

Estimating sector-specific data of the electric power industry to analyze the electricity system reform: the case of Japan

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Abstract

Electricity industry around the world has experienced liberalization. This essential industry consists of three sectors — an electricity generation, transmission, and retail (and distribution) sector —, and the degree of the liberalization is generally different among the sectors; in many countries or regions the generation and retail sector have been liberalized, while the transmission sector has not faced liberalization. Previous studies have analyzed the effects of the liberalization using the industry-level data because the electricity industry in input-output tables does not have sector-level data. In this study, we estimate the sector-level data of the electricity industry by using annual reports of the electric power companies, and we find that the industry-level data which are used by previous studies may lead to wrong policy decisions.

Keywords: electricity industry; electricity system reform; input-output table; competition policy

Category & Number: 5. Industrial Organization and Structural Policy

JEL Classification: C32, C33, Q41, Q48

1. Introduction

Electricity industries consist of several sectors; an electricity generation, transmission, and retail (and/or distribution) sector. We will observe system reforms in the representative countries, and then summarize how previous studies analyze the effects of the electricity system reform.

1.1 Liberalization of electricity industries

As a global trend, electricity system reforms, more specifically liberalization have proceeded. Liberalization is applied to sectors of electricity industry, not to the electricity industry as a whole in many countries/regions. We summarize the processes of electricity reform and liberalization.

U.S.A.: The federal government has authority over the generation sector, while the state government has authority over the retail sector. The wholesale electricity market was liberalized in 1992, then Independent Power Producers (IPPs) were allowed to enter the market. The liberalization of the electricity retail sector started in the 1990s as state-level legislation, as a result, thirteen states fully liberalized, six states partially liberalized, and the remained states do not liberalize at all in September 2019.

U.K.: The electricity supply was nationalized from 1947 to 1989, then it was privatized in 1990. The generation sector introduced transaction markets after the failure of the pool market, finally the sector was fully liberalized in 1990, while the retail sector was fully liberalized in 1999. The shares of the generation and retail sector differs, 60% of the generation sector and 70% of the retail sector is occupied by the major players (so called “Big 6”) in 2018.

Germany: The new legislation introduced the liberalization of the generation and the retail sector in 1998. However, the major players (“Big 4”) had market powers in the generation sector; the share of the companies is 72% in 2016. The market share of those companies in the retail one is 28% in business demand, 34% in households demand.

Japan: The electricity system reform started in 1995. Initially, 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, then, the sector is fully liberalized in 2016.

The transmission sector is allowed to be monopolistic in the countries/regions that experienced liberalization. It often appears that either the generation or the retail sector remains to be non-competitive after both of them are liberalized. As a result, the data of each sector is essential to analyze the effects of the liberalization and the effects of being competitive.

1.2 Studies about the effects of the liberalization

Many previous studies on an electricity system reform employ a partial equilibrium paradigm to analyze the effects of decreasing electricity prices and of introducing competition (e.g. Zhang et al. (2008), Hattori and Tsutsui (2004)), however, a general equilibrium might be a more suitable framework because the reform have influences not only on customers of electricity but also on suppliers to electricity industry. A few studies have analyzed electricity industries in a general equilibrium framework applying computational general equilibrium (CGE) models. Kunneke and Voogt (1997) analyzed an electric power industry in the Netherlands, who employed a dynamic CGE model to estimate a welfare improvement of liberalization in the Dutch electricity market. Hosoe (2006) analyzed a regulatory reform for the electric power industry in Japan, who simulated the effects of the regulatory reform using the CGE model.

The input-output tables used in the previous studies do not have sectoral data of the electricity industry; the data of all sectors are included/aggregated in the electricity industry-wide data. The previous studies defined the sectoral data by simplifying each sector in the electric power industry. Hosoe (2006), Akkemik and Oguz (2011), and Hwang and Lee (2015) assumed that the inputs which should have been input to the electric power industry are thrown only into the electricity generation sector, and the outputs of the electricity generation sector are sent to the electricity transmission sector (Figure 1). This assumption raises two problems. 1) The inputs to the electricity industry are duplicated; all of the inputs to the electricity industry as a whole is thrown into the generation sector, $\sum_{i=1}^n p_i a_{ig} X_g$, and the added value, $v_g X_g$, are thrown into the transmission sector. $\sum_{i=1}^n p_i a_{ig} X_g + v_g X_g + v_t X_t$ is defined as the output of the transmission sector, $\sum_{i=1}^n p_i a_{ig} X_g + v_g X_g + v_t X_t + v_r X_r$ is the output of the retail sector. All of the inputs to the electricity industry as a whole $\sum_{i=1}^n p_i a_{ig} X_g$ is counted three times. 2) The output of the retail sector will be larger than the one of the transmission sector and the

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generation sector regardless of the real size of the outputs; even if the output of the generation sector is the larger than the transmission and the retail sector, the effects on the retail sector is the largest. Thus, the effects of the system reform on the retail sector might be evaluated larger than the reform on the generation sector because the retail sector obtain all the inputs of the electricity industry and the outputs from the generation and transmission sector (Figure 2).

		Comodities / Activities						
		Industry 1	...	Generation	Transmission	Retail	...	Industry n
Comodities / Activities	Industry 1	$p_1 a_{11} X_1$	...	$p_1 a_{1g} X_g$	0	0	...	$p_1 a_{1n} X_n$
	⋮	⋮	⋮	⋮	0	0	⋮	⋮
	Generation	0	0	0		0	0	0
	Transmission	0	0	0		0	0	0
	Retail	$p_r a_{r1} X_1$	⋮	0	0	0	⋮	$p_r a_{rn} X_n$
	⋮	⋮	⋮	⋮	0	0	⋮	⋮
Industry n	$p_n a_{n1} X_1$	...	$p_n a_{ng} X_g$	0	0	...	$p_n a_{nn} X_n$	
Value Added	$v_1 X_1$	...	$v_g X_g$		$v_t X_t$	$v_r X_r$	...	$v_n X_n$
Total	...	...	$\sum_{i=1}^n p_i a_{ig} X_g + v_g X_g$		$\sum_{i=1}^n p_i a_{it} X_t + v_g X_g + v_t X_t$	$\sum_{i=1}^n p_i a_{ir} X_r + v_g X_g + v_t X_t + v_r X_r$	...	...

Figure 1: Separating the sectors of the electricity industry, as suggested by Hwang and Lee (2015)

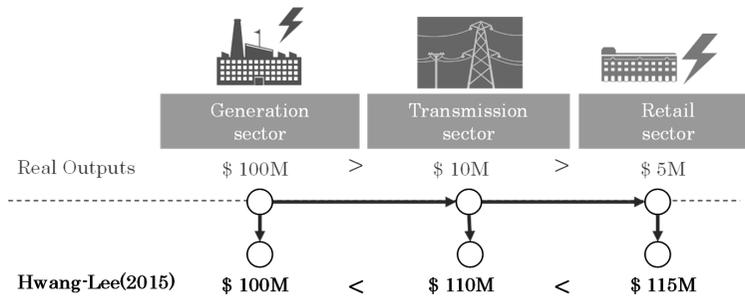


Figure 2: Examples of the real outputs and the ones estimated by Hwang-Lee(2015)

1.3 Outline of this study

In the following sections, we estimate the sectoral data of the electricity industry in an input-output table by using annual reports of the electric power companies, finally find that the data which is estimated by the previous methods as shown in Figure 1 is possible to distort policy decisions¹. The estimation is demonstrated by using the input-output table in Japan, but this result would be found to be beneficial to other countries. Figure 3 depicts the results that we attempt to obtain. 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. We assume that no transactions exist between the sectors in the electricity industry.

		Comodities / Activities						
		Industry 1	...	Generation	Transmission	Retail	...	Industry N
Comodities / Activities	Industry 1	$p_1 a_{11} X_1$	...	$p_1 a_{1g} X_g$	$p_1 a_{1t} X_t$	$p_1 a_{1r} X_r$	...	$p_1 a_{1n} X_n$
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	Generation	$p_g a_{g1} X_1$	⋮	0	0	0	⋮	$p_g a_{gn} X_n$
	Transmission	$p_t a_{t1} X_1$	⋮	0	0	0	⋮	$p_t a_{tn} X_n$
	Retail	$p_r a_{r1} X_1$	⋮	0	0	0	⋮	$p_r a_{rn} X_n$
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Industry N	$p_n a_{n1} X_1$	...	$p_n a_{ng} X_g$	$p_n a_{nt} X_t$	$p_n a_{nr} X_r$	...	$p_n a_{nn} X_n$	
Value Added	$v_1 X_1$	...	$v_g X_g$	$v_t X_t$	$v_r X_r$	...	$v_n X_n$	
Total	...	...	$\sum_{i=1}^n p_i a_{ig} X_g + v_g X_g$	$\sum_{i=1}^n p_i a_{it} X_t + v_t X_t$	$\sum_{i=1}^n p_i a_{ir} X_r + v_r X_r$	...	...

Figure 3: Separating the sectors of the electricity industry, as suggested by this research

¹ This method has been rarely employed in the peer-reviewed studies. Hienuki and Hondo (2013) reaggregated the 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.

2. Methodology

2.1 Modification of the input-output matrices

As mentioned previously, there have not been found the peer-reviewed studies that have re-aggregated the input-output tables across the three sectors using the annual reports of the electric power companies.

We employ hybrid approaches which have been proposed by Linder et al. (2013), Heijungs and Suh (2011), Rodriguez-Alloza, et al. (2015) for constructing the modified input-output tables. Firstly, we introduce the input weight factor ρ , which represents the proportion of each electricity sector to the sum of the electric power industry (equation (1), $k = \{generation, transmission, retail\}$). Secondly, we define the coefficients of an electricity industry in the original input-output table as $a_{i,ele}$, and the ones of each electricity sector is $a_{i,k}$ which can be defined as the modified coefficients in the disaggregated input-output table (equation (2)).

$$\rho_{i,k} = \frac{x_{i,k}}{\sum_k x_{i,k}} \quad (1)$$

$$a_{i,k} = \rho_{i,k} * a_{i,ele} \quad (2)$$

2.2 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

$$X = [I - (I - M')A]^{-1}[(I - M')F^d + E] \quad (3)$$

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 (Figure 4). The inverse matrix coefficients are denoted by $b_{i,j}$. The backward linkage is represented by equation (5). This indicates the degree how the increase in the final demand to sector j affect the production as a whole economy. The forward linkage is defined by equation (6) ($for j = \{1, 2, 3, \dots, n\}$). This indicates the degree how each sector is affected by other industrial production activities (Figure 5).

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

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

		Comodities / Activities					
		Industry 1	...	Industry j	...	Industry n	
Comodities / Activities	Industry 1	b_{11}	...	b_{1j}	...	b_{1n}	
	⋮	⋮	⋮	⋮	⋮	⋮	
	Industry i	b_{i1}	⋮	b_{ij}	⋮	b_{in}	
	⋮	⋮	⋮	⋮	⋮	⋮	
	Industry n	b_{n1}	...	b_{nj}	...	b_{nn}	

e_j

Figure 4: An inverse matrix and linkage effects

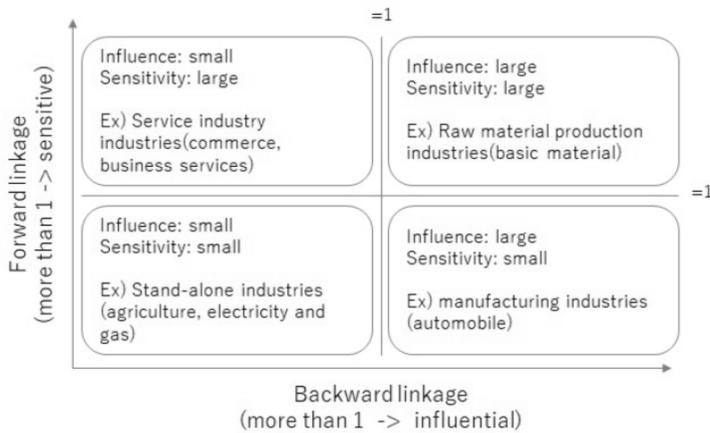


Figure 5: Backward linkage and forward linkage

3. Data

3.1 Original input-output table

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 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.

3.2 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 is stated: “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. 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.

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: Correspondence between the input-output table and annual reports

3.3 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 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 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.

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 methods.

4.1 *Input weight factors of each sector*

We calculated the input weight factors, ρ , that were calculated by matching 509 items in the original input-output table and 214 items in the electric utility operating expenses schedule. Table 2 shows the representative input weight factors of each sector in the electric power industry corresponding to the major industrial categories. 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.

Major industrial categories	Generation	Transmission	Retail
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

Table 2: Representative input weight factors of each industry (%)

4.2 The inverse matrix coefficients of the sectors

Figure 6 describes the inverse matrix coefficients of industries that are generated by the new electricity sectors. The electricity generation sector generates the largest inverse matrix coefficients in "Electricity, gas, and heat supply" industry, followed by "Business service", "Transport and postal services", and "Petroleum and coal products" industries. The largest inverse matrix coefficients that are generated by the electricity transmission sector is "Business services", followed by "Transport and communications", "Finance and insurance", "Commerce", "Construction", and "Real estate". The electricity retail sector generates the largest inverse matrix coefficients in "Business services", followed by "Transport and communications", "Finance and insurance", and "Commerce". The inverse matrix coefficients of the "Electricity, gas, and heat supply" and "Petroleum and coal products" industry is almost entirely generated by the electricity generation sector.

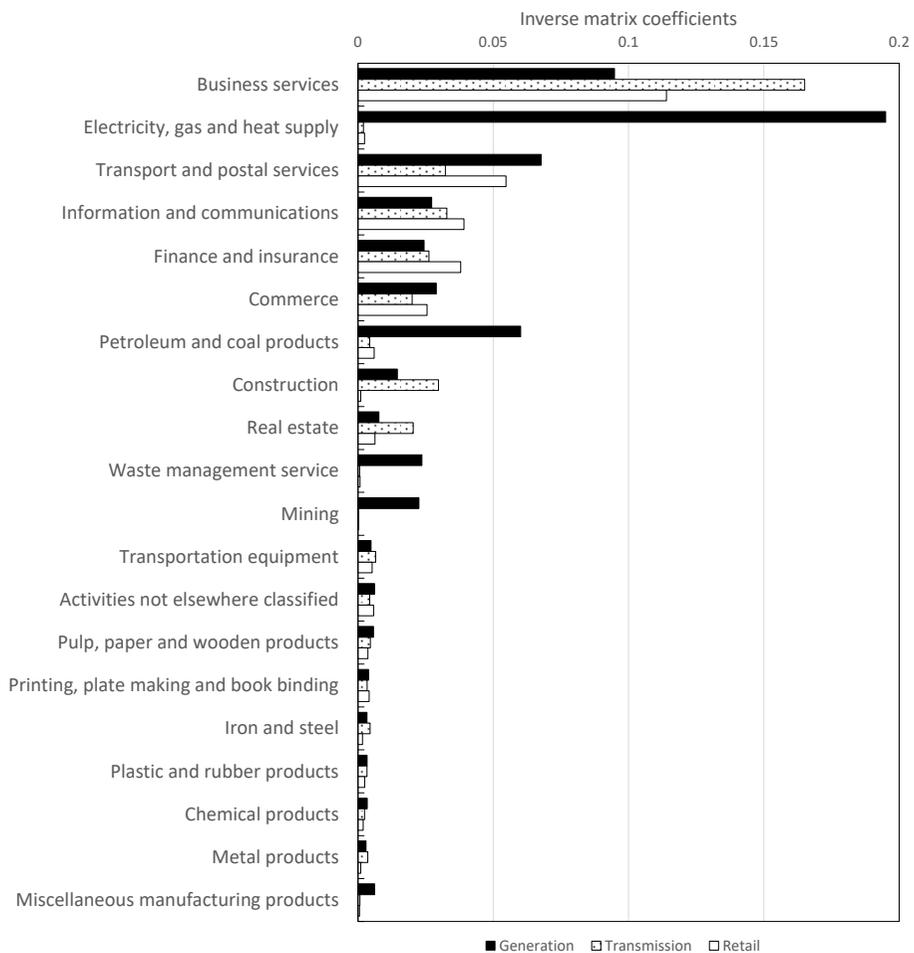


Figure 6: The ripple effects of each sector of the electricity industry

4.3 The forward/backward linkages of the sectors

The forward and backward linkages are shown in Figure 7. The forward linkages indicate the degree of sensitivity of the industries. This figure 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 5, 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 an agriculture.

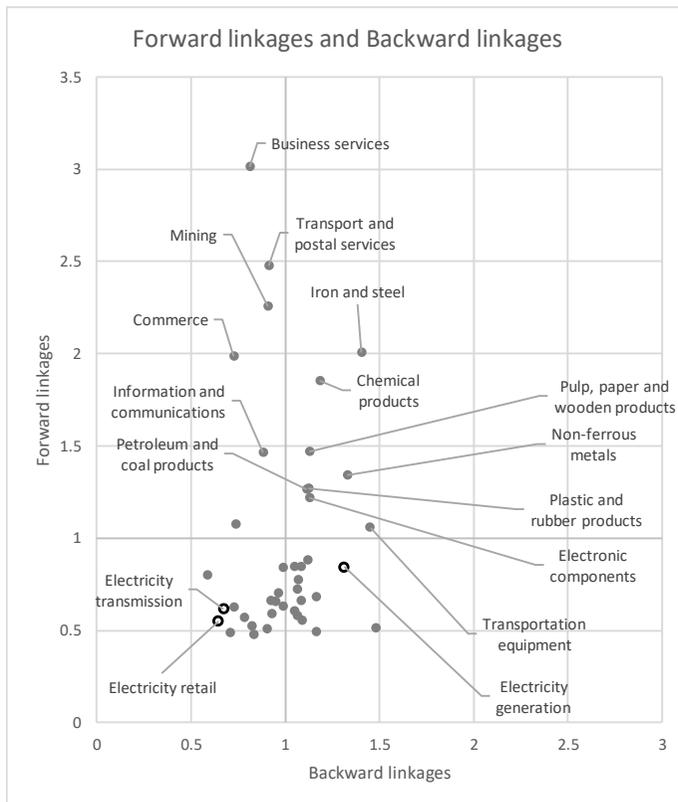


Figure 7: Backward and forward linkages

4.4 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 electricity industry are provided only to the electricity generation sector. The outputs of the electricity generation sector are sent to the electricity transmission sector, and then the outputs of the electricity transmission sector are forwarded to the electricity retail sector.

We compared the inverse matrix coefficients calculated by using our method and those by using method of previous studies. Figure 8 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 9 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 10 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 the 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.

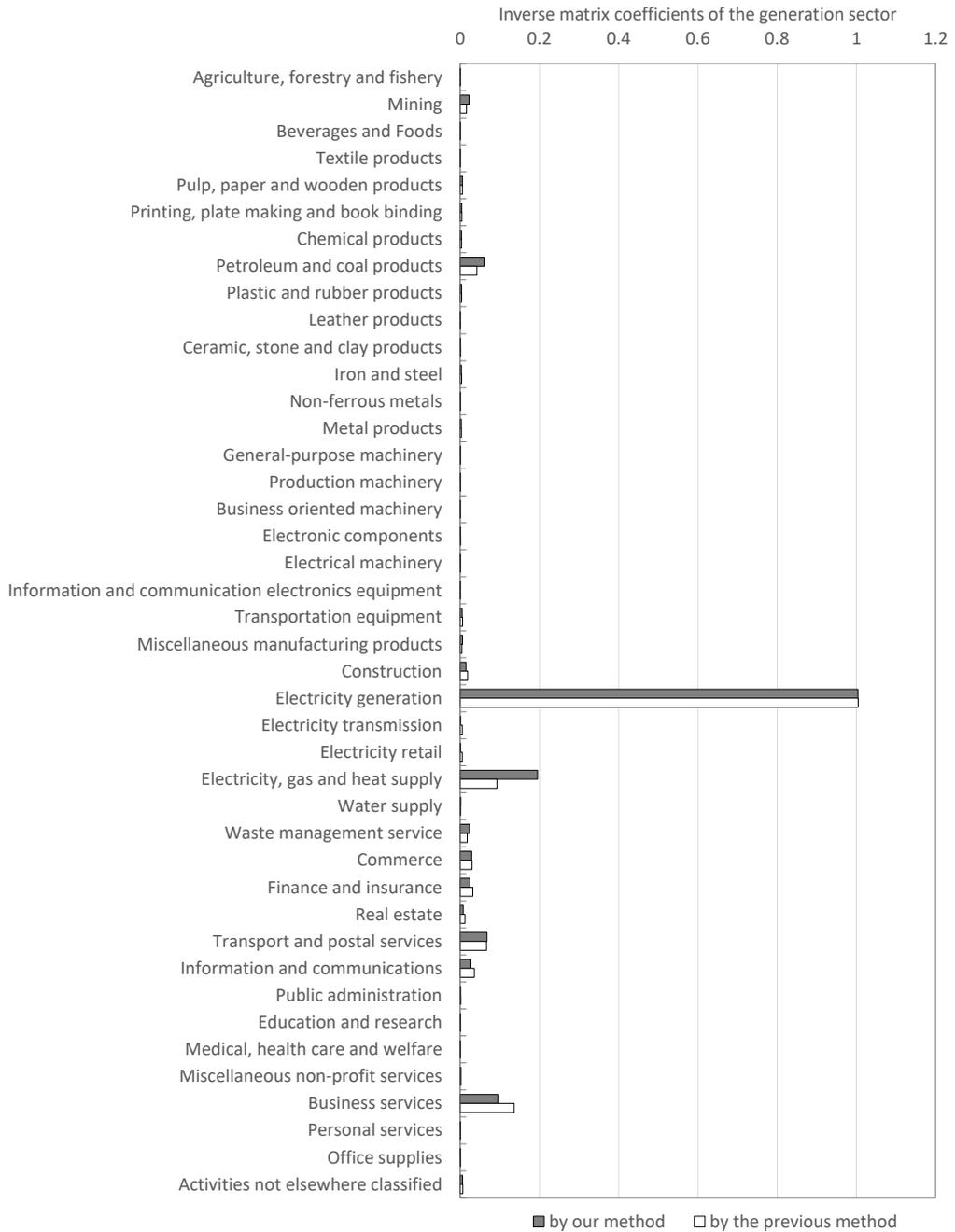


Figure 8: Inverse matrix coefficients of the electricity generation sector estimated using our method and the previous method

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Figure 9: Inverse matrix coefficients of the electricity transmission sector estimated using our method and the previous method

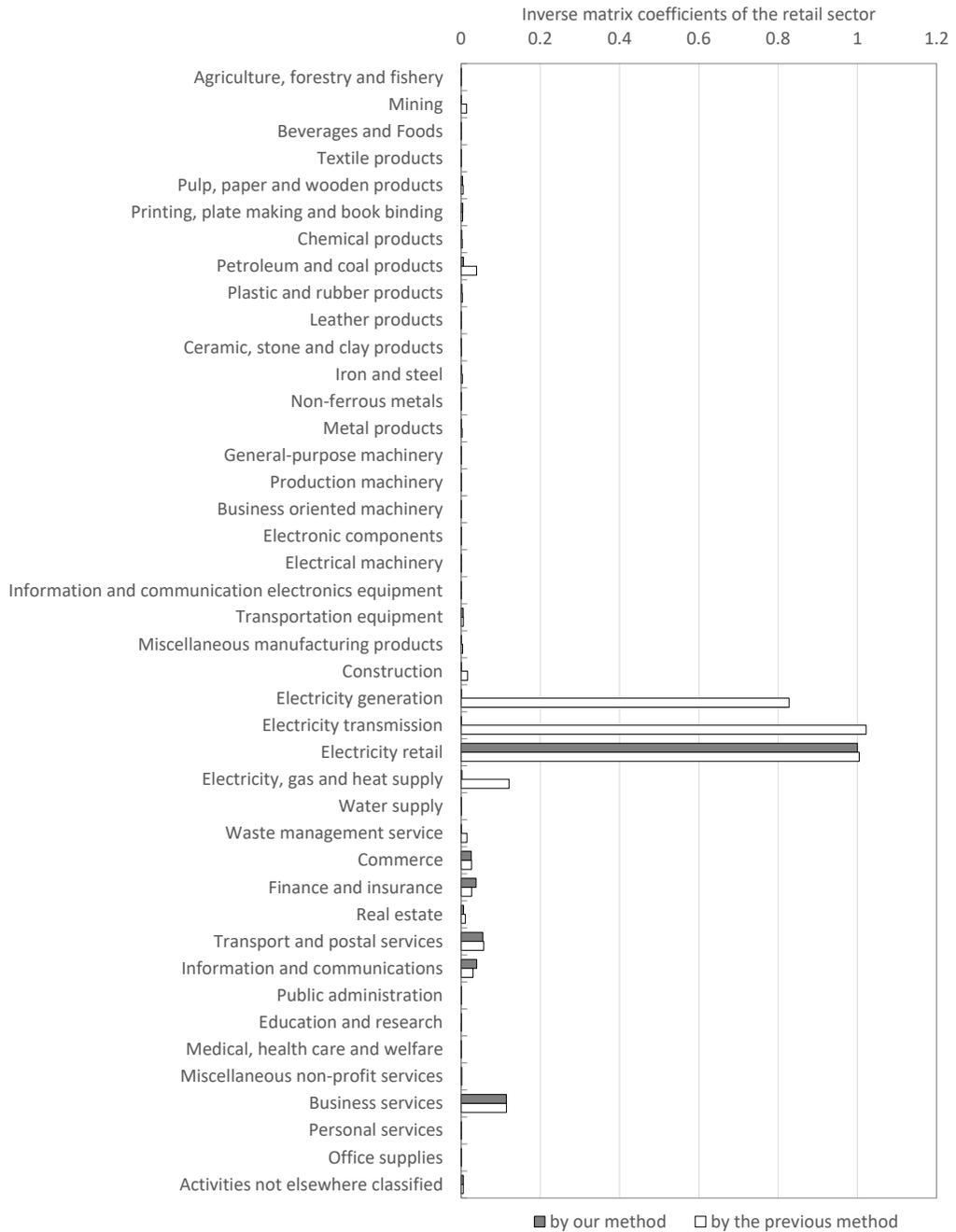


Figure 10: Inverse matrix coefficients of the electricity retail sector estimated using our method and the previous method

4.5 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 11 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 12 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 13 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.

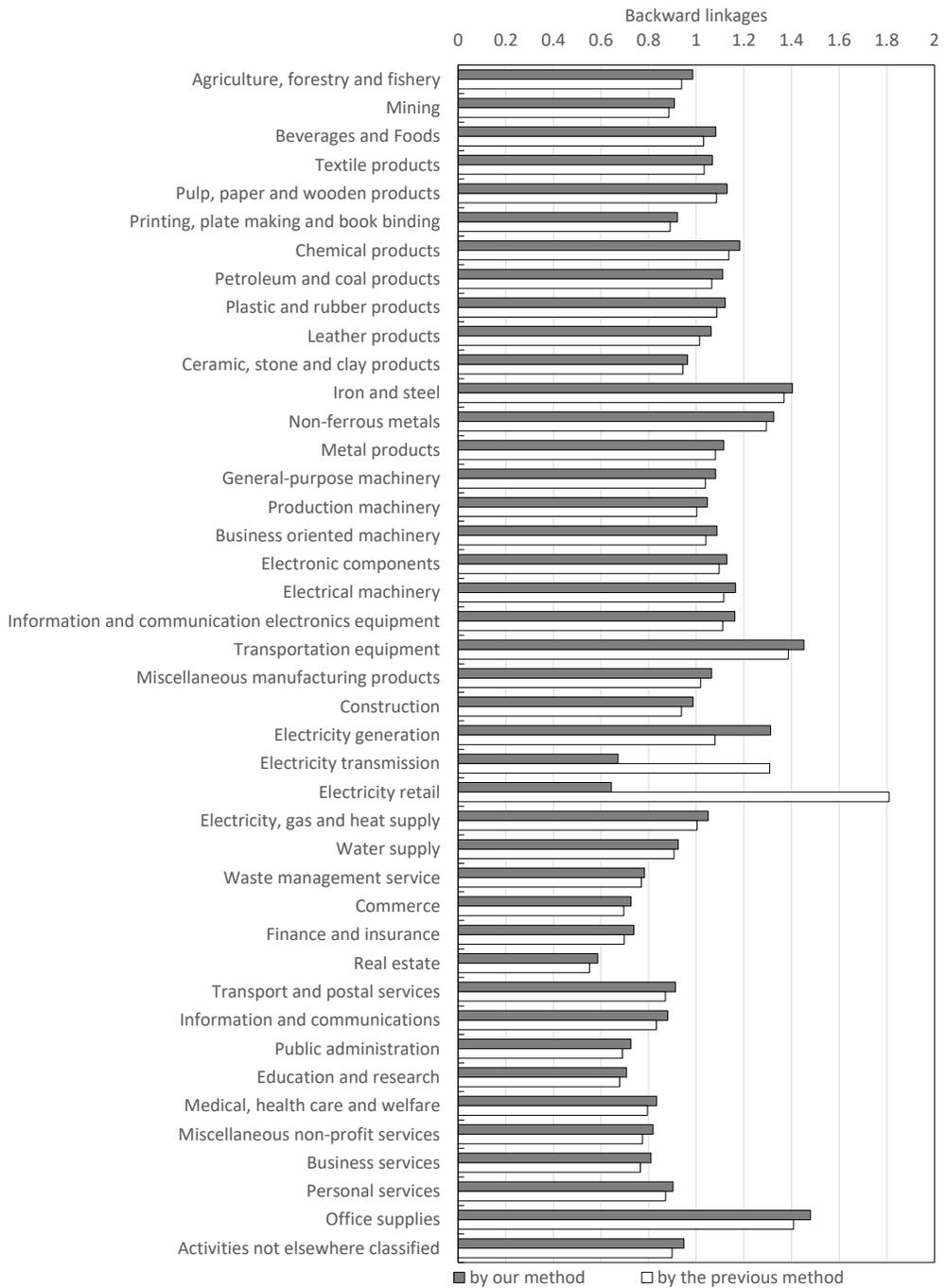


Figure 11: Backward linkages calculated using our method and the previous method

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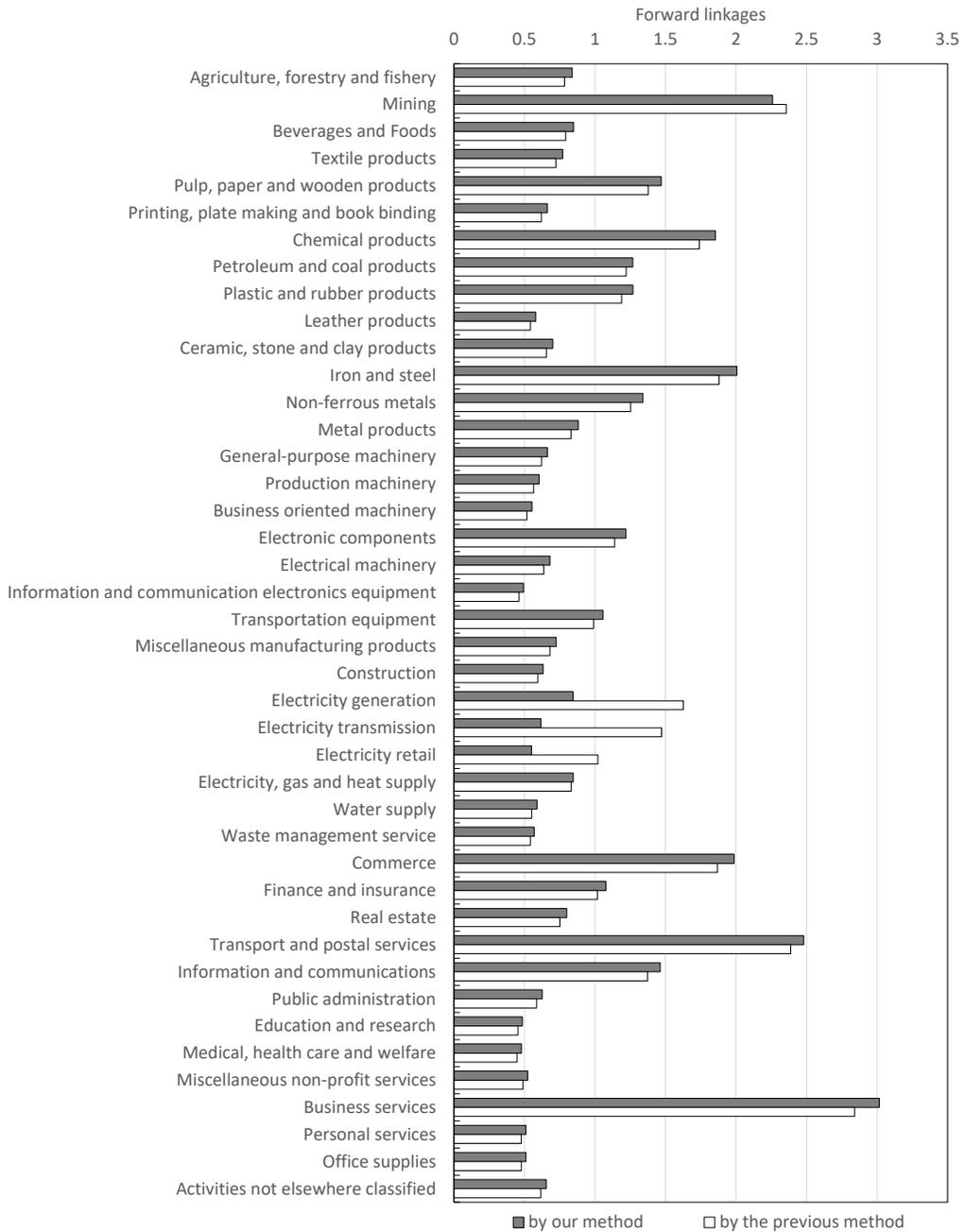


Figure 12: Forward linkages calculated using our method and the previous method

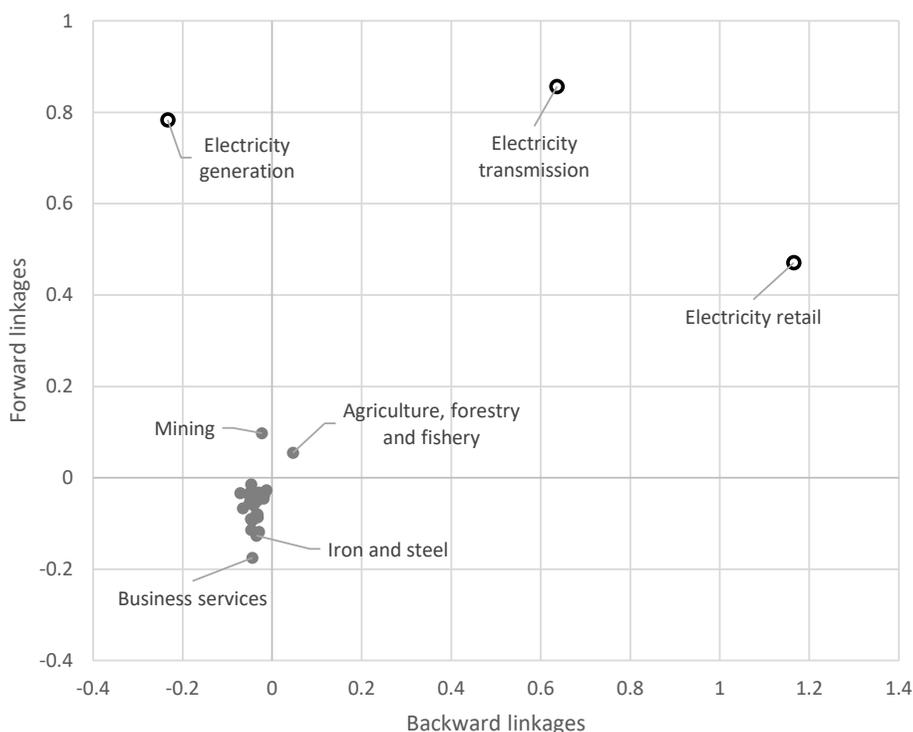


Figure 13: Differences of the backward and forward linkages calculated between using our method and the previous method

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.

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We discuss the effect of policy to the electricity industry. The industrial policy for the electricity industry has impacts on both the industries that provide goods to the electricity industry and those that consume electricity. The previous method implies that the policy to the retail sector is the most influential to industries that input to the electricity industry because this sector has the largest backward linkage, however, our method implies that the policy to the retail sector is the least influential whereas that to the generation sector is the most influential. Our method also implies that the effect to industries that use electricity will be only about half that estimated by the previous method forward linkages are overestimated by the previous method, by a factor of two.

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

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