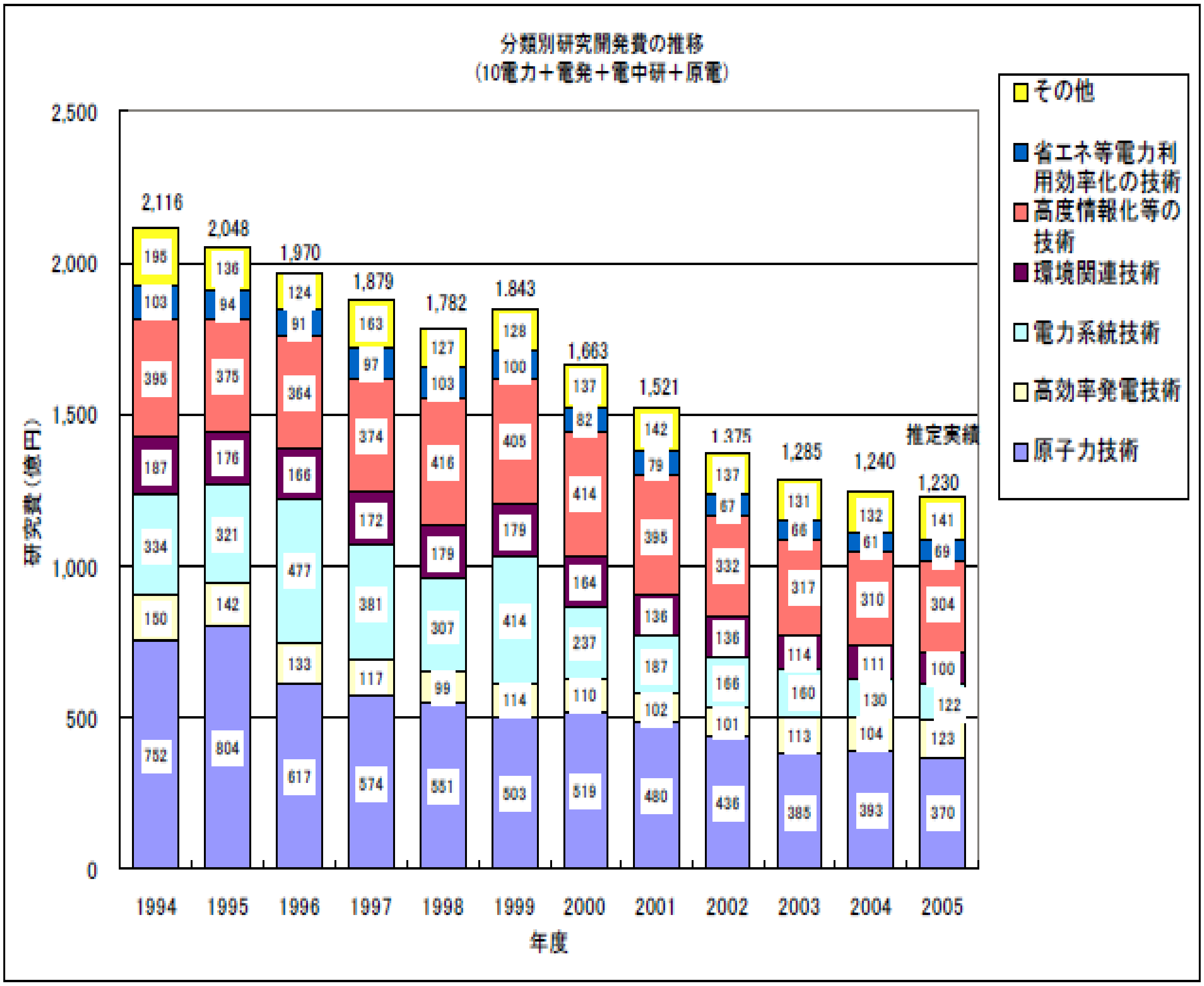

Fig.B.4. Breakup of the R&D expenditure of private sector in Japan (1994-2005). Source: Central Electric Power Council

LIST OF PUBLICATIONS

Electricity demand dynamics and TVP approach

Nan Wang, Junichi Ogasawara, Gento Mogi, An empirical study of the industrial electricity demand dynamics in Japan: a Time Varying Parameter Approach. 5th IAEE Asian Conference, 2016, Perth.

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Deregulation and utility R&D

Nan Wang, Gento Mogi, Evaluation the impacts of deregulation on Japan electricity sector R&D and patenting activities, 35th Annual Meeting on Japan Society of Energy and Resource ,2016, Osaka

Nan Wang, Gento Mogi. From regulation to deregulation: an empirical study of Japan electric utility R&D investment behavior under transition, 8th International Conference on Applied Energy, 2016, Beijing. (recommended to Applied Energy)

Nan Wang, Gento Mogi, From regulation to deregulation: an empirical study of Japan electric utility R&D investment behavior under transition, Energy Procedia (accepted).

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Electric sector regulation reform in developing countries

Nan Wang. Towards sustainable electricity development in Myanmar: Lesson from Nepal electricity reform.6th PARI-ERI-UC Berkeley joint workshop, 2016, Bangkok.