Input-Output Analysis of the electricity system reform in Japan

若城，康伸

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令和元年 12 月

神戸大学経済学研究科
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指導教員　柳川　隆

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Input-Output Analysis of the electricity system reform in Japan

（日本における電力システム改革の産業連関分析）

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Contents

Introduction

This paper examines the effects of power system reform in Japan by the framework of input-output analysis.

In the Japanese electric power industry, permissions of entrance have been given by sector. In the electricity generation sector, the entry of Independent Power Producers (IPPs) became possible in 1995, and in 2000. In the retail sector, although Power Producer and Suppliers (PPSs) was permitted to enter the retail market, it was prohibited to supply customers with under 50kW.

However, the necessity of power system reform came to be discussed in association with the power shortage following the 2011 Great East Japan Earthquake, and the retail market was fully liberalized in April 2016.

From a point of view in policy evaluations, it has been pointed out that since the full liberalization of retail, there has been an increase in new entrants, competition from former general electric utilities with other electric power, and diversification of services.

However, quantitative analyses that take into account the impact on each industry are rarely seen. Because the electric power system reform is expected to make further progress in the future, it is essential to quantitatively understand the impact of the policy so far in making policy. In particular, in the case of goods that are essential for almost all economic activities such as electricity, it is strongly needed to analyze the impact on each industry. Therefore, the analysis is performed in the framework of a general equilibrium allowing to analyze the effects on every economic activity.

The main contents and contributions

First, the input-output table was expanded. In the input-output table published by the Ministry of Internal Affairs and Communications, the electric power industry is aggregated only in the electricity generation sector and the table has no sectoral information – electricity generation sector, electricity transmission sector, and retail sector that are necessary for system reform evaluation. We disaggregated the electricity generation sector data into three sectors: electricity generation, electricity transmission, and retail using annual reports published by electric power companies. As far as we know, there is rarely seen in existing studies that disaggregate the input-output table into the electricity transmission and retail sector using the above-mentioned accounting method.

Secondly, the price elasticity parameter of demand, which is essential for the numerical simulation by applied general equilibrium, was estimated by an econometrically reliable method. There have been no studies in Japan that estimate the price elasticity of demand for electricity in a statistically reliable manner for each medium-class industry.

Finally, we simulated the effects of the liberalization of the Japanese electric power industry using applied general equilibrium. There are no studies that deal with power system reform in applied general equilibrium analysis. We believe that numerical simulations of power system reforms using the extended input-output table and precise price elasticity mentioned above will surely contribute to the analysis of the electric power industry.

Structure of thesis

This paper is organized into the following three chapters.

In Chapter 1, the published input-output table was expanded to include power generation, electricity transmission, distribution, and sales departments.

In the power industry, there should be input costs and output in each of the power generation, transmission, distribution, and electric power retail sectors. However, in the input-output table published by the Ministry of Internal Affairs and Communications, business power is concentrated only in the electricity generation sector. (It is not divided into the above three departments) and does not include the input of each department required for analysis. Therefore, using the securities reports published by 10 power companies nationwide, we divided the business power in the input-output table into three sections: power generation, electricity transmission and distribution, and retail. In addition, we have proposed a method that is closer to reality than the existing research on the input structure of the three sectors. It was also shown that the difference in this method has a significant effect on the analysis results.

Chapter 2 estimated the price elasticity of demand, which is the basis of numerical simulation, using a sophisticated econometric approach. The price elasticity of electricity demand in existing studies was often estimated by a method that has an econometric problem. In this chapter, we have obtained power price data with sufficient period and a number of samples sufficient for statistical confidence by using data (statistics of energy consumption by prefecture) that has not been used so far in power price estimation. Based on this data, we estimated by GMM using the manipulated variable method and succeeded in obtaining robust numerical values.

Chapter 3 analyzed the effect of reform using the method of applied general equilibrium analysis, using the extended input-output table created in Chapter 3 and the price elasticity of demand estimated in Chapter 4. First, in order to model the state before system reform, we analyzed the case of monopoly in both power generation and retail. Normally, monopoly profit is often modeled on the assumption that it results in the capital. However, since electricity prices were a cost-up structure, monopoly profit is allocated to labor and each input in addition to capital. Modeled assuming. After that, we are simulating the impact on each industry when the monopoly changes.

Acknowledgement

I owe a very important debt to my academic adviser Prof. Takashi Yanagawa. His deep and wide knowledge of economics, insightful discussions, careful consideration for guidance always have encouraged me. I would like to express my gratitude to Prof. Taiji Hagiwara for giving me as much of his resources as he could have. I also thank Associate Prof. Tomomichi Mizuno for beneficial comments in seminars.

Chapter 1. Extending an input-output table for analyzing structural changes in Japanese electricity system reforms

1.1. Introduction

As a global trend, electricity system reforms have been in progress.

Many studies have examined the effects of system reforms. Although most studies treat econometric analyses based on a partial equilibrium paradigm, a general equilibrium might be a more suitable framework for analyzing the effects of system reforms. This is because the general equilibrium enables us to consider the effects of system reforms on other industries in addition to the electric power industries.

Input-output tables are useful for analyzing the effects of system reforms. However, as the input-output tables in Japan are not aggregated in each sector of the electric power industry, it is impossible to evaluate the effects of the electricity system reform. We re-aggregated the table across the sectors of the electric power industry.

History of the liberalization of the electric power industry in Japan and its three sectors

Electric power companies in Japan have been permitted to monopolize the electric power markets in each region since 1951, as it is economically rational that monopolistic companies can supply fluent electric power to a rapidly growing economy without double investments in the power generation and transmission facilities.

However, it has been observed that such an industrial structure might increase the electricity price.

When miraculous/accelerated economic growth finally ended, the electricity prices in Japan were observed to be too high, thus burdening the global competitiveness of the Japanese industries at the beginning of the 1990s. The Japanese government and KEIDANREN (Japan Business Federation) discussed on an electricity system reform, as the electricity price was twice the average price in OECD (Organization for Economic Co-operation and Development) countries.

The electricity system reform started in 1995. It was applied only to the electricity generation sector. Independent power producers (IPPs) were allowed to enter the electric power market. The liberalization of the electricity retail sector started in 2000. A third party could draft a contract with the consumers in the cases where the electricity demand was over 2,000 kW. The liberalization progressed further and consumers with demand above 50 kW could enter into a contract with the electric power companies apart from the incumbent.

Following the Great Earthquake in East Japan in 2011, discussions on the electricity system reform progressed and three steps were identified. The first step involved establishing the Organization for Cross-regional Coordination of Transmission Operators (OCCT) on April 1st, 2015. The second step expanded the liberalization of the electric power retail sector to all customers (instituted on April 1st, 2016). The final step implemented the legal separation of the electricity transmission sector.

Three sectors, namely the electricity generation, transmission, and electric power retail sectors exist in the Japanese electricity industry. The electricity generation sector was liberalized in 2000, while the electric power retail sector was fully liberalized in 2016. However, the electricity transmission sector has not yet been liberalized. Moreover, the electricity transmission sector has been allowed regional monopoly hereafter.

The data of each sector in the electric power industry are essential to evaluate the effect of liberalization, as the electricity transmission sector has not been liberalized, and the electricity generation and electricity retail sectors have faced different degrees of liberalization (Figure 1.1).

Figure 1.1: Liberalization of the three sectors of the electricity industry

Studies based on econometric analyses

Many empirical studies on electricity system reforms employ econometric methods to analyze the effects of decreasing electricity prices and introducing the competition.

Zhang et al. (2008) analyzed the electricity system reforms in developing countries.

They found that only privatization or regulations did not produce obvious results, while the introduction of competition stimulated improvement.

Hattori and Tsutsui (2004) investigated the panel data of nineteen OECD countries obtained from 1987 to 1999. They estimated the effects of regulatory reform and concluded that the expanding electricity retail sectors reduced prices in the industrial sectors, while producing a price difference between the industrial and household sectors. They also indicated that separating the electricity generation sectors and introducing the retail markets did not necessarily lead to price reduction, with an increase in the electricity price also likely.

Although econometric analyses might generate apparent results or clear implications, these analyses require sufficient cross-section data, long/lengthy time-series data, or panel data. Okajima and Okajima (2013) indicated that time-series data spanning 20 years are required for an autoregressive model. Wakashiro (2018) employed panel data, which covered 47 prefectures over 24 years, to analyze the price elasticity of electricity demand.

To analyze the effect of the electricity system reform, sufficient quantitative data are not yet available for econometrical analyses. This is because a full liberalization of the electricity retail sector in the electric power industry only began in 2016.

Studies on the input-output table

Econometric analyses, which we discussed in the previous subsection, have been based on a partial equilibrium paradigm.

However, it is favorable to analyze the influences of a system reform considering various aspects, including the effects on industries other than electric power. A general equilibrium might be a suitable framework for analyzing the effects of system reform.

A few studies have investigated general equilibrium frameworks to analyze the electricity sectors. Kunneke and Voogt (1997) analyzed an electric power industry in the Netherlands. The electricity sector in the Netherlands is dominated by the public sector; however, liberalization has been discussed based on the global development of the public sector reforms. They employed a dynamic CGE model to estimate a welfare improvement of the liberalization in the Dutch electricity market.

Hosoe (2006) analyzed a regulatory reform for the electric power industry in Japan. He supposed that a barrier to the new entries was removable only in the electricity generation sector --- the electricity transmission and electricity retail sectors were defended by the regulations of the new entrant ---, and the electricity transmission and electricity retail sectors received a fair rate of return. Hosoe (2006) simulated the effects of the regulatory reform using the CGE model and concluded that a welfare improvement and substitution could occur.

These studies employed the input-output tables. However, they simplified each sector in the electric power industry and ignored the specific inputs to each sector.

Studies on the reaggregation of the input-output tables

In the Japanese input-output tables, the electric power industry is aggregated into two sectors in a column and one sector in a row. The two sectors correspond to the thermal power generation and hydroelectric / other energy generation sectors. The Japanese input-output tables are aggregated only in the electricity generation sectors; the electricity transmission and electricity retail sectors are included in the electricity generation sectors.

To analyze the effect of system reform, the sectors in the electric power industries should be separated into these three sectors. Two methods are available for reaggregating these sectors.

The first method is based only on the input-output tables, while the second reaggregates the input-output tables using other sources.

Hosoe (2006) employed the first method, and their method was employed by Akkemik and Oguz (2011), and Hwang and Lee (2015).

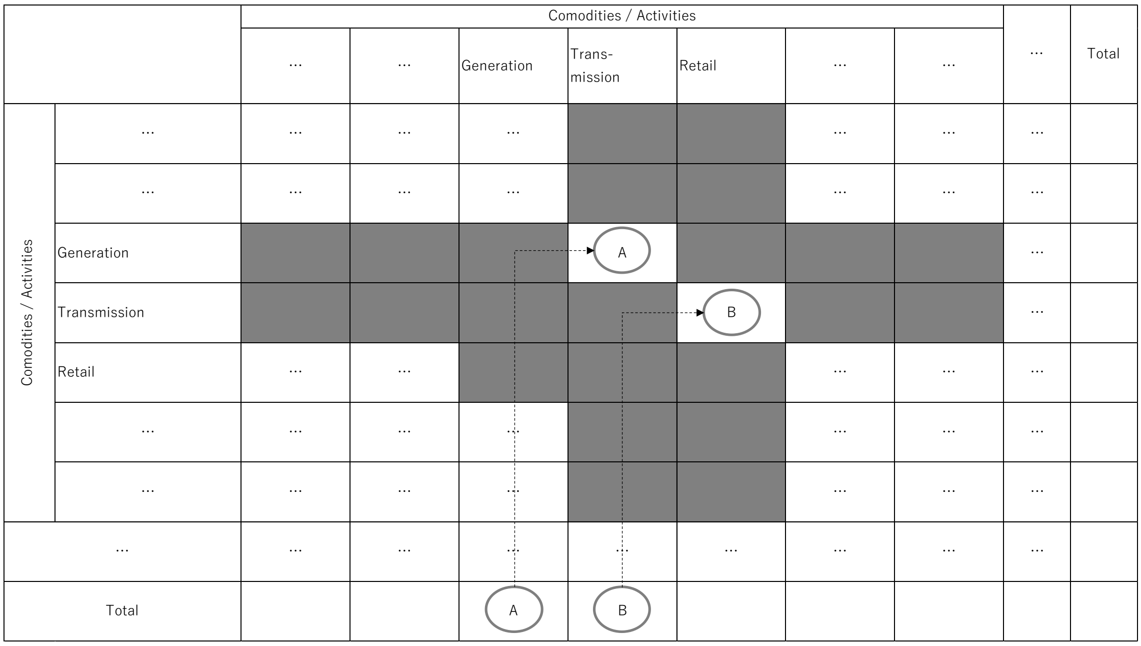


Figure 1.2: Separating the sectors of the electricity industry, as suggested by Hwang and Lee (2015)

They defined that the inputs to the electric power industry are input only to the electricity generation sector, and the outputs of the electricity generation sector are sent to the electricity transmission sector (the other inputs are not forwarded to the electricity transmission sector). The outputs of the electricity transmission sector are forwarded to the electricity retail sector (there are no inputs other than those from the electricity transmission sector).

Hwang and Lee (2015) described the method in detail. Figure 1.2 describes the method used by Hwang and Lee (2015) to separate the sectors.

However, it is unconvincing that the electricity transmission sector has no inputs from any other industry, along with the electricity retail sector. The electricity transmission and electricity retail sectors must have sector-specific inputs. In contrast, the second method has been rarely employed in the peer-reviewed studies in Japan.

Hienuki and Hondo (2013) reaggregated the 2005 input-output table using “the electric utility operating expenses schedule" detailed in the annual reports of the incumbent electric power companies. They created a new sector using this data source. However, their new sectors did not contain the electricity transmission and electricity retail sectors because they intended to create renewable energy sectors.

1.2. Methodology

Modification of the input-output matrices

As mentioned previously, there have been no published studies in Japan that have re-aggregated the input-output tables across three sectors (generation, transmission, and retail) using the electric utility operating expenses schedule.

We will correspond/link the input-output table and electric utility operating expenses schedule to estimate the proportions of the three sectors in the electric power industry of Japan.

Hybrid approaches have been proposed by a few studies (Linder et al. (2013), Heijungs and Suh (2011), Rodriguez-Alloza, et al. (2015)) for constructing the modified input-output tables.

We will introduce the following modifications based on the study by Linder, et al. (2013).

We introduce the input weight factor, which represents the proportion of outputs allocated to each sector in the electric power industry. This factor is similar to the one employed by Linder, et al. (2013) and Marriot (2007).

The input weight factor ρ represents the ratio of the proportion of each electricity sector to the total inputs of the electric power industry ($\rho_{i,k} = x_{i,k} / \sum_k x_{i,k}$). Then, the sum of the factors equals one.

$$\sum_k \rho_{i,k} = 1 \tag{1}$$

We define the coefficients of an electric power industry in the original input-output table as a. Then, we can define the modified coefficients in the disaggregated input-output table as:

$$a_{i,k} = \rho_{i,k} * a^*_{i,ele} \text{ , } for\ k = \{generation,\ transmission, retail\} \tag{2}$$

where

$$a^*_{i,ele} = \sum_{ELE} a_{i,ELE}, for\ ELE = \{thermal, others\} \tag{3}$$

It should be noted that the factors of ELE in Equation (3) correspond to those in the original input-output table.

Inter-sectoral transactions in the electricity industry

As previously mentioned, our definition of inter-sectoral relationship in the electric power industry differs from the ones proposed by Hosoe (2006), Akkemik and Oguz (2011), and Hwang and Lee (2015). They assumed that all outputs of the electricity generation sector were forwarded to the electricity transmission sector, and all outputs of the electricity transmission sector were forwarded to the electricity retail sector.

Although their assumption was reasonable with respect to the flow of electricity (Figure. 1.3 above), it greatly differed with regards the flow of business. For example, if their assumption is applied to the car industry, the sales amount of car makers gets loaded on the transportation industry, and subsequently the total amount of the traffic industry is purchased by the retail industry. Furthermore, duplication among the sectors exists.

We suppose that each sector (generation, transmission, and retail) has its sector-specific inputs. Furthermore, each sector has outputs to other industries as intermediate goods and to the consumers as the final demand (Figure. 1.3 below). We assume that no transactions exist between the sectors in the electricity industry (described in Figure 1.4).

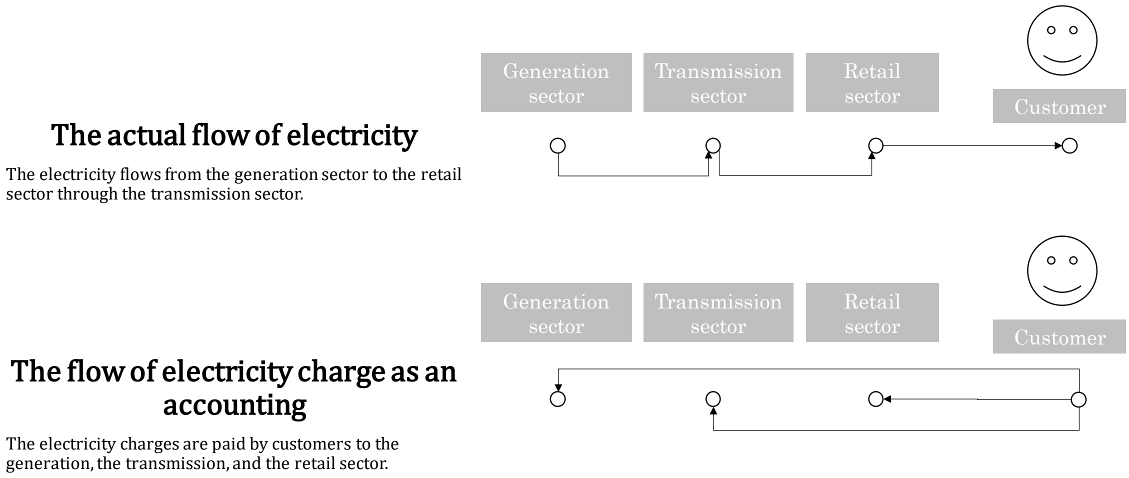


Figure 1.3: Money flow among the three separate/distinct sectors

		Comodities / Activities					...	Total
		...	Generation	Trans-mission	Retail	...		
Comodities / Activities	...	...	...	...	...	...	...	
	Generation	...				...	...	
	Transmission	...				...	...	
	Retail	...				...	...	
	...	...	...	...	...	...	...	
...		...	...	...	...	...	...	
Total								

Figure 1.4: Separating the sectors of an electricity industry

Inverse matrices and forward/backward linkages

In the Leontief framework, the total output X should correspond to the sum of the intermediate consumption and final demand. Therefore, the inverse matrix can be defined as

$$\mathrm{X} = [I - (I - M')A]^{-1}[(I - M')F^d + E]\ , \tag{4}$$

where I is a unit matrix, M' is a diagonal matrix of import coefficients, and A is a matrix of input coefficients.

Linkage effects are used to analyze how each sector influences on the other sectors or how each sector is influenced by the other sectors (Hirschman (1958), Nagashima et al. (2017)).

There are two linkage effects, namely backward linkage and forward linkage (Fig. 1.5).

The backward linkage is represented by

$$e_j = \frac{\sum_{i=1}^{n} b_{i,j}}{\left(\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} b_{i,j}}{n}\right)} \tag{5}$$

This indicates the degree how the increase in the industrial final demand to industrial sector j affect the production. The forward linkage is defined by

$$r_i = \frac{\sum_{j=1}^{n} b_{i,j}}{\left(\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} b_{i,j}}{n}\right)},\quad for\ j = \{1, 2, 3, , , n\} \tag{6}$$

This indicates the degree how each sector is affected by other industrial production activities.

		Inputs					
		Industrial sector 1	Industrial sector 2	…	Industrial sector j	…	Industrial sector n
Outputs	Industrial sector 1	b_{11}	b_{12}	…	b1j	…	b1n
	Industrial sector 2	b21	b22	…	b2j	…	b2n
		…	…	…	…	…	…
	Industrial sector i	bi1	bi2	…	bij	…	b3n
	…	…		…			…
	Industrial sector n	bn1	bn2	…	bn3	…	bnn

Figure 1.5: An inverse matrix and linkage effects

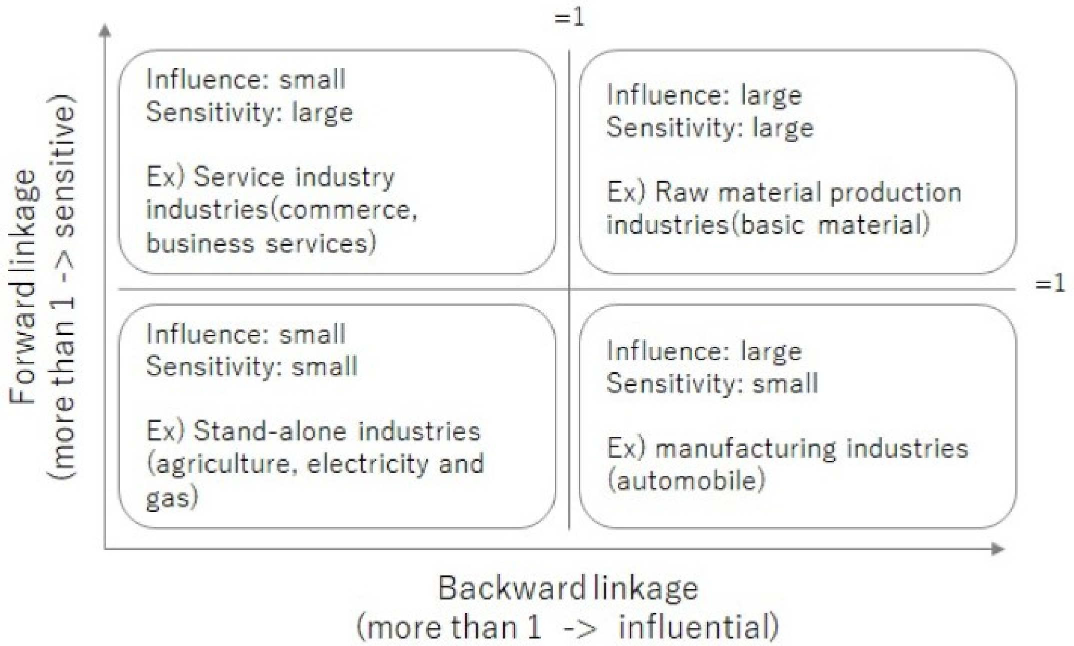


Figure 1.6: Backward linkage and forward linkage

1.3 Data

We employed the latest input-output table in Japan, belonging to the year 2015 (we termed this table 2015-table). In the original input-output table, there is one electricity sector (‘electric power industry’) in a row, while there are two sectors in a column (thermal and other generation).

The size of the 2015-table is 509 × 391. We reaggregated the sectors of the electric power industry into three new sectors (generation, transmission, and retail) using the cost tables of the electric power companies, thus, the size of the modified table was 511 × 392.

Finally, we summarized the table into a square matrix of size 191 × 191 to conduct the input-output analyses.

To disaggregate the input-output table, we referred to "the electric utility operating expenses schedule” provided in the annual reports of the electric power companies, which have to be mandatorily disclosed.

A base input-output table

Input-output tables in Japan are constructed every five years.

The 2011-table was built instead of the 2010-table to analyze the influence of the Great Earthquake in East Japan. This disaster disrupted infrastructures, disturbed value chains, and decreased the industrial demand.

The previous table was provided in 2005, which was the year before the liberalization of the electricity retail sector, and the economic downturn precipitated by the bankruptcy of the Lehman Brothers.

We used the 2015-table, as this year preceded the full liberalization of the electricity retail and witnessed no major economic disasters.

As mentioned above, the 2015-table contains 509 input sectors and 391 output sectors. Nevertheless, the 2015-table does not have the electricity transmission and electricity retail sectors. The inputs and outputs of the electricity transmission and electricity retail sectors were included in one sector in the rows, and two sectors in the columns.

We reaggregated the 2015-table into the electricity generation, transmission, and electricity retail sectors to analyze the effects of the system reform.

Annual reports for estimating the costs in an input-output table

The Ministry of Internal Affairs and Communications (2017) provides the definition and the estimation method of the "Electric power business" in the 2015-table.

The estimation method states: "We allocate the electricity generation costs using 'the electric utility operating expenses schedule', and also allocate other costs (transmission, substation, distribution, selling, general and administrative expenses)". The electric utility operating expenses schedules are published in the annual reports of the incumbent electric power companies (we termed as "EPCOs").

The electric utility operating expenses schedules, which all the EPCOs are obliged to submit, are printed in the annual reports and categorized by the accounting names.

The correspondence between the input-output table and electric utility operating expenses schedule has not been clearly described by the Ministry of Internal Affairs and Communications (2017). Furthermore, as the inputs of the input-output tables are activity-based, while those of the expenses schedules are occurrence-based, there is no match between those.

Thus, we reaggregated the information of the electric power industry in the input-output table into three sectors based on their proportions using the electric utility operating expenses schedule.

In the electric utility operating expenses schedules, there are fifteen sectors, namely hydropower generation, steam power generation, nuclear power generation, internal combustion power generation, alternative energy generation, purchased power from other zones, purchased power from other company, transmission, substation, distribution, selling costs, outage facility, loan facility, general and administrative expenses, and others.

In this study, we defined the correspondence between the sectors in the electric utility operating expenses schedules and an input-output table, as described in Table 1.1.

Sectors in the input-output table	Costs in the electric utility operating expenses
Generation	Nuclear, Steam, Internal combustion, Hydroelectric, Renewable energy power generation
Transmission	Transmission, Substation, Distribution
Retail	Retail

Table 1.1: Correspondence between the input-output table and annual reports

Correspondence between the electric utility operating expenses schedule and input-output table

We used the electric utility operating expenses schedule detailed in the annual reports of the EPCOs to estimate the costs of the electricity generation, electricity transmission and electricity retail sectors.

We used aggregation for all the ten EPCOs and allocated inputs to the electric power industry in the 2015-table proportional to the costs in electric utility operating expenses schedule.

We compared the input-output table with the total electric utility operating expenses schedule. The definitions and number of items did not match. The number of items in the input-output the table was 509, while it was 214 in the electric utility operating expenses schedule. We confirmed the former by referring to the information published by the Ministry of Internal Affairs and Communications (2017). The latter was confirmed by referring to the definition of the account name corresponding to the electric utility industry law accounting rules in Article 3.

It should be noted that the annual reports of the EPCOs are published on a fiscal year basis, while the input-output tables are based on the calendar year in Japan. We converted EPCOs' annual costs (fiscal year basis) to a calendar year basis. We aggregated the costs in the annual reports of the 2014 FY by multiplying with 3/12 and those of the 2015 FY by multiplying with 9/12.

1.4 Results

We reaggregated the new input-output table, and then calculated the inverse matrix and backward / forward linkages using the newly defined sectors of the reaggregated input-output table. We compared our results with those calculated using previous research methods.

Input weight factors of each sector

We calculated the input weight factors, ρ. The input weight factors were calculated by matching 509 items, which were inputs to the electric power industry in the original input-output table, and 214 items in the electric utility operating expenses schedule. Table 1.2 shows the representative input weight factors of each sector in the electric power industry corresponding to the major industrial categories.

Table 1.2: Representative input weight factors of each industry (%)

Major industrial categories	Generation sector	Transmission sector	Reta¥il sector
Mining	100.0	0.0	0.0
Chemical products	63.2	18.9	17.8
Petroleum and coal products	99.5	0.3	0.2
Non-ferrous metals / Metal products	62.7	19.2	18.1
Construction	46.3	53.7	0.0
Commerce	62.7	19.2	18.1
Finance and insurance	50.6	25.8	23.5
Real estate	19.9	75.6	4.5
Transport and postal services	68.4	14.7	16.9
Information and communications	50.7	25.3	24.0
Business services	44.1	41.3	14.6

The electricity generation sector consumes all the inputs in the “Mining” industry, and most of the inputs in the “Petroleum and coal products” industry.

The electricity transmission sector consumes a majority of the inputs in the “Construction” and “Real estate” industries.

A certain amount of inputs in the “Information and communications” and “Finance and insurance” industries is sent to the electricity retail sector.

The inverse matrix coefficients and forward/backward linkages of the sectors

Figure 1.7 describes the inverse matrix coefficients of the new sectors. The "Electricity, gas, and heat supply" industry has the largest inverse matrix coefficient in the electricity generation sector, followed by the "Business service", "Transport and postal services", and "Petroleum and coal products" industries.

In the electricity transmission sector, "Business services" has the largest inverse matrix coefficients, followed by "Transport and communications", "Finance and insurance", "Commerce", "Construction", and "Real estate".

In the electricity retail sector, "Business services" has the largest coefficient, followed by "Transport and communications", "Finance and insurance", and "Commerce".

The inverse matrix coefficient of the "Electricity, gas, and heat supply" industry is almost entirely due to the electricity generation sector, while the electricity generation sector provides many coefficients for the "Petroleum and coal products".

The inverse matrix coefficients and forward/backward linkages of the sectors

The forward and backward linkages are shown in Figure 1.8.

The forward linkages indicate the degree of sensitivity of the industries. Figure 1.8 shows that all the newly added sectors are < 1, which implies that all sectors are less sensitive than the average sensitivity of all the industries.

The backward linkages indicate how much influence each industry has on the others.

The backward linkages of the electricity transmission and electricity retail sectors are < 1, which implies that the impacts of these industries are less than the average. The electricity generation sector has a backward linkage > 1, indicating that the impact on the other industries is greater than the average.

Based on the examples shown in Figure 1.6, it can be observed that the electricity generation sector is close to the manufacturing industries such as the automobile industry, while the power transmission and electricity retail sectors are close to the stand-alone industries, such as agriculture or electricity.

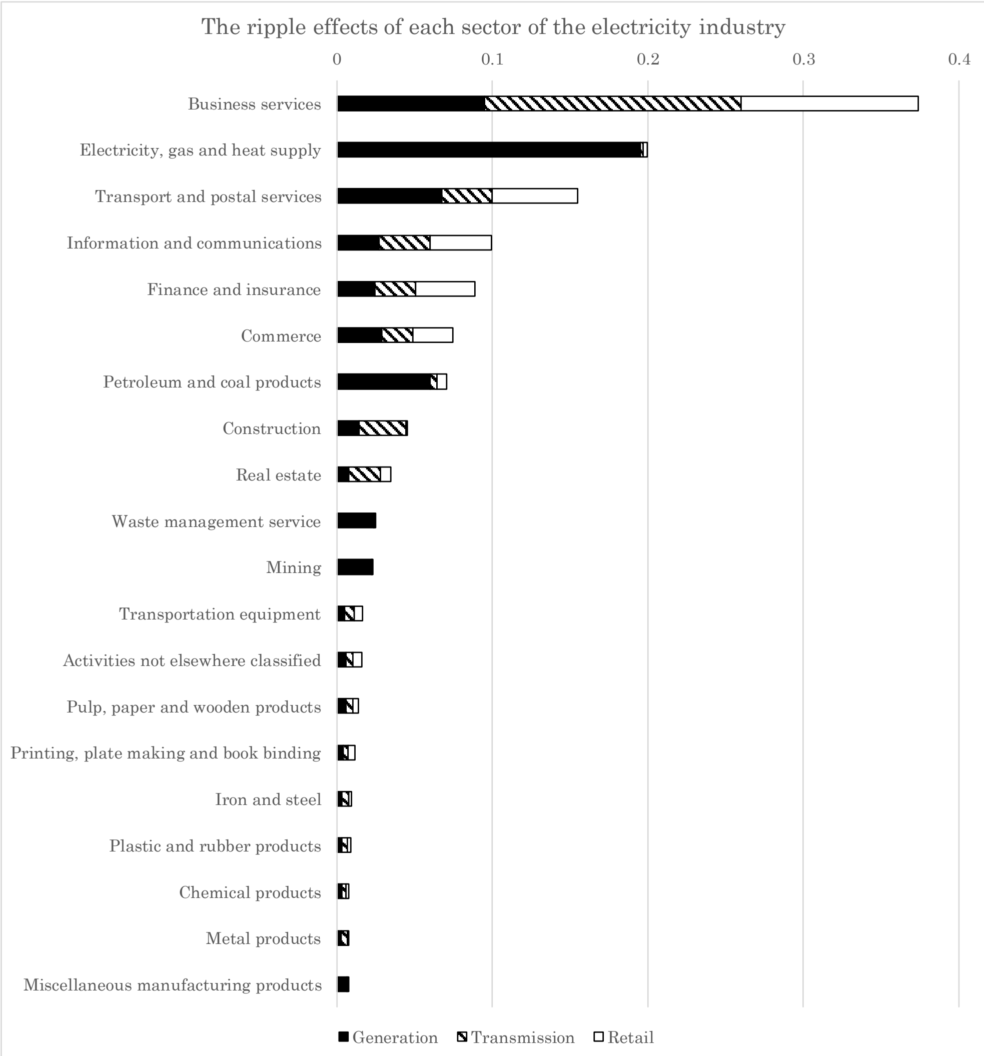


Figure 1.7: Inverse matrix coefficients of each sector

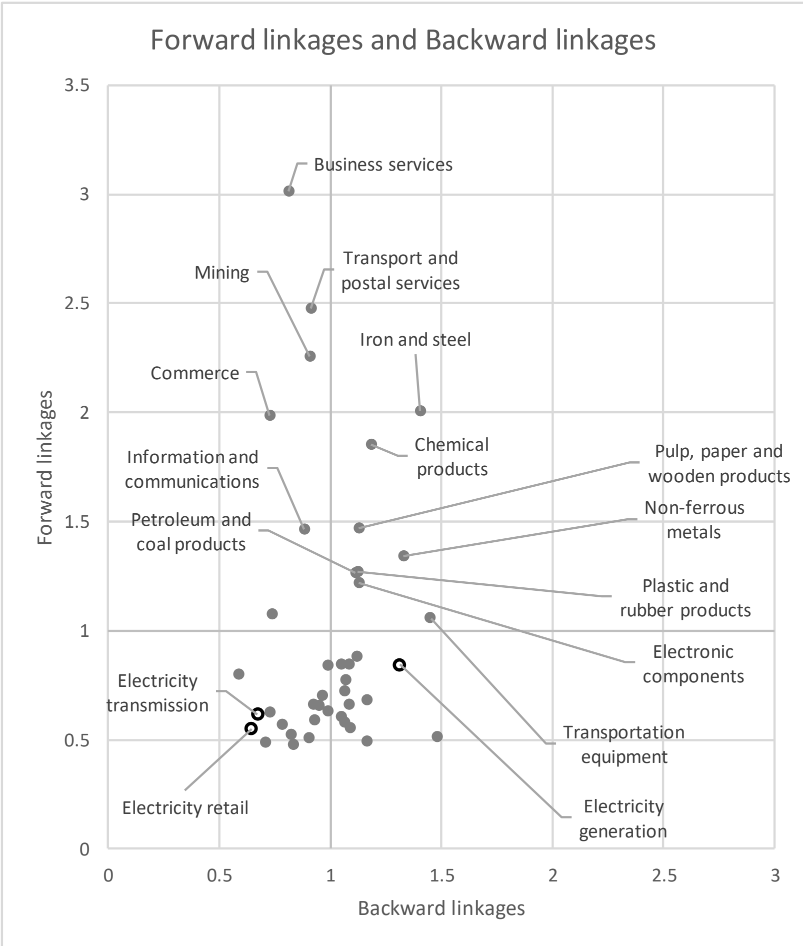


Figure 1.8: Backward and forward linkages

Comparison of the inverse matrix coefficients

We assumed that the goods and services would be directly input to the power generation, transmission, and electricity retail sectors. In contrast, previous studies such as Hosoe (2011) and Hwang-Lee (2013) assumed that the inputs to the electric power industry are provided only to the electricity generation sector. The outputs of the electricity generation sector are then sent to the electricity transmission sector, and finally the outputs of the electricity transmission sector are forwarded to the electricity retail sector.

We compared the inverse matrix coefficients calculated using our method and those using method of previous studies.

Figure 1.9 shows that the inverse matrix coefficients of the electricity generation sector on the “Mining”, “Petroleum and coal products”, and “Electricity, gas and heat supply” industries are larger in our method, as compared to the previous method. In contrast, those on the “Business services” industry are smaller using our method, as compared to the previous method.

Figure 1.10 shows that the electricity transmission sector has a large inverse matrix coefficient on the electricity generation sector when using the previous method, while there is very small coefficient using our method. This is because we assumed that there are no inter-sectoral transactions (based on this assumption, the electricity retail sector has very small coefficients on the electricity generation or electricity transmission sectors).

The electricity transmission sector has inverse matrix coefficients on the “Petroleum and coal products” and “Electricity, gas and heat supply” industries when using the previous method, while our method does not have coefficients on any of these industries. The coefficient on the “Business services” industry is larger when using our method, as compared to the previous method.

Figure 1.11 shows that the electricity retail sector produces large inverse matrix coefficients on the electricity generation and electricity transmission sectors when using the previous method. In contrast, there are very small coefficients when using our method due to the different definition of the inter-sectoral transaction. The large inverse matrix coefficients in the “Petroleum and coal products” and “Electricity, gas and heat supply” industries by our method exist by the previous method is same as described above.

The inverse matrix coefficients on the “Business services” industry are similar to those previously seen when using our method and the previous method.

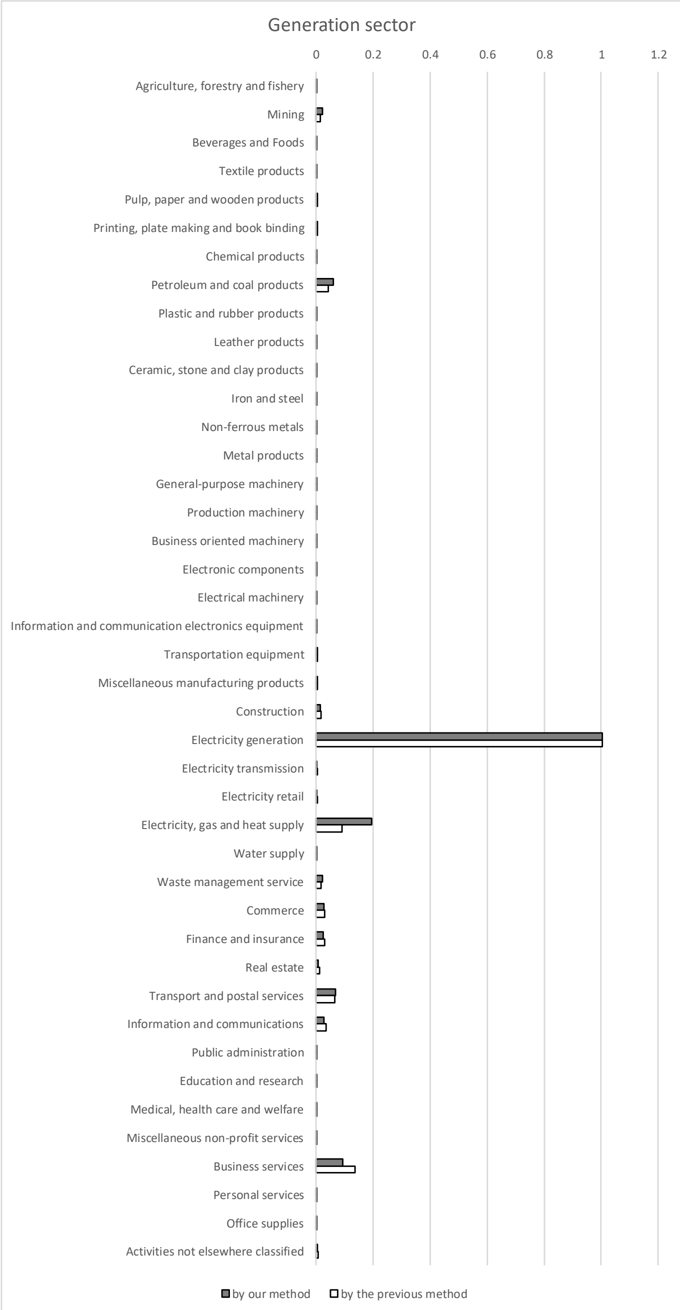


Figure 1.9: Inverse matrix coefficients of the electricity generation sector estimated using the method proposed by Wakashiro and Hwang-Lee

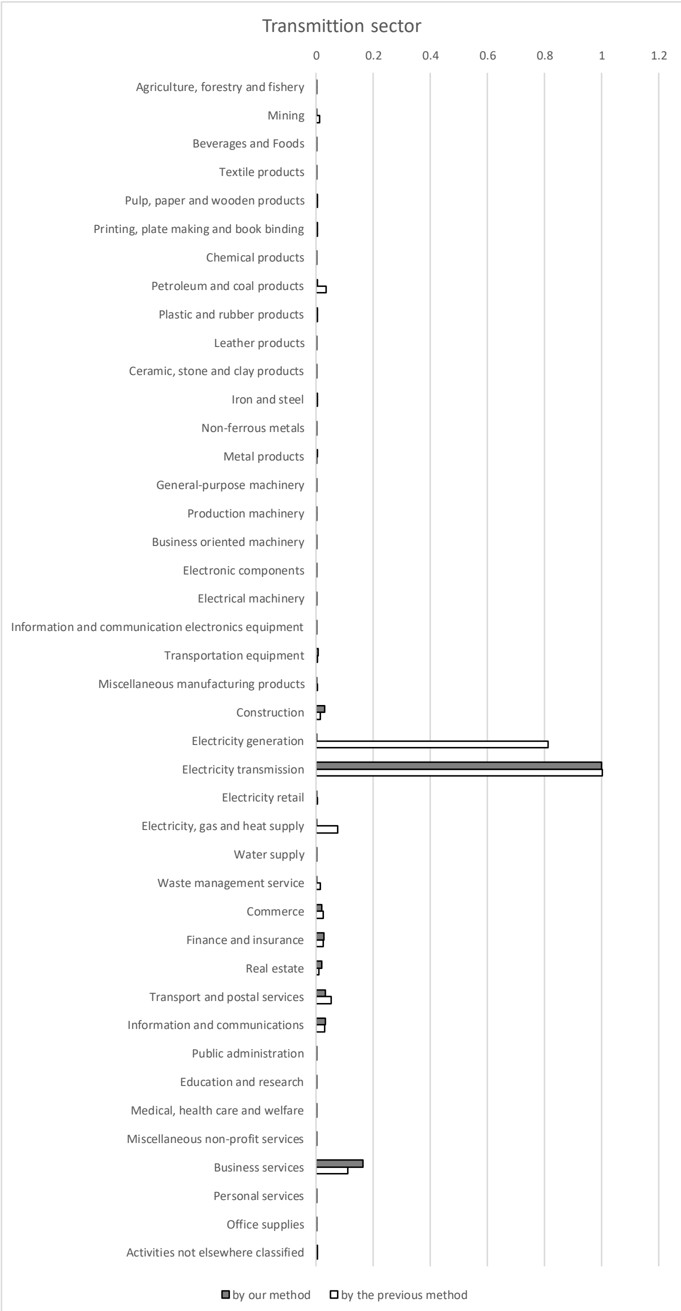


Figure 1.10: Inverse matrix coefficients of the electricity transmission sector estimated using the method proposed by Wakashiro and Hwang-Lee

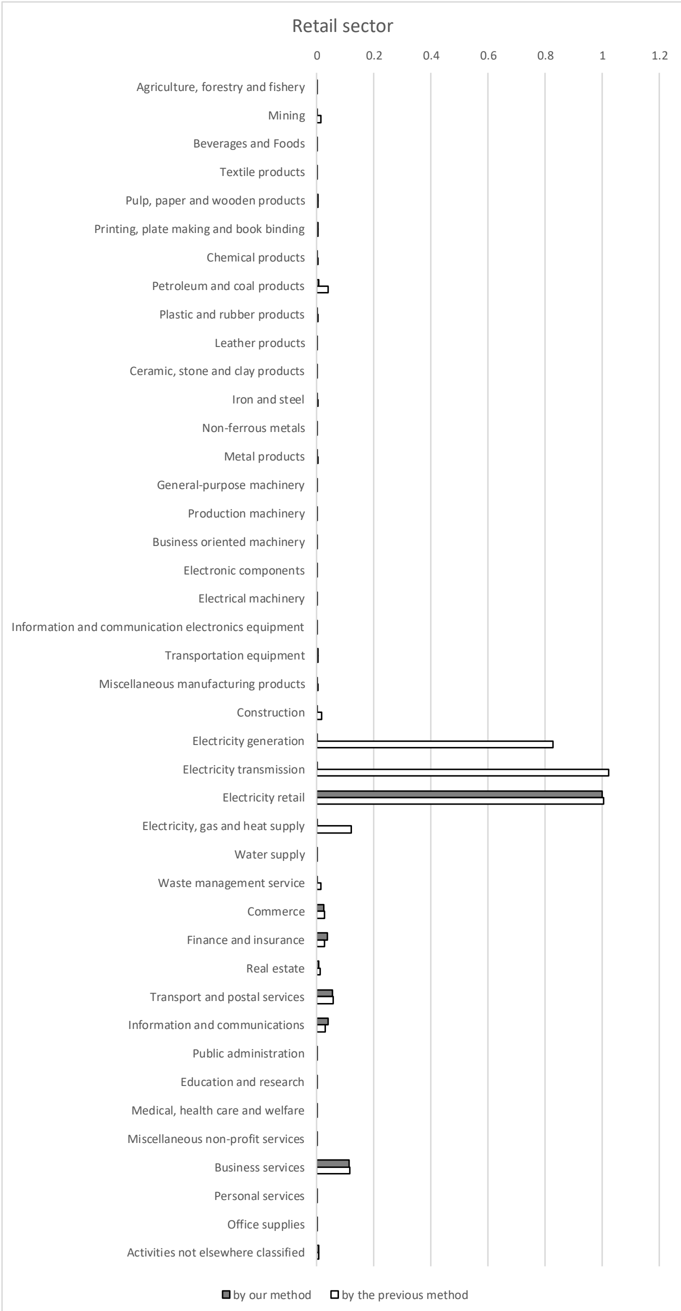


Figure 1.11: Inverse matrix coefficients of the electricity retail sector estimated using the method proposed by Wakashiro and Hwang-Lee

Comparison of the forward / backward linkages

The forward linkages represent the influence that each receives from the other industries, whereas the backward linkages represent the influences of each industry on the other industries.

Figure 1.12 shows that the influence of the electricity transmission and electricity retail sectors calculated using the previous method are larger than that obtained using our method, while the influence of the electricity generation sector calculated using the previous method is smaller. This figure also shows that all the backward linkages, except those of the electricity transmission and electricity retail sectors, obtained using the previous method are smaller as compared to our method.

Figure 1.13 shows that the influences that the electricity generation, electricity transmission, and electricity retail sectors, and the “Mining” industry receive are larger when using the previous method, as compared to our method.

These results indicate these industries are too sensitive when the previous method are used. We assumed that the electricity sectors receive the inputs and sell the outputs directly, while the previous method assumed that all the inputs are received by the electricity generation sector, and all the electricity is sold by the electricity retail sector.

Figure 1.14 shows the differences of the forward and backward linkages calculated between using the previous and our methods.

This shows that the electricity generation is more influential on the other industries, while the electricity transmission and electricity retail sectors are less influential when using our method as compared to the previous method, and also shows that all of the electricity sectors are less sensitive when using our method. Furthermore, the forward and backward linkages of most industries other than electricity sectors are smaller when calculated using the previous method, as compared to our method.

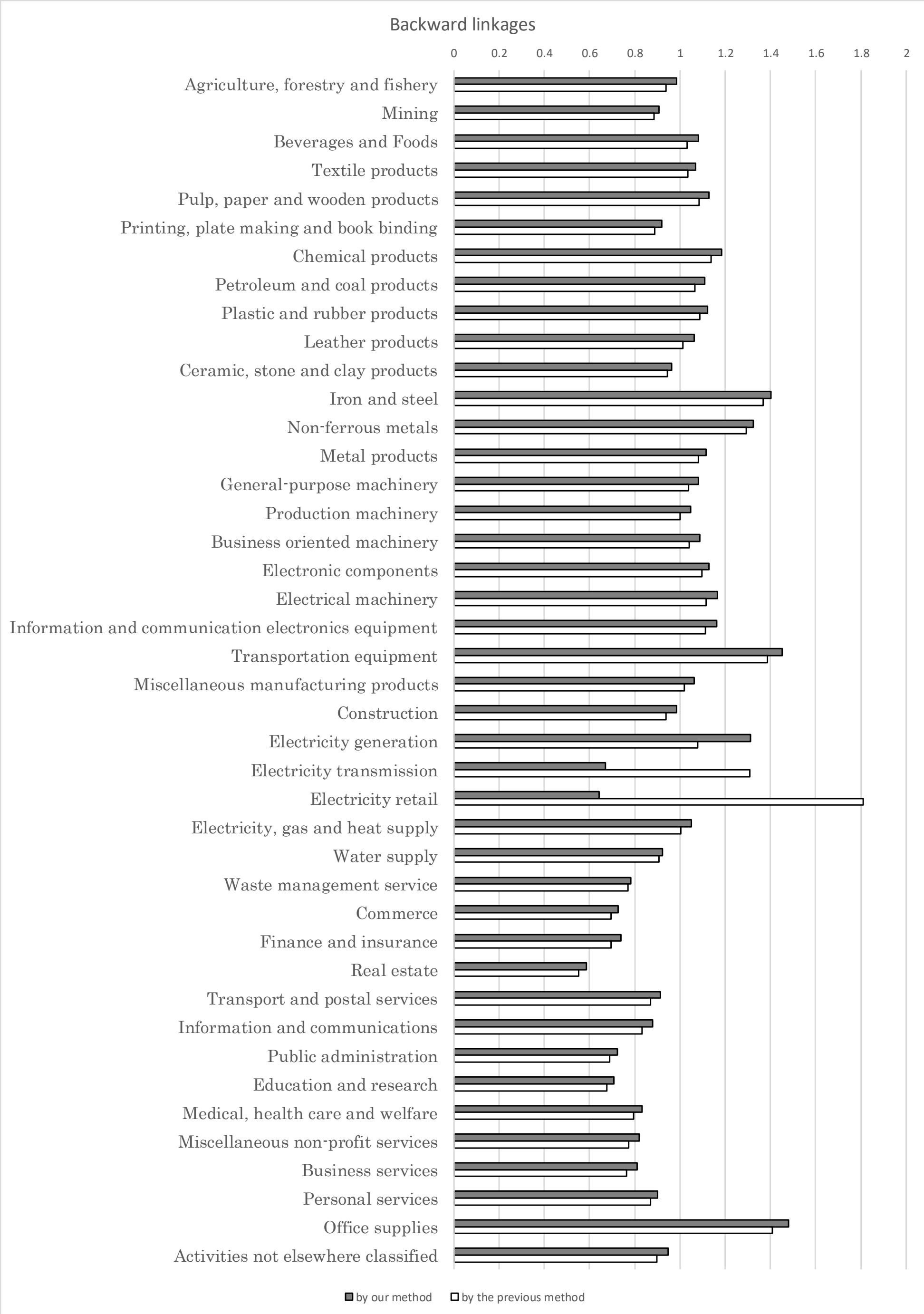


Figure 1.12: Backward linkages calculated using our method and the previous method

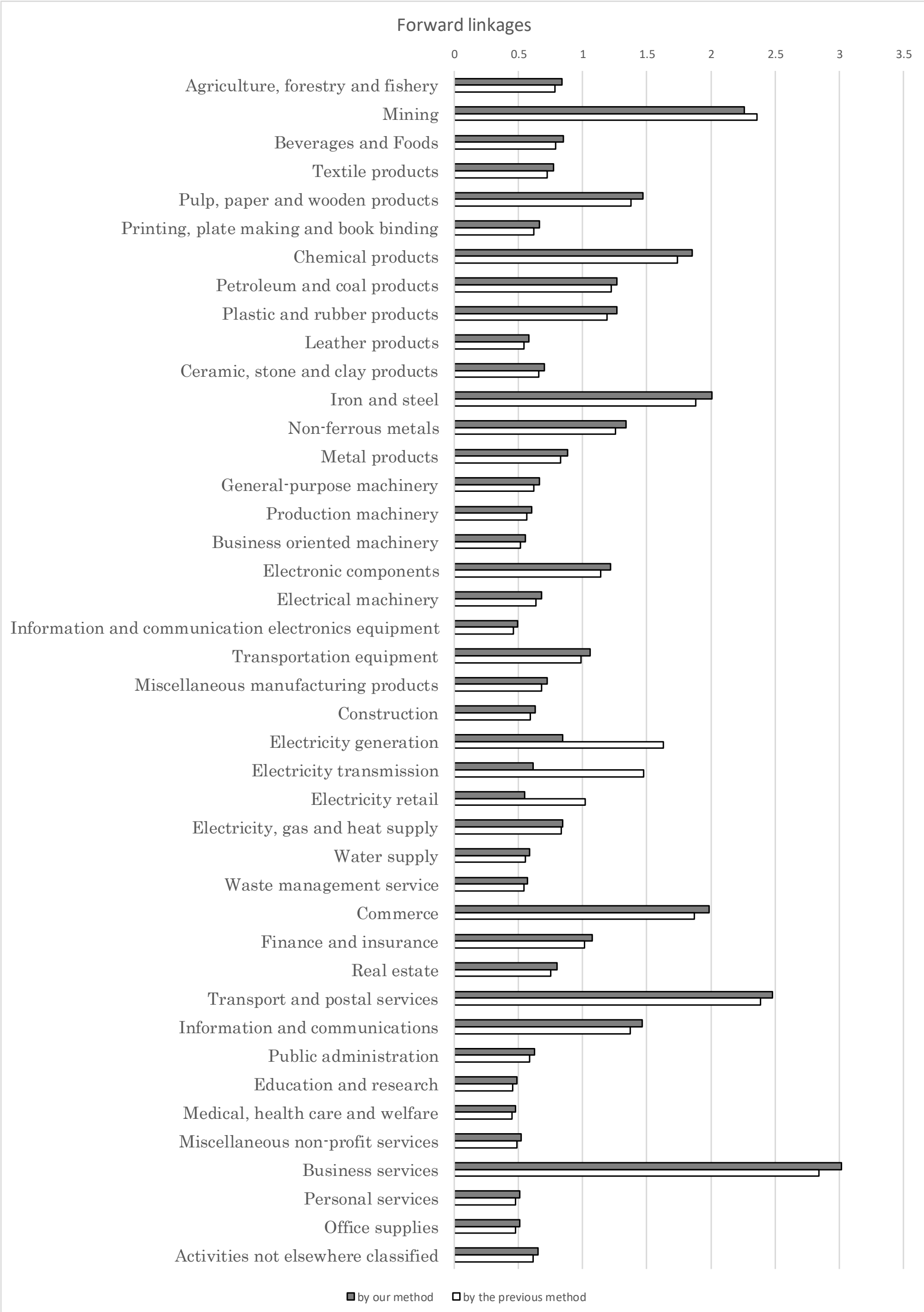


Figure 1.13: Forward linkages calculated using our method and the previous method

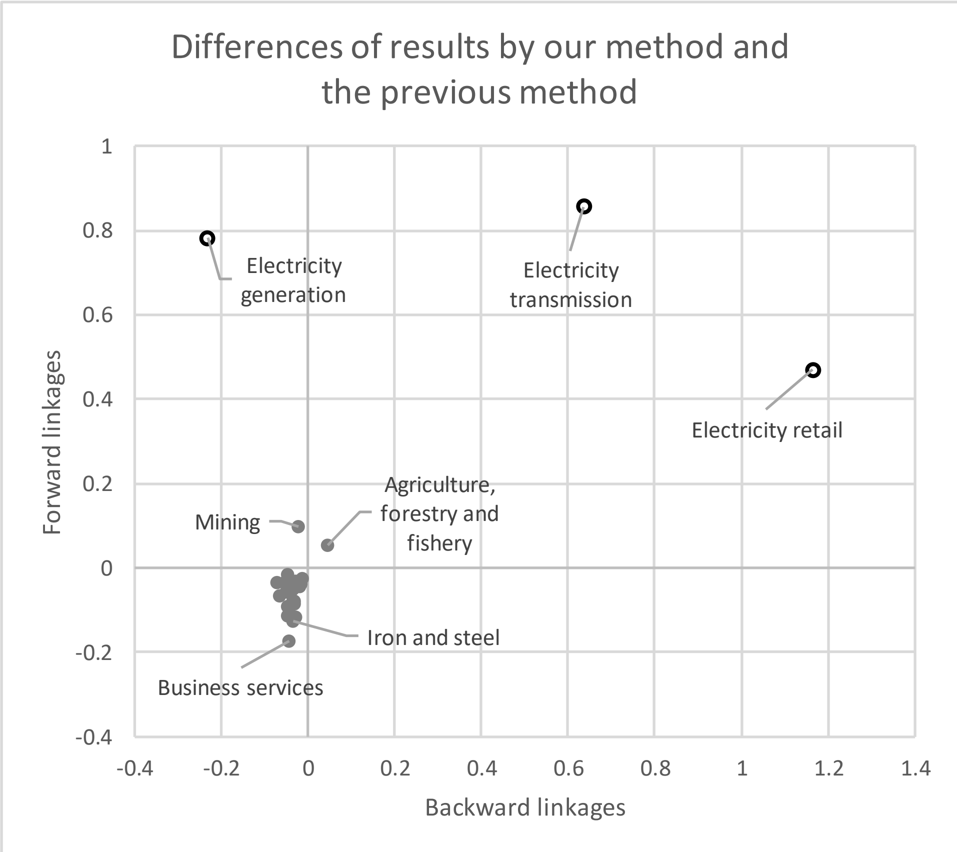


Figure 1.14: Differences of the backward and forward linkages calculated between using our method and the previous method

1.5 Discussion and Conclusion

We separated the electric power industry into the electricity generation, electricity transmission, and electricity retail sectors in the input-output table, and analyzed the inverse matrix coefficients, forward linkages, and backward linkages. Prior to separating the electric power industry in the input-output tables, we could only estimate the electric power industry as a whole; however, after separation, we could estimate the sectoral inverse matrix coefficients and backward / forward linkages.

We showed that the inverse matrix coefficients and forward / backward linkages largely differed among the sectors. These results allowed us to estimate the degree to which the competition policy of a certain sector would affect the industries other than the electric power industry. This enabled us to compare the effects of liberalization of each sector. In contrast, in the original input-output table, only the competition policies applied to the electric power industry as a whole could be evaluated. The sectoral cost-benefit analyses could be introduced in the competition policy of the electric power industry.

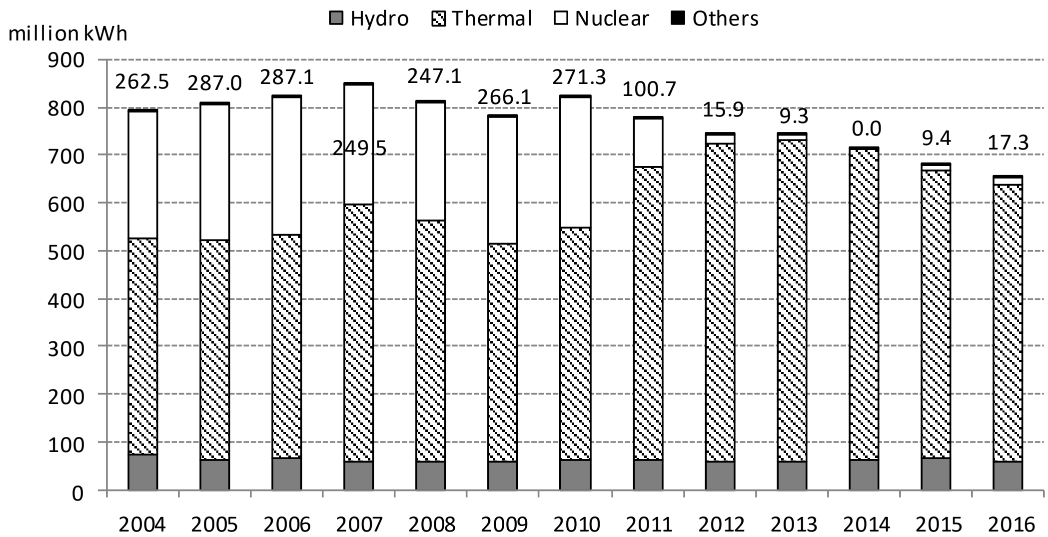
Our estimation showed that the influences of the retail and electricity generation sectors are different. Thus, policy makers can simulate the sector wise influences of the competition policy on the other industries.

The results presented in this chapter could offer suggestions for other countries where the technical structures of the electricity industry are similar to those in Japan.

Chapter 2. Estimating price elasticity of demand for electricity: the case of Japanese manufacturing industry

2.1. Introduction

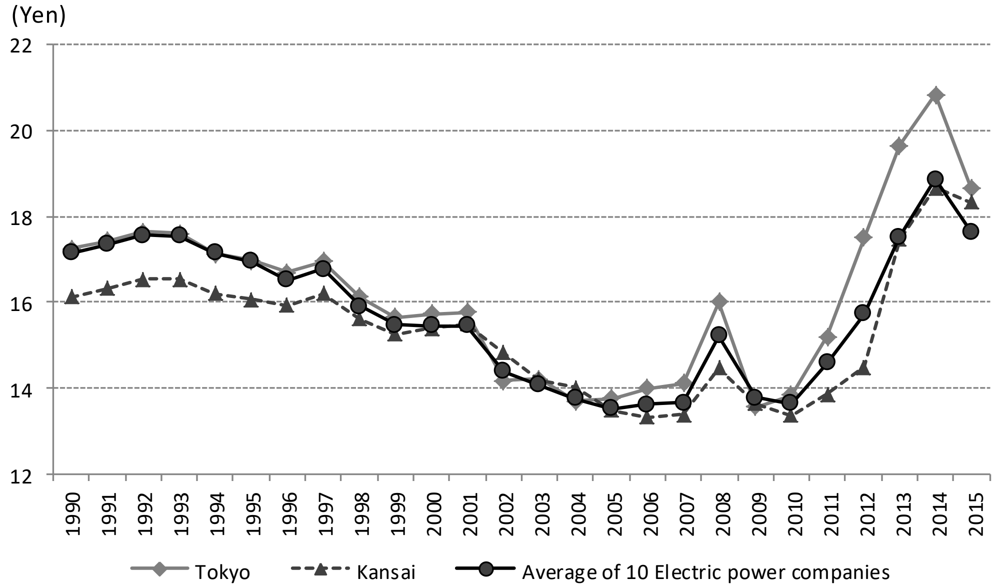
During the Great East Japan Earthquake of 2011, nuclear power plants at the Fukushima Daiichi Power Station suffered severe damages from the tsunami caused by the earthquake. This incident increased distrust of nuclear power generation among the Japanese population, which resulted in policy makers deciding to halt operations at all nuclear power plants in Japan. Figure 2.1 illustrates the electricity generation of Japanese incumbent electric companies. Note that electricity generated by nuclear power plants decreased to zero in 2014.



(Source) Agency for Natural Resources and Energy (2016)

Figure 2.1: Electricity Generation in Japan

Figure 2.1 also indicates that electric power companies had to use thermal power plants to generate electric power that was previously generated by nuclear power plants. This increased the electricity price because thermal power plants use expensive fossil fuels such as coal, petroleum and liquefied natural gas (LNG). Figure 2.2 shows that the electricity price was tending downwards until 2010, but began rising thereafter.



(Source) Federation of Electric Power Companies of Japan (2017)

Figure 2.2: Electricity Price of Electric Power Companies (Yen, Fiscal Year)

The increase in electricity price imposed a heavy burden on manufacturing companies that consume a large amount of electricity. The Ministry of Economy, Trade and Industry (2011) estimated that the cost of electricity generation would increase by 3 trillion yen if all nuclear power plants ceased operations, and all the substituted electricity was generated by thermal generation power plants. In such a case, the decline in profits was estimated to be over 50% in the plastics industry, and over 30% in the non-ferrous metal, fibers and transport equipment industries.

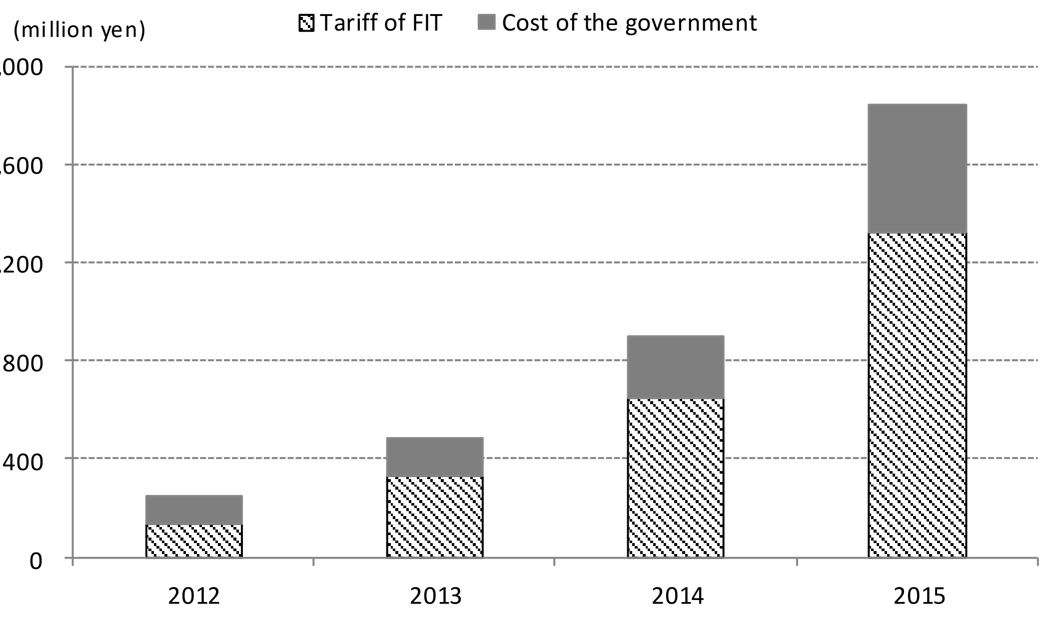
The Ministry of Economy, Trade and Industry (2011) also reported the influence of an increase in electricity price using the following examples. An electric furnace company expressed concerns that its competitiveness decreased because of the increase of imported steel from Korea, where the electricity price is lower. A chemical manufacturer reported that their manufacturing cost increased by one billion yen for each yen/kWh increase in electricity price.

This manufacturer reported that they had to shift investment to factories abroad.

Hosoe (2014) showed that some domestic manufacturing companies were facing disadvantages and accelerated off-shoring to avoid the soaring electricity price. The paper simulated the effects of the power crisis on Japanese industrial sectors using a CGE (Computable General Equilibrium) model. The simulation indicated that the power crisis would decrease the domestic output of the wood, paper and printing, pottery, steel and nonferrous metal, and food sectors, and would accelerate foreign direct investments in these sectors.

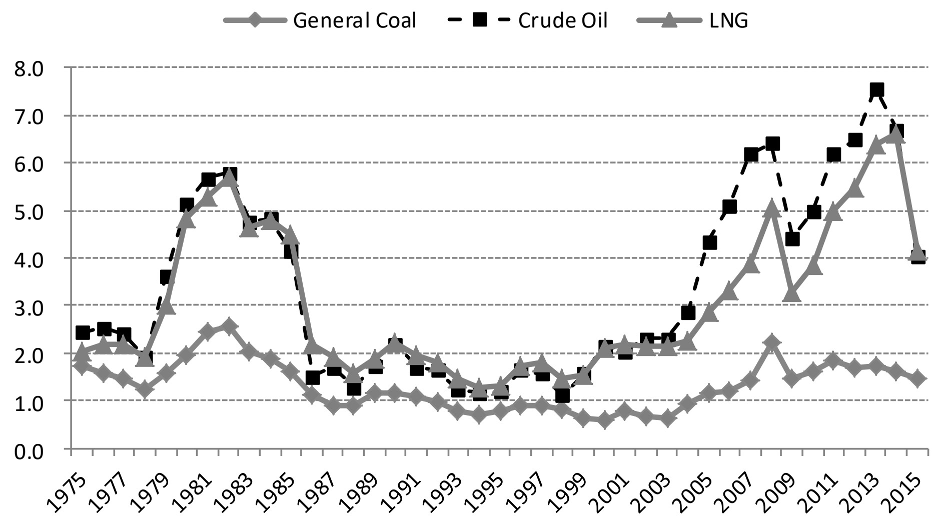
A power crisis like the one in 2011 rarely happens. However, electricity prices can rise due to other factors such as an increase in the costs and tariffs of Feed-in-tariffs (FIT :Figure 2.3), and fluctuations in fuel prices (Figure 2.4).

We estimate the sectoral elasticities of manufacturing industries. We believe this kind of analysis is essential in discussing the effects of industrial policies because policy makers should understand which sectors are affected the most by an increase in electricity prices when they formulate industrial policies including tariffs, grants, and other industry-specific policies.



(Source) Agency for Natural Resources and Energy (2017)

Figure 2.3: Costs and Tariffs of FIT



(Source) Institute of Energy Economics, Japan (2017)

Figure 2.4: Prices of Fuels (yen/calorie)

2.2. Literature review

Many past studies have estimated residential and industrial elasticities of electricity demand. Our paper studies Japanese industrial elasticities using several models. Therefore, we categorize past studies in the following terms: (i) studies of Japanese electricity demand, (ii) studies about industrial sectors, and (iii) studies about estimation models.

Author	Country or Region	Model	period	Category	Short run elasticity
Hosoe and Akiyama (2009)	Japan(regional)	PA	1976-2006	Industrial	-0.105 to -0.300
				Commercial	
Otsuka (2015)	Japan(regional)	PA	1990-2010	Industrial	-0.034
				Commercial	
Wang.N and Mogi.G(2017)	Japan	KF	1989-2014	Residential	-0.511
				Industrial	-0.16
Tamechika (2014)	Japan(prefectural)	PA	1996-2009	Residential	-0.26 to -0.35
Okajima and Okajima (2013)	Japan(regional)	PA	1990-2007	Residential	-0.397
Tanishita (2009)	Japan(regional)	PA	1986-2006	Residential	-0.60 to -0.92
Nakajima (2010)	Japan	ADL	1975-2005	Residential	-1.13 to -1.2
Chang.et.al(2014)	Korea	TVC	1995.01-2012.12	Residential	-0.07
			1985.01-2012.12	Industrial	0.12
				Commercial	-0.22
Arisoy and Ozturk (2014)	Turkey	KF	1960-2008	Residential	-0.014
				Industrial	-0.023
Dilaver and Hunt (2011a)	Turkey	ADL	1960-2008	Industrial	-0.161
Blignaut,et.al (2015)	South Africa	PA	2002-2011	Agriculture	-0.235
				Coal Mining	-0.291
				Commercial	-0.19
				Gold Mining	-0.417
				Iron and Steel	-0.279
				Liquid Fuels	-0.418
				Non-ferrous Metals	-0.342
				Rest of Chemicals	-0.24
				Rest of Manufacturing	-0.251
				Rest of Mining	-0.465
				Transport	-0.346
Inglesi-Lotz.R and Blignaut.J.N(2011)	South Africa	panel data	1993-2006	Industrial	-0.869
				Agriculture	0.152
				Transport	-1.22
				Commercial	0.677
				Mining	0.204
Zachariadis.T and Pashourtidou.N(2007)	Cyprus	VEC	1960-2004	Residential	-0.103
				Commercial	-0.009
Inglesi-Lotz (2011)	South Africa	KF	1986-2005	Aggregate	-0.075
Amusa.et.al(2009)	South Africa	ADL	1960-2007	Aggregate	0.0387
Kamerschen and Porter (2004)	The United State	PA	1973-1998	Residential	0.13
Alberini and Filippini (2011)	The United State	PA	1995-2007	Residential	-0.08 to -0.15
Narayan and Smyth (2005)	Australia	ADL	1959-1972	Residential	-0.26
Halicioglu (2007)	Turkey	ADL	1968-2005	Residential	-0.33
Ziramba (2008)	South Africa	ADL	1978-2005	Residential	-0.02
Dilaver and Hunt(2011b)	Turkey	ADL	1960-2008	Residential	-0.092
Holtedahl.P and Joutz.F.L(2004)	Taiwan	VEC	1955-1995	Residential	-0.154172
Hondroyiannis.G(2004)	Greece	VEC	1986-1999	Residential	-0.41
Narayan.P.K, et.al (2007)	G7	PC	1978-2003	Residential	-0.0001

PA : Partial Adjustment
KF : Kalman filter
ADL : Autoregressive distributed lag
VEC : vector error-correction model
TVC : Time-Varying Cointegrating vector
PC : Panel cointegration

Table 2.1: Literature Review

Studies of Japanese electricity demand

Several studies have estimated the Japanese electricity demand function in residential, industrial, and commercial sectors. Most studies have focused on the residential sector (e.g., Tamechika, 2014; Okajima and Okajima, 2013; Tanishita, 2009; Nakajima, 2010; Otsuka, 2015), and reported that the elasticity of the residential sector ranges from -0.26 to -1.204.

Wang and Mogi (2017) estimated the elasticity of electricity demand in the residential and industrial sectors, and reported that the industrial sector is much more inelastic than the residential sector (industrial: -0.16, residential: -0.51)[1]. Otsuka (2015) estimated elasticity for the industrial sector and found it to be rather inelastic (-0.034). Hosoe and Akiyama (2009) reported that industrial elasticity ranges from -0.105 to -0.300. Studies that showed that the elasticity of the industrial sector is less elastic (-0.034 to -0.300) employed partial adjustment and Kalman filter models.

Studies of industrial sectors

Most studies using data from foreign countries analyzed the residential sector (e.g., Kamerschen and Porter, 2004; Alberini and Filippini, 2011; Narayan and Smyth, 2005; Halicioglu, 2007; Dilaver and Hunt, 2011b; Holtedahl and Joutz, 2004; Hondroyiannis, 2004; Narayan et al., 2007; Ziramba, 2008). Elasticities estimated in these papers ranged from -0.08 to -0.41, which are higher than those for Japan.

Some studies examined the aggregate industrial sector (Chang et al., 2014; Arisoya and Ozturk, 2014; Dilaver and Hunt, 2011a). Zachariadis and Pashourtidou (2007) estimated the price elasticity of electricity demand for the commercial sector. Inglesi-Lotz and Blignaut (2011) estimated the sectoral price elasticity of electricity demand in South Africa from 1993 to 2006. Blignaut et al. (2015) estimated the price elasticity of electricity demand for various industrial sectors in South Africa from 2002 to 2011. They focused on showing that a majority

1 Some studies state that whether the industrial sector is more inelastic than the household sector is ambiguous. Sonoda,K., et.al(1999) estimated that the elasticity of the household sector is -0.219～-1.368, the commercial sector is -0.268～-0.943. Kaino,K.(2002) estimated long-run elasticities, and found the household sector is -0.121, and the industrial sector is -0.033～-0.157.

of industrial sectors became much more sensitive to electricity price change after the sharp rise of electricity tariffs in 2007/2008. In their study, the estimated sectors are agriculture, mining, iron and steel, liquid fuels, non-ferrous metals, chemicals (other), manufacturing (other), transport, and commercial. The price elasticity was estimated using SUR (seemingly unrelated regression). However, most of their estimation results were statistically insignificant.

There are only a few studies that have estimated the elasticity of electricity demand at a detailed sectoral level. To the best of our knowledge, we do not know of any peer-reviewed paper that has estimated the elasticity of electricity demand in Japan at a detailed sectoral level.

Studies of estimation models

Panel data and time series analyses have been used to estimate the price elasticity of electricity demand. The main model used in the panel data analysis to estimate the elasticity of electricity demand is a partial adjustment model. This can estimate stable parameters even for data with only a short time-length. A time series analysis contains two main models, an autoregressive distributed lag (e.x. Amusa et al., 2009) and a Kalman filter (e.x. Inglesi-Lotz, 2011). Some papers have adopted the autoregressive distributed lag model, but this model requires a long-time series of more than 20 years, as Okajima and Okajima (2013) have pointed out. A Kalman filter model is a kind of state-space model that can estimate a non-stationary model, while an autoregressive distributed lag model can estimate only a stationary model. As indicated in Table 4.1, we do not see any agreed model in estimating elasticities of electricity demand.

2.3. The model

The partial adjustment model

In this paper, the elasticity of electricity demand is estimated by employing partial adjustment because our data has a small T and a large N (T = 24 and N = 47). A first difference estimator was used to control for individual effects because it is well known that the correlation of individual effects and independent variables causes a dynamic panel bias.

The estimation model is formulated as below.

$$\Delta lnELE_{i,t} = \alpha + \beta_1 \Delta lnp_{i,t}^{ELE} + \beta_2 \Delta lnEMP_{i,t} + \beta_3 \Delta lnELE_{i,t-1} + \Delta\mu \tag{1}$$

where Δ denotes the first difference operator, ln represents the natural logarithm, i (i = 1, 2, …, N) stands for the prefecture, and t (t = 1, 2, …, T) means time. The dependent variable, $ELE_{i,t}$, is the electricity consumption in each industry. Independent variables are defined as follows. ${p_{i,t}}^{ELE}$ is the real electricity price (yen/kWh), $EMP_{i,t}$ is the number of employees, and $ELE_{i,t-1}$ is lagged electricity consumption. One of the independent variables is electricity consumption in the previous period, which indicates that electricity demand depends not only on electricity use in the present period but also on use in the previous period. This is because facilities that use electricity cannot be replaced in a single time period but, instead, can only be replaced gradually. The number of employees is a control variable. This represents the scale of an industry. Tanishita (2009) estimates the elasticity of the electricity price by using a partial adjustment model based on OLS (ordinary least squares) estimation. However, the paper indicates that a lagged dependent variable has the possibility of endogeneity (Hsiao, 2002). In other words, a lagged dependent variable may correlate with the error term. This dynamic panel bias would make the estimated long-run price elasticity higher than the true value.

Electricity demand is affected by other factors beyond those captured by the independent variables, as seen in the relationship between the electricity price and the error term. To avoid these biases, we employ an additional lag of a lagged dependent variable, $\Delta ELE_{i,t-2}$ and a lagged electricity price, $\Delta {p_{i,t-1}}^{ELE}$ as instrumental variables, and estimate by using the first difference generalized method of moments (FD GMM). β_1 is the short-run price elasticity of electricity demand and $\beta_1 / (1 - \beta_3)$ is the long-run price elasticity.

The Kalman filter model

Some papers adopt the autoregressive distributed lag model, which requires a long time-series. Okajima and Okajima (2013) pointed out that such a model would require data over more than 20 years. A Kalman filter model is a kind of state-space model, and can estimate a non-stationary model, while an autoregressive distributed lag model can only estimate a stationary model. The advantage of a Kalman filter is that this model does not need a large sample size. In our estimation, the only required data are electricity consumption and electricity price.

The model is expressed as:

$$Y_{i,t} = \beta_{0t} + \sum_{j=1}^{k} \beta_{jt} x_{jt} + \epsilon_t, \tag{2}$$

$$\beta_{j,t+1} = \beta_{jt} + \mu_{jt}, \tag{3}$$

where $\mu_{1t}, \dots, \mu_{kt}$ are independent of each other, and the regression coefficients, β_{jt} vary over time, and are distributed as a random walk. We can fix the regression coefficients by $\sigma^2_{\mu,0} = \sigma^2_{\mu,1} = \cdots = \sigma^2_{\mu,k}$. Coefficients β_{jt} in equation (2) are updated by equation (3). The Kalman filter model employed in this study is described below.

$$lnELE_{i,t} = \alpha + \beta lnp_t^{ELE} + Z^{(\mu)}\mu_t + \epsilon_t, \tag{4}$$

$$\beta_{t+1} = \beta_t + \upsilon_t, \tag{5}$$

$$\mu_{t+1} = \mu_t + \eta_t, \tag{6}$$

where ln represents the natural logarithm, i (i = 1, 2, …, N) stands for the prefecture, and t (t = 1, 2, …, T) means time. The dependent variable, $ELE_{i,t}$, is industrial electricity consumption, the independent variables are ${p_{i,t}}^{ELE}$, which is real electricity price (yen/kWh) and Z, which is the trend variable.

2.4. Data

To estimate the elasticity of electricity demand, we use data on electricity consumption, electricity price and other control variables. To obtain a correct estimation, the period of the data should be long enough and the sample size should be large enough.

Industrial categories are listed below.

0. Manufacturing
1. Food, beverages, tobacco, and feed
2. Textile mill products
3. Lumber and wood products
4. Pulp, paper, and paper products
5. Printing and related industries
6. Chemical and related products
7. Plastic, rubber, and leather products
8. Ceramic, stone, and clay products
9. Iron, steel, non-ferrous metals and products
10. Machinery
11. Miscellaneous manufacturing industries

Electricity consumption

Electricity consumption data is obtained from the Prefectural Energy Consuming Statistics (Agency for Natural Resources and Energy, 2016). This is not primary data; however, it is used to evaluate CO_2 emissions and the energy balance of allocated electricity use data. This is done by using the proportion of employees in each industrial sector of electricity consumption for each prefecture. As far as we know, the prefectural energy consumption statistics are the only sectoral electricity consumption data aggregated by prefectures over a long period of time. The observation periods are from 1990 to 2014 (in fiscal years) and the number of samples per year is 47 (which is the number of prefectures).

Electricity price

The electricity price (yen/kwh) is calculated from the electricity sales revenues of the 10 existing electric power companies (Hokkaido, Tohoku, Tokyo, Hokuriku, Chubu, Kansai, Chugoku, Shikoku, Kyushu, and Okinawa) divided by their gross electricity generation, where the revenue includes sales from the commercial sector. The data is obtained from the Federation of Electric Power Companies of Japan (2017). The electricity price in each prefecture is derived from the corresponding electric power companies.[2] As of 1999, new electric companies can enter the electricity market. However, we calculated the prices only for the existing companies because the prices of the new companies are not available[3].

Control variables

The Ministry of Economy, Trade and Industry (2016) surveys manufacturers using

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[2] Each electric power company covers the prefectures as listed below.
Hokkaido Electric Power Company: Hokkaido
Tohoku Electric Power Company: Aomori, Iwate, Miyagi, Akita, and Yamagata
Tokyo Electric Power Company: Tokyo, Kanagawa, Saitama, Chiba, Tochigi, Ibaragi, Yamanashi, and Shizuoka
Hokuriku Electric Power Company: Toyama, Ishikawa, Fukui, and Gifu
Chubu Electric Power Company: Aichi, Nagano, Gifu, Mie, and Shizuoka
Kansai Electric Power Company: Shiga, Kyoto, Osaka, Hyogo, Nara, and Wakayama
Chugoku Electric Power Company: Hiroshima, Yamaguchi, Shimane, Tottori, and Okayama
Shikoku Electric Power Company: Kagawa, Tokushima, Ehime, and Kochi
Kyushu Electric Power Company: Fukuoka, Nagasaki, Oita, Saga, Miyazaki, Kumamoto, and Kagoshima
Okinawa Electric Power Company: Okinawa
*Shizuoka prefecture is covered by both Tokyo and Chubu Electric Power Companies. Therefore, the electricity price of Shizuoka is obtained by taking the average of the prices from Tokyo and Chubu.

[3] We should note that company–facing electricity prices are different from the accounting data, because the electricity price which each company faces depends on each company's electricity consumption volume, load facility, and load factor.

questionnaires. This survey contains data on electricity consumption, numbers of employees, salary payments, material uses, outputs, added value and other information. The period covered by these surveys is from 1990 to 2014 (in fiscal years) and the sample size is 47 per year.

In estimating the price elasticity of electricity, we chose the number of employees as an independent variable. Although outputs and added values can be independent variables, those variables have endogeneity with electricity use. Therefore we employed the number of employees as a control variable.

2.5. Empirical Results

Cross-sectional dependency test and panel unit root test

There are two panel unit root tests: first generation and second generation. The first-generation panel unit root test requires cross-sectional independency. To test the cross-sectional dependency in the panel data, Pesaran's cross-sectional dependency test is employed (Pesaran, 2015). The results of the tests are presented in Table 2.2. The estimation model is as below, where the instrumental variables are $\Delta lnELE_{i,t-2}$ and $\Delta lnp_{i,t-1}^{ELE}$.

$$\Delta lnELE_{i,t} = \alpha + \beta_1 \Delta lnp_{i,t}^{ELE} + \beta_2 \Delta lnEMP_{i,t} + \beta_3 \Delta lnELE_{i,t-1} + \Delta\mu \quad (7)$$

The results reject the null hypothesis that there is no cross-sectional dependence in the data, and as such, the second-generation unit root test is needed.

	z statictic	p.value
Manufacturing	70.4203	0.0000
Food, beverages, tobacco and feed	64.8231	0.0000
Textile mill products	63.2691	0.0000
Lumber and wood products	62.1269	0.0000
Pulp, paper and paper products	17.0303	0.0000
Printing and allied industries	64.4233	0.0000
Chemical and allied products	40.4038	0.0000
Plastic, rubber and leather products	55.0399	0.0000
Ceramic, stone and clay products	39.7333	0.0000
Iron, steel, non-ferrous metals and products	35.1928	0.0000
Machineries	51.1143	0.0000
Miscellaneous manufacturing industries	50.1331	0.0000

Table 2.2: Pesaran's Test of Cross-sectional Dependence in Panels

We employed an augmented Im, Pesaran, and Shin (IPS) test (Im, Pesaran, and Shin, 2003, Pesaran, 2007) to test the panel unit root. As indicated in Table 2.3 below, for the electricity price and electricity consumption, the test shows that there is no unit root.

	employee	electricity	electricity price
Manufacturing	-2.1035	-2.0592	-1.6313
Food, beverages, tobacco and feed	-1.8941	-1.8091	-1.6313
Textile mill products	-2.2724	-1.8782	-1.6313
Lumber and wood products	-2.3546	-1.9089	-1.6313
Pulp, paper and paper products	-1.9976	-2.2359	-1.6313
Printing and allied industries	-2.4459	-1.7549	-1.6313
Chemical and allied products	-2.3112	-2.2626	-1.6313
Plastic, rubber and leather products	-1.7704	-1.8105	-1.6313
Ceramic, stone and clay products	-2.3369	-2.2169	-1.6313
Iron, steel, non-ferrous metals and products	-2.6437**	-1.9938	-1.6313
Machineries	-1.7818	-1.8716	-1.6313
Miscellaneous manufacturing industries	-3.3085***	-1.9496	-1.6313

** indicates rejection of the null of a unit root at 5% level
*** indicates rejection of the null of a unit root at 1% level

Table 2.3: Cross-sectionally Augmented Im, Pesaran, and Shin (IPS) Test

Partial adjustment estimation

Table 2.4 below illustrates the estimation results of the partial adjustment model. The price elasticity of electricity demand in aggregate manufacturing is -0.400.

	$\Delta\ln(employee)$	$\Delta\ln(p_{ele})$	$\Delta\ln(elet_{-1})$
Manufacturing	-0.07732 *0.165*	-0.39667*** *0.000*	0.59478*** *0.000*
Food, beverages, tobacco and feed	0.03792 *0.827*	-0.46817*** *0.000*	0.74899*** *0.000*
Textile mill products	0.04368 *0.278*	-0.77529*** *0.000*	0.50475*** *0.000*
Lumber and wood products	-0.02587 *0.444*	-0.40256*** *0.000*	0.68423*** *0.000*
Pulp, paper and paper products	0.4518*** *0.002*	-0.56992*** *0.000*	0.53058*** *0.000*
Printing and allied industries	0.22984*** *0.001*	-0.52982*** *0.000*	0.70556*** *0.000*
Chemical and allied products	-0.76611** *0.010*	-0.14663* *0.059*	0.72031*** *0.000*
Plastic, rubber and leather products	0.63497** *0.012*	-0.70124*** *0.000*	0.64126*** *0.000*
Ceramic, stone and clay products	0.36655*** *0.007*	-0.70058*** *0.001*	0.41742*** *0.000*
Iron, steel, non-ferrous metals and products	-0.09363 *0.606*	-0.25065** *0.011*	0.40993*** *0.000*
Machineries	-0.02195 *0.693*	-0.4846*** *0.000*	0.6859*** *0.000*
Miscellaneous manufacturing industries	0.08995** *0.022*	-0.41272*** *0.000*	0.86954*** *0.000*

The individual coefficient is statistically significant at 1% level(***), 5% level(**), 10% level(*).

Table 2.4: Estimation Results of the Partial Adjustment Model

The more elastic sectors than aggregate manufacturing are textile mill products (-0.775) followed by plastics, rubber and leather products (-0.701), ceramic, stone and clay products (-0.701), pulp, paper and paper products (-0.570), printing and allied industries (-0.530), machinery (-0.485), food, beverages, tobacco and feed (-0.468), miscellaneous manufacturing industries (-0.413), and lumber and wood products (-0.403). On the other hand, the less elastic sector is iron, steel, non-ferrous metals and products (-0.251). The chemical and allied products (-0.147) sector is not statistically significant at 5% level.

Table 2.5 presents the short-run and long-run price elasticities of electricity demand.

	Short-run elasticity	Long-run elasticity
Manufacturing	-0.397	-0.979
Food, beverages, tobacco and feed	-0.468	-1.865
Textile mill products	-0.775	-1.565
Lumber and wood products	-0.403	-1.275
Pulp, paper and paper products	-0.570	-1.214
Printing and allied industries	-0.530	-1.799
Chemical and allied products	-0.147	-0.524
Plastic, rubber and leather products	-0.701	-1.955
Ceramic, stone and clay products	-0.701	-1.203
Iron, steel, non-ferrous metals and products	-0.251	-0.425
Machineries	-0.485	-1.543
Miscellaneous manufacturing industries	-0.413	-3.164

Table 2.5: Short-run and Long-run Price Elasticities of Electricity Demand

Kalman filter estimation

Table 2.6 presents estimation results of the Kalman filter estimation. We do not find any major differences between the “fluctuate estimation” and “constant estimation.” We refer to the coefficients from the “fluctuate estimation” below. The price elasticity of electricity demand in manufacturing is -0.28.

The more elastic sectors than aggregate manufacturing are miscellaneous manufacturing industries (-0.734) followed by plastic, rubber and leather products (-0.645), food, beverages, tobacco and feed (-0.531), lumber and wood products (-0.367), chemical and allied products (-0.358), machinery (-0.297), pulp, paper and paper products (-0.280). On the other hand, the less elastic sectors are ceramic, stone and clay products (0.049), iron, steel, non-ferrous metals and products (-0.075), printing and allied industries (-0.078), textile mill products (-0.095).

		Fluctuate Estimation		Constant Estimation	
		Estimate	Std.Error	Estimate	Std.Error
I1200	Manufacturing	-0.2778*	0.1921	-0.2778*	0.1921
I1201	Food, beverages, tobacco and feed	-0.5305*	0.2781	-0.5547*	0.3096
I1202	Textile mill products	-0.0954	0.3155	-0.0946	0.3156
I1203	Lumber and wood products	-0.3673*	0.3567	-0.3674*	0.3568
I1204	Pulp, paper and paper products	-0.2804*	0.2045	-0.2804*	0.2045
I1205	Printing and allied industries	-0.07816	0.4112	-0.0782	0.4112
I1206	Chemical and allied products	-0.3577**	0.1593	-0.3577*	0.1593
I1207	Plastic, rubber and leather products	-0.6449*	0.3236	-0.6448*	0.3237
I1208	Ceramic, stone and clay products	0.04937	0.2447	0.0493	0.2447
I1209	Iron, steel, non-ferrous metals and products	-0.07477	0.0773	-0.0749	0.0773
I1210	Machineries	-0.2971*	0.2441	-0.2971*	0.2441
I1211	Miscellaneous manufacturing industries	-0.7343**	0.3577	-0.8458**	0.3950

The individual coefficient is statistically significant at 5% level(**), 10% level(*).

Table 2.6: Estimation Results of the Kalman Filter Model

In the Kalman filter model, however, coefficients of sectors other than miscellaneous manufacturing industries and chemical and allied products are statistically insignificant at 5% level.

In the next section, we refer to the results of the partial adjustment model.

2.6. Conclusions

In this paper we estimated the price elasticity of electricity demand for each manufacturing industry (major groups) using the partial adjustment and the Kalman filter models.

In general, less price-elastic industries need electricity more. In other words, electricity is a necessary good for inelastic industries. The low elasticity implies that these industries cannot reduce electricity consumption even when electricity prices increase. This implies that a high electricity price is a heavy burden on these companies. Figure 2.5 illustrates the relationship between electricity consumption per unit of output and price elasticity.

As stated before, we are not aware of any studies that have calculated Japanese sectoral price-elasticities of electricity demand in peer-reviewed papers, and thus it is difficult to directly compare our results with other econometric studies. We refer to three studies to compare results.

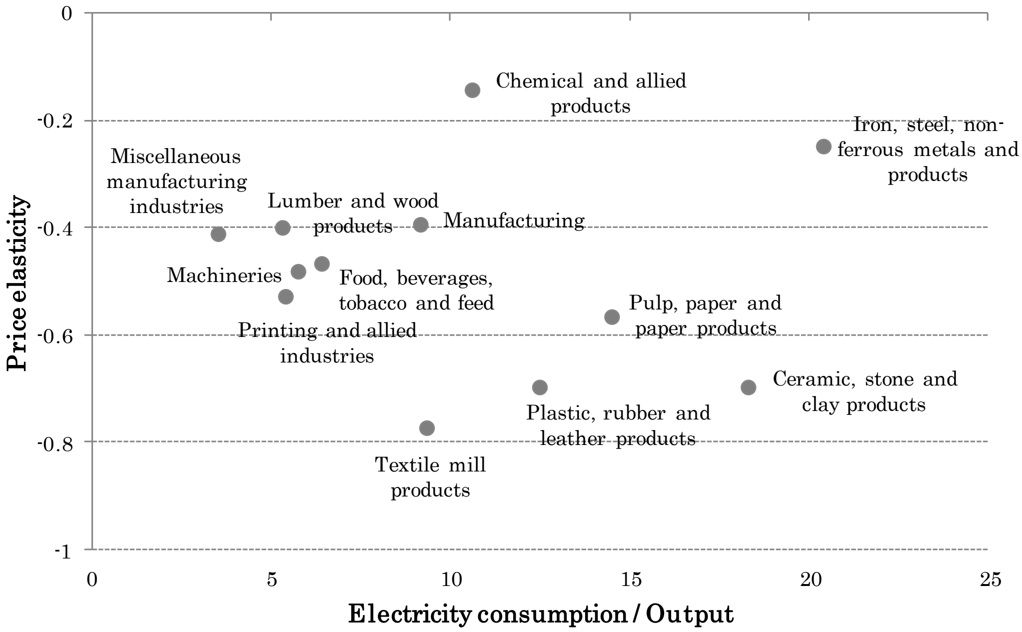

Figure 2.5: Electricity Consumption per Output and Price Elasticity (Partial Adjustment)

In Blignaut et al. (2015), the estimated sectors in the manufacturing industry are iron and steel (-0.79), non-ferrous metals (-0.34), chemicals (other) (-0.24), and manufacturing (other) (-0.251). These results are consistent with ours in that the iron, steel, non-ferrous metals and products sector is more elastic than the chemical and allied products sector.

In the Ministry of Economy, Trade and Industry (2011), sectors that have decreased profits due to increased electricity prices are identified, and their likely profit decrease estimated. However, because the sectoral definition differs from ours, the consistency with our results is ambiguous.

Hosoe (2014) simulates the effects of the power crisis on Japanese industrial sectors using a CGE model. The simulation indicated that the power crisis would decrease domestic outputs of the wood, paper and printing, pottery, steel and nonferrous metal and food industries in Japan, and would accelerate foreign direct investment in these sectors. In our estimation of the partial adjustment model, the price-elasticity in the iron, steel, non-ferrous metals and products is low. Because it means it's impossible for this sector to adjust electricity consumption when electricity price increases, this sector has to decrease their output or increase foreign direct investment. Then their result is consistent with our result in iron, steel, non-ferrous metals and products sector.

There are three studies that estimate Japanese price-elasticities of electricity demand including industrial sectors. Hosoe and Akiyama (2009) and Otsuka (2015) estimate the industrial and commercial elasticity, the results are -0.105 to -0.300 and -0.034 each. Wang and Mogi (2017) estimate the industrial elasticity: the result is -0.16. We find that the manufacturing sector is more elastic than total industry, and also find that many sectors within manufacturing are more elastic.

Our results showed that price-elasticities vary greatly between different sectors. Policy makers need to understand which sectors are most affected by an increase in electricity prices in order to formulate industrial policies including tariffs, grants, and other industry-specific policies, because an increase in electricity price has the real possibility of accelerating de-industrialization and/or raising the unemployment rate.

Finally, we discuss possible extensions of this study. First, we can straightforwardly extend this study to all industrial categories beyond manufacturing (e.g., construction, services). We are certain that such an exercise will yield many useful findings. This paper focuses on manufacturing industry, because we assumed that this industry is sensitive to electricity prices, and because of the often controversial relationship between electricity prices and global competitiveness.

Second, we can simulate the influence of an increase in electricity prices on each industry's global competitiveness. We are currently constructing a CGE model to account for this effect. Finally, the cross-elasticity of demand can be examined. In the short-run, an increase in electricity price may increase the use of alternative energy resources, and in the long-run, it may lead to acquiring energy-saving machines, and also investing in private power generation. Since companies which own private power generations can switch to private power generation when the electricity price increases, industrial categories in which many companies introduce private power generation reduce electricity consumption more than actual electricity use. We recognize that we need to examine the cross-elasticity of electricity and alternative energy resources.

In the future, we are planning to study a simulation model which uses the elasticities estimated in this paper to draw more definite conclusions, while we also recognize that it is effective to research the reasons why elasticities are different among industrial sectors.

Chapter 3. Simulating the effects of the liberalization of the electricity retail sector

3.1. Introduction

Electric power companies in Japan were allowed to monopolize an electric power market in each region since 1951, therefore, new entrants and inter-regional competition did not exist. Electricity system reforms in Japan have progressed stepwisely since 1990s. In the electricity generation sector, the independent power producers (IPPs) were allowed to enter the electric power market in 1995. In the electricity retail sector, the third party can make a contract with consumers in the case of over 2,000kw in 2000. Finally, the electricity retail sector was perfectly open to new entrants and incumbents in other regions in 2016.

After the full liberalization in 2016, the regulatory authority discussed the detailed design of the system, in order to maximize the effects of competition with considering a stable supply of electric power.

A lot of previous studies measured the effects of system reform by the degree of competition or the electricity price levels.

However, we think the effects of introducing competition may appear not only in electricity prices, but also in production and prices of other industries. Following studies analyzed the liberalization of the electric power industries in a general equilibrium framework.

Kunneke and Voogt (1997) analyzed the Dutch electric power industry, and Hosoe (2006) analyzed the regulatory reform of the Japanese electric power industry. Their contributions were stated in chapter1.

Hwang and Lee(2015) analyzed the electric power industry in Korea. They modeled the entire economy with the top down model, and estimated imperfect competition parameters with the bottom up model. They showed that a model that integrates bottom up and top down converges, and simulated the economy after the liberalization of Korea's electric power industry.

However, we should note that studies stated as above used neither exact input-output tables nor the concisely estimated parameters that are essential for analyses.

This chapter makes three contributions, 1) we estimate the effects of the liberalization precisely by using realistic input output table and statistically reliable parameters, 2) we model the behavior of the incumbents by supposing that they charge different prices depending on price elasticity of each customer, 3) we simulate a case that the liberalization is achieved in the electricity retail sector.

3.2. Methodology

A basic CGE model

We employed a CGE model like Hosoe, et.al(2016). Since they suppose that all industries are competitive, we modify the model that only one sector of the electric power industry is monopolistic.

Imperfect competition of the electric industry

Although the electricity retail markets of high voltage and ultra-high voltage have been liberalized before 2015, the share of the new entrants in the electricity retail market was only 7.57% in 2015FY (based on generated electric power). The new entrants were too few to influence the electricity price in the high and ultra-high markets, and they were not allowed to enter a low voltage market. It is rational to suppose that the incumbents behave as monopoly.

In 2015, 66.6% of electricity demand is occurred in the high voltage and ultra-high voltage market that is not under the rate of return regulation, so the incumbents are able to determine the prices as they prefer when they supply electric power to those markets. However, the incumbents are not allowed to determine the prices as they prefer when they supply electric power to the low voltage markets that constitute 33.4% of all electricity demand. They face the rate of return regulation in the low voltage market.

Rents of the electric power industry

As written in standard textbooks of microeconomics, prices are not equal to marginal costs in monopolistic markets (for example, see Varian,H.R.(1992)). The monopoly rents are defined as markups on the marginal cost.

The monopolistic rents can be expressed by using price elasticities of demand. For example, if the electricity generation sector is monopolistic, the price of electricity generation sector is p_{gen} , while the price elasticity of demand is η_{gen} and the marginal cost of electricity generation sector is MC_{gen}, the price of the electricity generation sector is denoted as

$$p_{gen} = \left(\frac{\eta}{1+\eta}\right) MC_{gen}$$

Moreover, the monopolistic rent of the electricity generation sector, RT_{gen}, is described as

$$RT_{gen} = \eta/(1+\eta)\, p^{q}_{gen} Q_{gen}$$

Although the electric power companies in Japan were able to determine the price as above in the high and ultra-high voltage markets, they faced the rate of return regulation in the low voltage markets. Under the rate of return regulation, the electric power companies had little incentives to lower the costs, because the costs that used in their activities would be compensated by the increase of the revised electricity price.

As Laffont and Tirole (1996) pointed out that asymmetric information gives regulated companies the information rents. Their argument is based on the assumption that electric power companies can invest to decrease their rents. We suppose that all of the costs to supply electric power are visible for regulatory authority.

We define the monopoly rent in the low voltage market as below, where ω_{gen} is the information rent.

$$RT_{gen} = \omega p^{q}_{gen} Q_{gen}$$

In the CGE model, we suppose that the price of the electricity demand as intermediate input is determined at the level of monopoly pricing, while the electricity price for households is determined at the level including the information rent.

Modelling allocation of the rents

In our CGE model, we calculated the monopoly rents from outputs of the electric power industry. Since monopoly rents that we identified don't appear in the original social accounting matrix, we should modify the social accounting matrix in order that those rents are included in some rows or column of the matrix. If not so, our CGE model doesn't close.

Outputs in original input-output tables contain the monopoly rents implicitly, because an input-output table records the transaction results, and the results include the payments to capitals and labors and others.

We suppose that the monopoly rents are loaded on the capital of the electric power industry, and also suppose that the rents are allocated to stock shares of the electric power companies that households own. Finally, the monopoly rents are supposed to be resulted in incomes of all households as stock holders.

$$L_i = L_i^{origin} - \frac{L_i}{\sum_i L_i} * \sum_{el} RT_{el}$$

Consumption, direct tax, and savings will increase because the rents are added to their income as below.

$$X_i^p = \frac{\alpha_i}{p_i^q}\left[\sum_h p_h^f FF_h + \sum_{ele} RT_{el} - S^p - T^d\right]$$

$$T^d = \tau^d \left[\sum_h p_h^f FF_h + \sum_{ele} RT_{el}\right]$$

$$S^p = ss^p \left[\sum_h p_h^f FF_h + \sum_{ele} RT_{el}\right]$$

It is rational to suppose that the electricity price that consumers and industries face is a domestic price p_{ele}^d and thus the monopoly rent is loaded on the domestic price. In the case of that, the export price of the electric power industry will be greatly affected when the domestic price rises by markup, because it is assumed that the goods are allocated to domestic goods and export goods according to the assumption of Armington in the model. However, in the real economy, electric powers are neither imported nor exported. Therefore, we obtain a realistic result by modeling so that the markup is placed on p_{ele}^q, which is the price before allocation. As defined before, the electricity prices as intermediate inputs have monopoly rents $1/(1+\eta_i)$, while the electricity prices to consumers, governments and investment have information rents ψ.

As assumed before, the stock shares of the electric power companies are held by the whole households in the economy, and the monopoly rents are finally resulted in the incomes of the households.

$$X_{el}^{p} = \frac{\alpha_{el}}{(1+\omega_i)p_{el}^{q}}\left[\sum_{h} p_h^f FF_h + \sum_{ele} RT_{el} - S^p - T^d\right]$$

$$X_{el}^{g} = \frac{\alpha_{el}}{(1+\omega_i)p_{el}^{q}}\left[T^d + \sum_{j} T_j^z + \sum_{j} T_j^m - S^g\right]$$

$$X_{el}^{v} = \frac{\lambda_{el}}{(1+\omega_i)p_{el}^{q}}\left[S^p + S^g + \epsilon S^f\right]$$

$$p_j^z = ay_j p_j^y + \sum_{el} ay_{el,j}\frac{\eta_j}{1+\eta_j}p_{el}^q + \sum_{i} ay_{i,j}p_i^q$$

Previous studies including Hwang and Lee (2015) assumed that the prices of electricity supplied by the monopoly are identical across all industries.

However, the electric power companies can charge different price of electricity by customer in the high voltage and the ultra-high voltage markets, therefore, the monopoly rents must be different among the purchasing industry.

Simulating vanishment of the electricity retail sector and the electricity generation sector

It is assumed that the monopoly rents obtained by the electricity retail sector will be vanished by the liberalization of the electricity retail sector in the electric power industry.

We analyze the impact when the monopolistic electricity retail sector becomes completely competitive, simulating that the competition is introduced and monopoly rents go vanished ($\omega \rightarrow 0$ and $\eta_i \rightarrow 0$).

3.3 Data

Reaggregation of an input output table

Since all data of the electric power industry in the original Japanese input-output table is aggregated in electricity generation sectors (thermal and hydro/other generations), it is necessary to reaggregate those electricity generation sector into three sectors (the electricity generation sector, the electricity transmission sector and the electricity retail sector) for analyzing the effect of the liberalization by sector.

There are not so many studies that reaggregate the input-output table based on actual cost data of the electric power industry.

Although Hienuki, S. and Hondo, H. (2013) reaggregated the data of the electric power industry by using the electric utility operations cost schedule, they did not reaggregate those three sectors.

Hosoe(2006), Akkemik and Oguz(2011) and Hwang and Lee(2015) separated the electric power industry as the electricity generation sector, the electricity transmission sector, and the electricity retail sector. Intermediate goods which were input to electric power industry are input only to the electricity generation sector.

In the above method, in the electricity transmission and distribution sector and electricity retail sector, there will be no sector-specific inputs other than capital and labor. This is not appropriate for our purposes.

Therefore, we estimate the input amount of the Input-Output Table according to the expenditure ratio of the annual report of electric power companies in chapter1.

In order to calculate the electricity transmission and electricity retail sectors, we use the " Electric utility operating expense schedule "published in the incumbent electric power companies' annual reports. These annual reports are prepared on a yearly basis, and the input-output table is calendar year based. Therefore, each item of the electricity business operating cost schedule table is created by summing up 3/12 of 2014 and 9/12 of 2015.

Estimation of parameters

Among the parameters that are used to estimate CGE models, price elasticity of electricity demand is essential for calculating monopoly rents. The price elasticity of electricity demand for each industry, η_i, was estimated in chapter2.

We employed the partial adjustment model and the Kalman filter model, using the data from the Prefectural Energy Consuming Statistics. The price elasticities are shown in Table 3.1.

Gasmi, Laffont, and Sharkey(1997) estimated an information rent of a monopolistic company. They estimated the expected ratio of rents to total cost, ω, is 16.64%.

	Short-run elasticity	Long-run elasticity
Manufacturing	-0.397	-0.979
Food, beverages, tobacco and feed	-0.468	-1.865
Textile mill products	-0.775	-1.565
Lumber and wood products	-0.403	-1.275
Pulp, paper and paper products	-0.570	-1.214
Printing and allied industries	-0.530	-1.799
Chemical and allied products	-0.147	-0.524
Plastic, rubber and leather products	-0.701	-1.955
Ceramic, stone and clay products	-0.701	-1.203
Iron, steel, non-ferrous metals and products	-0.251	-0.425
Machineries	-0.485	-1.543
Miscellaneous manufacturing industries	-0.413	-3.164

Table 3.1: Price elasticity of electricity demand

3.4 Results

As supposed before, the monopoly rents are finally resulted in labors through the stocks of the electric power companies held by the households. And we note that the monopoly rents are loaded on the price of the composite goods p^q_{ele} of the electric power industry.

We analyze the impacts of the liberalization on the domestic goods, export goods, import goods, prices of those goods, and domestic demand[4].

	Monopolistic (million yen)	Competitive (million yen)	Increase of domestic goods (million yen)	Rate of increase (%)
All industries	983,536,230	984,665,450	1,129,220	0.11
Electricity retail	2,244,700	2,329,200	84,500	3.76
Electricity transmission	3,731,100	3,795,700	64,600	1.73
Medical, health care and welfare	67,234,000	67,366,000	132,000	0.20
Public administration / Education and research	82,730,000	82,871,000	141,000	0.17
Commerce	91,399,000	91,551,000	152,000	0.17
Iron and steel / Non-ferrous metals	35,598,000	35,648,000	50,000	0.14
Business services	71,104,000	71,201,000	97,000	0.14
Finance and insurance	35,182,000	35,228,000	46,000	0.13
Transport and postal services	52,645,000	52,704,000	59,000	0.11
Ceramic, stone and clay products	6,107,200	6,113,900	6,700	0.11
Personal services	51,842,000	51,898,000	56,000	0.11
Plastic and rubber products	13,483,000	13,496,000	13,000	0.10
Transportation equipment / Miscellaneous manufacturing products / Construction	118,750,000	118,860,000	110,000	0.09
Chemical products	27,409,000	27,432,000	23,000	0.08
Agriculture, forestry and fishery / Mining / Beverages and Foods	48,938,000	48,973,000	35,000	0.07
Pulp, paper and wooden products	11,649,000	11,657,000	8,000	0.07
Miscellaneous non-profit services	4,376,800	4,379,500	2,700	0.06
Information and communications	48,327,000	48,353,000	26,000	0.05
Electronic components	13,393,000	13,400,000	7,000	0.05
Water supply / Waste management service	9,371,900	9,376,700	4,800	0.05
Production machinery	16,566,000	16,573,000	7,000	0.04
Electrical machinery	15,975,000	15,980,000	5,000	0.03
Electricity, gas and heat supply	6,833,700	6,835,700	2,000	0.03
Real estate	76,743,000	76,755,000	12,000	0.02
Petroleum and coal products	13,173,000	13,175,000	2,000	0.02
Electricity generation	10,105,000	10,106,000	1,000	0.01
Business oriented machinery	6,811,200	6,811,500	300	0.00
General-purpose machinery	10,375,000	10,374,000	-1,000	-0.01
Metal products	11,400,000	11,398,000	-2,000	-0.02
Printing, plate making and book binding	4,788,500	4,786,700	-1,800	-0.04
Textile products	3,423,300	3,421,600	-1,700	-0.05
Office supplies / Activities not elsewhere classified	6,101,100	6,098,000	-3,100	-0.05
Information and communication electronics equipment	5,386,900	5,383,300	-3,600	-0.07
Leather products	339,830	334,650	-5,180	-1.52

Table 3.2: Domestic goods of each industry

[4] We define "Domestic demand" as the sum of intermediate inputs and final consumption.

Table 3.2 shows impacts of the liberalization of the electricity retail sector on domestic goods of each industry. Although domestic goods of many industries increase due to the vanishments of rents, the rates of increase in those are not significant. In many industries, the rates of increase are less than 1%.

	Competitive (million yen)	Monopolistic (million yen)	Difference of Competitive and Monopolistic (million yen)	Rate of increase (%)
Domestic goods	984,665,450.0	983,536,230.0	1,129,220.0	0.115
Export goods	86,769,460.0	86,806,547.1	-37,087.1	-0.043
Import goods	93,036,033.1	93,073,497.7	-37,464.6	-0.040
Price of domestic goods (indexed)	1.000	1.002	-0.002	-0.203
Price of export goods (indexed)	1.000	0.969	0.031	3.151
Price of import goods (indexed)	1.000	0.970	0.030	3.078
Domestic demand	789,506,800.0	789,478,600.0	28,200.0	0.004

Table 3.3: Domestic goods, export goods, import goods, prices of those goods, and domestic demand

Table 3.3 shows the impacts on the domestic goods, export goods, import goods, the prices of those goods, and domestic demand. As stated above, after the liberalization of the electricity retail sector, domestic goods increase and the price of the goods decrease, while the export and import goods decrease, and the prices of those goods increase.

Domestic demand increases by 28.2 billion yen.

3.5 Discussion and Conclusion

Hwang-Lee (2015) estimated the decreasing rate of GDP competitive market to oligopolistic market is 0.484%. This difference may come from two factors. (1) They defined the rents as a total of the electric power industry while we define that monopoly rent is loaded on the retail price. (2) In Hwang-Lee's model, the monopoly rents which must be resulted in somewhere before the liberalization are not explicitly described in the competitive settings.

Figure 3.1 shows the integration scheme of two models in Hwang-Lee (2015). Hwang-Lee

(2015) estimated rents of incomplete competition by using a partial equilibrium model, and applied the estimated parameters calculated to the CGE model. As a result, the economic situation at each parameter was modeled.

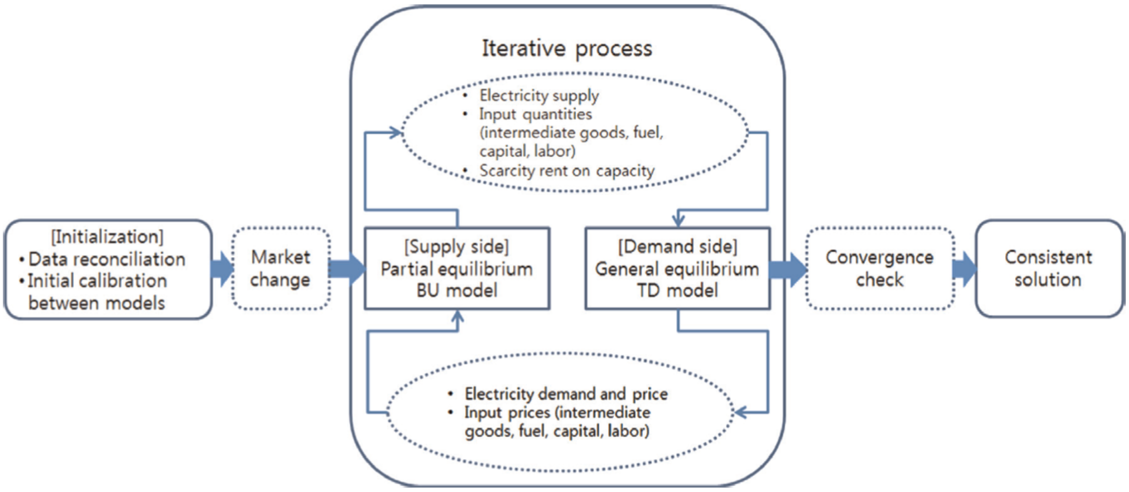

Figure 3.1: Integration scheme of two models in Hwang-Lee(2015)

Hwang-Lee(2015) did not describe where the monopoly rents are resulted in.

We assumed that households receive a portion of the monopoly rents through stocks before the liberalization, also that the purchasing power of households decreases by vanishment of the monopoly rent after the liberalization.

In this study, it is shown that the impact on domestic demand is not significant when assuming that the monopoly rents are resulted in households, even if the electricity price falls.

Appendix 3.A Models

3.A.1. Firms' profit function

Firms' productions are divided into two steps for convinience.

First step

$$max_{Y_i,F_{h,i}}\ \pi_i^y = p_i^y * Y_i - \sum\nolimits_h p_i^f * F_{h,j}$$

$$s.t.\ Y_i = b_i \prod\nolimits_i F_{h,i}^{\beta_i^h}$$

Second step

$$max_{Z_i,Y_i,X_{i,j}}\ \ \pi_i^Z = p_i^Z * Z_i - \left[p_i^Y * Y_i + \sum\nolimits_h p_i^f * F_{h,j}\right]$$

$$s.t.\ Z_i = min\ \left(\frac{X_{j,i}}{ax_{j,i}}, \dots, \frac{Y_i}{ay_i}\right)$$

3.A.2. Households' utility function

$$U = \prod\nolimits_i X_i^{p^{\alpha_i}}$$

$$s.t.\ \ \sum\nolimits_i p_i^q X_i^p = \sum\nolimits_h p_i^f FF_{h,j} - S^p - T^d$$

3.A.3. Optimal behavior of composite production

$$max_{Q_i,M_i,D_i}\ \ \pi_i^q = p_i^q Q_i - \left[(1+\tau_i^m)p_i^m M_i + p_i^d D_i\right]$$

$$s.t.\ Q_i = \ \gamma_i\left(\delta_{m_i} M_i^{\eta_i} + \delta_{d_i} D_i^{\eta_i}\right)^{\frac{1}{\eta_i}}$$

3.A.4. Transformation of export and domestic goods

$$max_{Z_i,E_i,D_i}\ \ \pi_i^Z = \left(p_i^e E_i + p_i^d D_i\right) - (1+\tau_i^z)p_i^z Z_i$$

$$s.t.\, Z_i = \theta_i \left(\xi_{e_i} E_i^{\phi_i} + \xi_{d_i} D_i^{\phi_i} \right)^{\frac{1}{\phi_i}}$$

Profits

	Profits
π_i^y	Profit of goods Yi
π_i^z	Profit of goods Zi
π_i^m	Profit of i th import goods
π_i^d	Profit of i th domestic goods
π_i^q	Profit of i th composite goods

Activity variables

	Variables
Y_i	Production of goods in sector i in the first step
$X_{i,j}$	i th Intermediate goods used by the j th sector
Z_i	Domestic production of the i th goods
E_i	Export of i th goods
M_i	Import of i th goods
Q_i	Production of i-th composite goods
D_i	Production of i-th domestic goods
X_i^g	Government consumption of i th goods
X_i^v	Investment demand for i th goods
CAP_i	Capital ow of i th sector in the first step
LAB_i	Labor of i th sector in the first step
S^p	Private saving
S^g	Government saving
S^f	International deficit denominated in foreign currency
S_i^f	Foreign currency current account deficit
T^d	Direct tax
T_i^z	Indirect tax of i th goods production
T_i^m	Import tarrif of i th goods
$CCAP$	Capital endowment of households
$LLAB$	Labor endowment of households

Prices

	Prices
p_i^y	Price of i th composite goods
p_i^d	Price of i th domestic goods
p_i^q	Price of i th composite goods
p_i^e	Price of i th export goods denominated in domestic currency
p_i^m	Price of i th import goods denominated in domestic currency
p_i^d	Price of i th domestic goods
p_i^f	Price of input factor
$p_i^{W_e}$	Price of i th export goods denominated in foreign currency
$p_i^{W_m}$	Price of i th import goods denominated in foreign currency

Coefficients

	Coefficients
$ax_{i,j}$	Input coefficient of j th intermediate goods to i th goods production
$ay_{i,j}$	Input coefficient of j th composite goods to i th goods production
ss^p	Average saving prospensity of households
ss^g	Average saving prospensity of government

Parameters

	Parameters
τ^d	Direct tax rate
τ_i^z	Indirect tax rate of i th goods production
τ_i^m	Import tarrif rate of i th goods
μ	Proportion of i th goods in the total government consumption
ε	Exchange rate
λ_i	Proportion of i th goods in the total investment
γ_i	Scale coefficient of i th composite goods
$\delta_{m_i}, \delta_{d_i}$	Input ratio coefficient of i th composite goods production function
η_i	Elasticity of substitute i th goods
σ_i	Elasticity of substitute i th composite goods
θ	Scale coefficient of i th transformation function
ξ_{e_i}, ξ_{d_i}	Calculation ratio coefficient of transformation function for i th goods
ϕ_i	Elasticity of transformation for i th goods
ψ_i	Elasticity of i th goods' transformation

Appendix 3.B Equations

3.B.1. Production of general goods

$$Y_i = b_i \prod_i F_{h,i}^{\beta_i^h}$$

$$F_{h,i} = \frac{\beta_i^h p_i^y}{p^f} Y_i$$

$$X_{i,j} = ax_{i,j} Z_j$$

$$Y_j = ay_j Z_j$$

$$p_i^z = ay_j p_j^y + \sum_i ax_{i,j}\, p_i^q + ax_{el,j} p_{el}^q$$

3.B.2. Government behavior

$$T^d = \tau^d \left[\sum_h p^f FF^h\right]$$

$$T_i^z = \tau^d p_j^z Z_j$$

$$T_i^m = \tau^m p_j^m M_j$$

$$X_i^g = \frac{\mu_i}{p_i^q}\left(T^d + \sum_j T_j^z + T_{el}^z + \sum_j T_j^m + T_{el}^m - S^g\right)$$

3.B.3. Investment and Saving

$$S^p = ss^p \left[\sum_h p^f FF^h\right]$$

$$S^g = ss^g \left(T^d + \sum_j T_j^z + T_{el}^z + \sum_j T_j^m + T_{el}^m\right)$$

$$X_i^v = \frac{\lambda_i}{p_i^q}\left(S^p + S^g + \varepsilon S^f\right)$$

3.B.4. Household behavior

$$X_i^p = \frac{\alpha_i}{p_i^q}\left(\sum\nolimits_h p^f FF^h - S^p - T^d\right)$$

3.B.5. Prices of export goods and import goods

$$p_i^e = \epsilon p_i^{We}$$
$$p_i^m = \epsilon p_i^{Wm}$$

3.B.6. Substitutions of import goods and domestic goods

$$Q_i = \gamma_i\left(\delta_{m_i} M_i^{\eta_i} + \delta_{d_i} D_i^{\eta_i}\right)^{\frac{1}{\eta_i}}$$

$$M_i = \left(\frac{\gamma_i^{\eta_i}\delta_{m_i} p_i^q}{(1+\tau_i^m)p_i^m}\right)^{\frac{1}{1-\eta_i}} Q_i$$

$$D_i = \left(\frac{\gamma_i^{\eta_i}\delta_{d_i} p_i^q}{p_i^d}\right)^{\frac{1}{1-\eta_i}} Q_i$$

3.B.7. Transformation of export goods and domestic goods

$$\sum_i p_i^{W_i} E_i + \sum_{el} p_{el}^{W_{el}} E_{el} + S^f = \sum_i p_i^{W_m} M_i + \sum_{el} p_{el}^{W_m} M_{el}$$

$$Z_i = \theta_i\left(\xi_{e_i} E_i^{\phi_i} + \xi_{d_i} D_i^{\phi_i}\right)^{\frac{1}{\phi_i}}$$

$$E_i = \left(\frac{\theta_i^{\phi_i}\xi_{e_i}(1+\tau_i^z)p_i^z}{p_i^e}\right)^{\frac{1}{1-\phi_i}} Z_i$$

$$D_i = \left(\frac{\theta_i^{\phi_i}\xi_{d_i}(1+\tau_i^z)p_i^z}{p_i^d}\right)^{\frac{1}{1-\phi_i}} Z_i$$

3.B.8. Market clearing conditions

$$\sum_j F_j^{cap} + \sum_{el} F_{el}^{cap} = CCAP$$

$$\sum_j F_j^{lab} + \sum_{el} F_{el}^{lab} = LLAB$$

$$Q_i = X_i^p + X_i^g + X_i^v + \sum_j X_{i,j} + \sum_{el} X_{i,el}$$

$$F_{h,i} = \frac{\beta_i^h p_i^y}{p^f} Y_i$$

$$X_{i,j} = ax_{i,j} Z_j$$

$$Y_j = ay_j Z_j$$

$$p_i^z = ay_j p_j^y + \sum\nolimits_i ax_{i,j}\, p_i^q + ax_{el,j} p_{el}^q$$

$$T^d = \tau^d \left[\sum\nolimits_h p^f FF^h\right]$$

$$T_i^z = \tau^d p_j^z Z_j$$

$$T_i^m = \tau^m p_j^m M_j$$

$$X_i^g = \frac{\mu_i}{p_i^q}\left(T^d + \sum\nolimits_j T_j^z + T_{el}^z + \sum\nolimits_j T_j^m + T_{el}^m - S^g\right)$$

$$S^p = ss^p \left[\sum\nolimits_h p^f FF^h\right]$$

$$S^g = ss^g \left(T^d + \sum\nolimits_j T_j^z + T_{el}^z + \sum\nolimits_j T_j^m + T_{el}^m\right)$$

$$X_i^v = \frac{\lambda_i}{p_i^q}\left(S^p + S^g + \varepsilon S^f\right)$$

$$X_i^p = \frac{\alpha_i}{p_i^q}\left(\sum\nolimits_h p^f FF^h - S^p - T^d\right)$$

Conclusion

This thesis estimated the effect of the electricity system reform in Japan by using the input-output analysis. Here, we summarize the results obtained in three chapters that construct this thesis. Afterward, we propose some plans for future research.

Chapter1 separated the data of the electric power industry into those of the electricity generation, electricity transmission, and electricity retail sectors in the input-output table by using cost information of each sector printed in annual reports of the electric power companies. Previous studies such as Hosoe (2011) and Hwang-Lee (2015) have not separated the sectors by each cost, but have supposed that all costs of the electric power industry were input to the electricity generation sector, and then, all outputs of the electricity generation sector were forwarded to the electricity transmission sector, and all outputs of the electricity transmission sector were forwarded to the electricity retail sector. Their assumption greatly differed with regards to the flow of business, and duplication among the sectors exists. We suppose that each sector (generation, transmission, and retail) has its sector-specific inputs, also suppose that each sector has outputs to other industries as intermediate goods and to the consumers as the final demand.

We compared the inverse matrix coefficients, the forward and backward linkages by using our method and those by using method of previous studies. The results shown below are caused by the difference in the definition of sectors.

Firstly, the inverse matrix coefficients of the industries that are used in the electricity generation sector are larger, and the inverse matrix coefficients of the industries that are used in the electricity retail sector are smaller by using our method. The electricity transmission sector has little inverse matrix coefficient on the electricity generation sector by using our method (this sector has a large inverse matrix coefficient on the electricity generation sector when using the previous method). The electricity retail sector has little inverse matrix coefficient on the electricity generation and electricity transmission sectors when using our method (this sector has a large inverse matrix coefficient on the electricity generation and electricity transmission sectors when using the previous method).

Secondly, the influence of the electricity transmission and electricity retail sectors to other industries using our method is smaller, while the influence of the electricity generation sector calculated using our method is larger.

Finally, the sensitivities of the electricity generation, electricity transmission, electricity retail sectors, and the “Mining” industry are evaluated smaller when using our method, as compared to the previous method.

Chapter 2 estimated price elasticities of electricity demand for individual industries, which is essential to calculate the monopoly rent for the numerical simulation by applied general equilibrium. Most papers that study industrial elasticities analyze the elasticity for the whole industrial sector. Only a few studies have estimated elasticities for individual sectors, but even then, sectors are classified by broad divisions (alphabetical-letter industrial classification) such as agriculture, manufacturing, and services. Studies that classify sectors by major groups (two-digit industrial classification) such as food, chemicals or iron are rare. Companies that require large amounts of electricity are likely to be influenced by an increase in the electricity price. We estimated the price elasticity of the electricity demand for each industry (major groups) in manufacturing, using the partial adjustment model. There have been no studies in Japan that estimate the price elasticity of demand for electricity in a statistically reliable manner for each medium-class industry. Previous studies show that elasticity of the whole industry is low, however, we find that the manufacturing sector is more elastic than the whole industry, and also find that many sectors within manufacturing are more elastic.

Chapter 3 simulated the effects of the electricity system reform in Japan. We suppose that the monopoly rents of the electric power companies are resulted in households through stock shares, all of which are held by households. We analyze the effect of the system reform on domestic goods, export goods, import goods, price levels of those goods, and domestic demand. We showed that domestic goods increase and the prices of those goods decrease, also show that the prices of the export and import goods increase, thus the export goods and import goods decrease. Although domestic demand increased by 28.2 billion yen, the rate of increase is only 0.004%. Hwang-Lee (2015) estimated the rate of increase in GDP due to the structural change from an oligopolistic market to a competitive one is 0.484%. This difference comes from two factors. (1) They defined the rents as a whole of the electric power industry while we define that monopoly rents are loaded on the electricity retail sector. (2) In Hwang-Lee’s model, the monopoly rents which must be resulted in somewhere before the liberalization are not explicitly described in the competitive settings. They modeled incomplete competition by the partial equilibrium model and applied the estimated parameters to the general equilibrium model, which does not describe where the monopoly rents are resulted in after liberalization. We assumed that before the liberalization, households receive a portion of the monopoly rents through stocks, thus also that the purchasing power of households decreases by vanishment of the monopoly rent after the liberalization.

Next, we provide some plans for future research as follows.

In this study, it was assumed that monopoly rents of the electric power industry are resulted in households through stocks before liberalization. We think this is a reasonable assumption, however, also think that other assumption can be possible. For example, (1) it is assumed that rents will be invested in other industries through capital, or (2) rents are allocated to investments of foreign capital. Further analyses are needed. We also examine the assumptions about elasticity by industry. Although it is assumed that the elasticity of substitution of energy and other inputs is the same in this study, the substitutability of energy and other inputs is considered to be extremely low in reality.

This study consistently assumed that the electricity retail sector would be completely monopolistic before liberalization and would be completely competitive after liberalization. However, in reality, although a lot of new entrants enter to the liberalized retail market and prices are decreasing, the market share of incumbent power companies is still large, thus it is controversial that the market is competitive. After the liberalization of the retail market, electricity prices have fallen, but it is possible that this is due to intense competition from incumbent electric power companies and large gas companies which have large electric generation capacities. Thus, it is rational to understand that the monopoly rents are vanished due to fierce competition but the market is oligopolistic in terms of market share.

A lot of new entrants are essential to keep the electricity price low with avoiding the strategic behavior of oligopolistic players in the future. Since the "balancing rule restrictions" are imposed on retail market entrants, stable electric power purchase is essential. However, many new entrants find difficult to ensure sufficient electric power. Although incumbent electric power companies are required to vertically separate the electricity transmission sector in

2020, the electricity generation and the electricity retail sectors are not necessarily needed to be separated. Since the existing electric power companies occupy the electricity generation market, it's possible that vertical integration of existing electric power companies is a barrier to a new entry.

When a lot of electric power supply is obtained by the existing electric power companies, new entrants will expect that existing electric power companies differentiate the electricity price by cross-subsidization and this expectation may block their entry. We plan to study this theoretical analysis in the future.

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