Analysis of Electric Supply Shortage and Change in a Factor of Production in Japan caused by Earthquakes using the GTAP-E Model

by

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Abstract

This study analyzes the impact of earthquakes on the Japanese economy and, in particular, on electric supply shortage, using the GTAP-E model. To verify that the simulation undertaken using this model can reproduce the impact of a real-world earthquake, this study uses Japanese data on electric supply shortage and capital stock in 2011—the year in which the Great East Japan Earthquake occurred—as exogenous values. Thereafter, the study compares the simulation results with actual macroeconomic data from 2011.

Section 2 of this paper analyzes Japanese time-series data concerning electric supply and the macroeconomy. The results of the data survey indicate that in 2011, Japan's total electric supply decreased by 4.57%, while the total capital stock decreased by around 1.1%. Section 3 discusses the structure of substitution between capital and energy goods in the GTAP-E model. Following a brief survey of previous studies, Section 4 presents a concrete methodology for analyzing the economic impacts of electric supply shortage in Japan caused by earthquakes, using the GTAP-E model.

The simulation results are discussed in Section 5. The result with respect to the percentage change in Japan's real GDP (-0.65%) is not overly different from that observed in the actual 2011 data (-0.50%). Section 6 undertakes systematic sensitivity analysis concerning the substitution parameters (1) between capital and energy and (2) between energy goods.

The overall results suggest that the GTAP-E model can reproduce the situation caused by a real-world earthquake—in this case, the Great East Japan Earthquake. Japan's electricity sector is a rather exceptional case in that it is characterized by a substitutional relationship between energy and capital. Thus, it is advisable to use the GTAP-E model to analyze the Japan's electricity sector, as this model incorporates the structure of substitution between energy and capital.

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1. Introduction

This study analyzes the impact of earthquakes on the Japanese economy, using the GTAP-E model. To verify that the simulation undertaken with this model can reproduce the impact of a real-world earthquake, this study uses Japanese data on electric supply shortage and capital stock in 2011—the year in which the Great East Japan Earthquake occurred—as exogenous values. Thereafter, the study compares the simulation results with actual macroeconomic data from 2011.

Section 2 analyzes Japanese time-series data concerning electric supply and the macroeconomy. The results of the data survey indicate that in 2011, Japan's total electric supply decreased by 4.57%, while the total capital stock decreased by around 1.1%.

Section 3 discusses in detail the structure of substitution between capital and energy goods in the GTAP-E model. Burniaux and Truong (2002) explain in GTAP Technical Paper No. 16 that the values of the final elasticity of substitution (also referred to as the "outer" elasticity of substitution in the concerned paper) between capital and energy goods can be estimated using the formula for the case of a nested CES structure derived from Keller (1980). This formula uses the given substitution elasticity (also referred to as the "inner" elasticity of substitution in the concerned paper) between capital and energy, the given substitution elasticities between the primary factors, and the cost share of the capital and energy composites. The study shows that although most industries are characterized by an overall complementary relationship between energy and capital, "electricity" in the United States and "electricity," "ferrous metals," and "chemical, rubber, plastic products" in Japan are characterized by overall substitutional relationships. Section 3 estimates, too, the overall ("outer") elasticity of substitution between capital and energy based on the GTAP 8.1 database and, as an exception, we can still find a substitutional relationship between energy and capital in Japan's electricity sector.

Following a brief survey of previous studies, Section 4 presents a concrete methodology for analyzing the economic impacts of electric supply shortage in Japan caused by earthquakes, using the GTAP-E model. To use the exogenous values taken from the data survey in Section 2 in the GTAP-E model, the basic closure is changed in the first simulation by setting aoall ("Electricity," "JPN") as endogenous and qo ("Electricity," "JPN") as exogenous. By using the exogenous values taken from the survey in Section 2 (i.e., the reduction rate of electric supply and that of capital stock), we can obtain the rate at which productivity in the Japanese electricity sector decreased in 2011. In the second simulation, which uses the basic closure, by setting the reduction rate of productivity in the Japanese electricity sector (taken from the first simulation) and that in the capital stock (used in the first simulation as an exogenous value) as exogenous values, we can estimate the impacts of decreased productivity in the electricity sector and damage to capital stock in Japan, both on account of the Great East Japan Earthquake in 2011. Following explication on the methodology, the aggregation of regions (12 regions) and sectors (28 sectors) in this study is presented.

Section 5 discusses the simulation results. The result with respect to the percentage change in Japan's real GDP (-0.65%) is not overly different from that observed in the actual 2011 data (-0.50%). The result regarding the change in real imports is -0.19%, whereas in the actual data, the figure was +11.1% in 2010, +5.9% in 2011, +5.3% in 2012, and +3.4% in 2013; these numbers indicate that Japan's real imports continue to fall. Thus, it could be said that the simulation result of the GTAP-E model reproduces the tendency of Japan's real imports in the post-2011 years. As for the change in real exports, the simulation result is -1.26%, whereas in the actual data, this figure was +22.4% in 2010, -0.4% in 2011, -0.1% in 2012, and +1.6% in 2013. Thus, regarding the Japanese real exports data as well, it could be said that the simulation results derived from the GTAP-E model align with the tendency of Japan's real exports during the post-2011 years.

The simulation results concerning both the macroeconomy and the sectors (i.e., industrial output, private consumption, supply price, export, and import by sectors) show that the two channels of the impact of earthquakes—namely, the decrease in productivity in the electricity sector and the damage to capital stock—would each have an impact, but of rather different kinds. To analyze the impact of earthquakes on the economy, it would be useful to examine not only the total impact, but also the individual effects of each channel.

Section 6 undertakes systematic sensitivity analysis of the substitution parameters (1) between capital and energy and (2) between energy goods. The values of these parameters range from a decrease of 50% to an increase of 50%. As both cases are analyzed in all Japanese industries, two types of systematic sensitivity analysis are undertaken. The results show that the simulation results are rather robust against changes in the value of the parameters between capital and energy, and between energy goods. It is noted, however, that when the number of varying parameters increases, the change in the simulation results of energy goods could become considerable.

Section 7 details the conclusions of this paper. It could be said that the GTAP-E model can reproduce the situation caused by a real-world earthquake—in this case, the Great East Japan Earthquake. Japan's electricity sector is a rather exceptional case in that it is characterized by a substitutional relationship between energy and capital. Thus, it is advisable to use the GTAP-E model to analyze the sector, as this model allows to take account of the effect of energy substitution. By examining the results of the systematic sensitivity analysis, we see that in the GTAP-E model, the energy sector shows a tendency that differs from that seen in other sectors. As a conclusion, when the main theme of the simulation concerns the energy sectors, the GTAP-E model could become a useful analytical tool.

2. Analysis of Japanese data concerning electric supply and the macroeconomy

This paper intends to use Japanese data concerning electric supply shortage and capital stock as exogenous values to analyze the impact of the Great East Japan Earthquake on the Japanese economy. Following the analysis of Japanese time-series data, this chapter identifies the changes in Japan's total electric supply and capital stock in 2011.

2.1 Time-series data concerning electric demand (sales)

Table 2-1 shows the Japanese time-series data concerning the electricity demand (sales) by use[2]. After the decrease in FY2008 and FY2009, Japan's electricity demand increased by 5.6% in FY2010. In FY2011, however, this demand decreased significantly by 5.1% after the Great East Japan Earthquake, and continued to decrease in the FY2012 and FY2013.

Table 2-2 shows the change in electricity demand by company in Japan in 2011. We can see that the demand for electricity was steady in January and February. After the Great East Japan Earthquake in March, however, the demand suddenly decreased, especially in Tohoku and Tokyo regions. The decrease in electricity sales caused by the damage on power plants spread gradually throughout Japan, and thus the demand for electricity decreased by 4.57% in 2011.

[2] This data reflects the electricity sales in Japan.

Table 2-1 Change in electricity demand by use in Japan

(Units: 100 GWh, %)

By Use \ By Period		FY2013		FY2012		FY2011		FY2010		FY2009		FY2008	
Other than Eligible Customers Use	Lighting	2,843.4	−0.7	2,862.2	−0.9	2,889.5	−5.0	3,042.3	6.8	2,849.6	−0.1	2,852.8	−1.5
	Power	427.8	−2.1	436.9	−2.8	449.3	−5.3	474.5	5.0	451.7	−3.4	467.6	−6.0
	Lighting & PowerTotal	3,271.2	−0.8	3,299.1	−1.2	3,338.8	−5.1	3,516.8	6.5	3,301.4	−0.6	3,320.4	−2.2
Eligible Customers Use	Commercial Power	1,892.2	−0.8	1,906.9	1.4	1,881.2	−8.4	2,053.8	1.8	2,017.0	−1.4	2,045.5	−0.6
	Industrial Power	3,322.0	0.4	3,309.9	−2.0	3,378.1	−3.3	3,493.5	6.9	3,266.8	−7.3	3,523.4	−5.8
	Eligible Customers Use Total	5,214.2	0.0	5,216.8	−0.8	5,259.3	−5.2	5,547.3	5.0	5,283.8	−5.1	5,569.0	−4.0
Total Electricity Sales		8,485.4	−0.4	8,515.9	−1.0	8,598.1	−5.1	9,064.2	5.6	8,585.2	−3.4	8,889.3	−3.3

Source: The Federation of Electric Power Companies of Japan, "Electricity Demand in Fiscal 2011 (Confirmed Report)," "Electricity Demand in Fiscal 2012 (Confirmed Report)," "Electricity Demand in Fiscal 2013 (Confirmed Report)."

Table 2-2 Change in electricity demand by company in Japan in 2011

(% change on year)

	January	February	March	April	May	June
Hokkaido	1.5	1.5	−0.5	−2.8	−5.3	0.3
Tohoku	2.8	4.3	−14.0	−20.3	−14.9	−13.0
Tokyo	1.5	3.0	−5.9	−13.8	−11.9	−10.4
Chubu	2.9	4.2	1.2	−2.3	−4.4	−2.5
Hokuriku	5.7	6.1	5.2	0.9	−0.1	−0.1
Kansai	3.8	5.4	4.4	1.4	−1.3	−1.1
Cyugoku	4.1	6.6	3.7	0.7	−2.3	−1.6
Shikoku	5.9	5.2	4.9	−0.2	−0.5	0.0
Kyusyu	4.5	9.2	4.7	0.4	−0.5	1.5
Okinawa	3.2	3.3	−1.9	−2.9	−1.6	2.4
Total	3.0	4.6	−1.4	−6.5	−6.5	−5.1

	July	August	September	October	November	December
Hokkaido	−3.6	−4.5	−2.9	−0.6	−2.2	2.1
Tohoku	−10.5	−16.9	−14.5	−9.9	−10.0	−6.7
Tokyo	−11.0	−16.8	−16.4	−10.6	−7.7	−4.8
Chubu	−1.6	−7.6	−7.1	−2.8	−2.8	−1.1
Hokuriku	−0.7	−6.8	−6.8	−1.3	−4.8	−2.8
Kansai	−0.6	−9.5	−9.2	−4.9	−3.7	−2.9
Cyugoku	−1.2	−7.2	−9.5	−4.7	−6.2	−3.8
Shikoku	−1.5	−7.5	−8.0	−2.5	−1.5	−2.5
Kyusyu	2.0	−5.1	−9.0	−3.1	−2.1	−3.9
Okinawa	2.3	−2.1	−4.5	−3.6	−1.7	4.2
Total	−5.0	−11.3	−11.4	−6.3	−5.4	−3.5

Source: The Federation of Electric Power Companies of Japan, "Electricity Demand in January - December in 2011 (Confirmed Reports)."

2.2 Time-series data concerning total power generated and purchased

Table 2-3 shows the time-series data concerning power generated and purchased in Japan. We can see that Japan's power supply configuration has changed quite significantly after 2011; the percentage of nuclear power in the total electricity generation decreased largely and that of thermal power increased. Furthermore, nuclear power has been completely stopped since the second half of 2011, and thus the maintenance of electric supply becomes an urgent issue in Japan.

Table 2-3 Overview of total power generated and purchased in Japan (10 companies total)

(Units: MWh, %)

		FY2013		Year-on-year Change (%)				
		Summary	Year-on-year Change (%)	FY2012	FY2011	FY2010	FY2009	FY2008
Total Power Generated and Purchased		922,902,144	-0.1	-1.4	-5.1	5.1	-3.3	-3.1
Generated by Source (MWh)	Hydro	58,842,231	3.2	-9.2	-0.1	9.0	2.2	-1.3
	Thermal	673,015,666	0.9	9.2	25.8	6.3	-9.8	-6.0
	Nuclear	9,302,750	-41.6	-84.2	-62.9	1.9	7.7	-1.0
	New Energy etc.	2,540,771	-1.0	-0.6	6.3	-9.8	4.9	-6.5
Purchased (MWh)		186,011,245	-2.1	12.6	-3.1	6.6	-2.4	-0.1
Power for Pumped-Storage Hydro (MWh)		-68.1	-21.2	3.3	-4.0	28.9	-13.0	-35.6
Flow Rate (%)		100.3	—	95.1	106.8	103.1	95.7	91.7
Nuclear Capacity Factor (%) (inc. JAPC)		2.3	—	3.9	23.7	67.3	65.7	60.0

Source: The Federation of Electric Power Companies of Japan, "Electricity Generated and Purchased in Fiscal 2011 (Bulletin)," "Electricity Generated and Purchased in Fiscal 2012 (Bulletin)," "Electricity Generated and Purchased in Fiscal 2013 (Bulletin)."

2.3 Changes in electricity price by company

Table 2-4 shows the changes in Japan's electricity price by company. Owing to the discontinuation of nuclear power after the Great East Japan Earthquake and the increase in fuel price, seven of the ten electricity companies in Japan decided to raise their electricity prices between 2012 and 2014.

Table 2-4 Changes in Japan's electricity price by company

Electric Company	Residential Use Increase Rate	Industrial Use Increase Rate	Date
Hokkaido	7.73%	11.00%	09/01/2013
Tohoku	8.94%	15.24%	09/01/2013
Tokyo	8.46%	14.90%	09/01/2012
Chubu	3.77%	7.21%	05/01/2014
Kansai	9.75%	17.26%	05/01/2013
Shikoku	7.80%	14.72%	09/01/2013
Kyusyu	6.23%	11.94%	05/01/2013

Source: Press release of each electricity company

2.4 Time-series data concerning the macroeconomy

Table 2-5 shows the time-series data concerning the changes from the previous year (real: calendar year) in the Japanese macroeconomy. After the economic downturn precipitated by the Lehman Brothers bankruptcy, the Japanese macroeconomy showed signs of recovery in 2010. In 2011, however, Japan's real GDP growth rate recorded -0.5%, and real export growth rate recorded -0.4%. The real import growth rate still continued to increase even in 2011 and recorded +5.9%, nevertheless much less than +11.1% recorded in the precedent year.

The real GDP growth rate attained +1.4% in 2012 and +1.5% in 2013, continuing almost at the same modest rate.

Table 2-5 Time-series data concerning the Japanese macroeconomy
(real: calendar year, %)

	GDP (Expenditure Approach)	Private Consumption	Private Residential Investment	Private Non-Residential Investment	Government Consumption	Public Investment	Goods & Services	
							Exports	Imports
2000	2.3	0.4	0.8	6.5	4.6	-9.4	12.6	10.7
2001	0.4	1.6	-5.0	-0.4	4.2	-3.8	-7.0	0.9
2002	0.3	1.2	-3.4	-5.2	2.6	-5.1	7.9	0.3
2003	1.7	0.5	-1.3	4.9	1.9	-8.6	9.5	3.9
2004	2.4	1.2	1.7	3.5	1.5	-7.5	14.0	7.9
2005	1.3	1.5	-0.9	5.7	0.8	-10.1	6.2	4.2
2006	1.7	1.1	0.6	4.0	0.0	-5.1	9.9	4.5
2007	2.2	0.9	-9.8	4.9	1.1	-5.9	8.7	2.3
2008	-1.0	-0.9	-6.6	-2.6	-0.1	-7.4	1.4	0.3
2009	-5.5	-0.7	-16.6	-14.3	2.3	7.0	-24.2	-15.7
2010	4.7	2.8	-4.5	0.3	1.9	0.7	24.4	11.1
2011	-0.5	0.3	5.1	4.1	1.2	-8.2	-0.4	5.9
2012	1.4	2.0	2.9	3.7	1.7	2.8	-0.1	5.3
2013	1.5	1.9	8.9	-1.6	2.2	11.4	1.6	3.4

Source: Cabinet Office: http://www.esri.cao.go.jp/jp/sna/menu.html

2.5 Changes in capital stock

The Cabinet Office (2011) estimates the damage to capital stock caused by the Great East Japan Earthquake, using the data from the case of the Great Hanshin-Awaji Earthquake as reference. This study assumes two cases: in Case 1, the extent of damage in the areas affected by tsunami is larger than that in the areas affected by the Great Hanshin-Awaji Earthquake, and the damage ratio of buildings in the former is about twice as large as that in the latter. In Case 2, the damage ratio of buildings is significantly higher and it attains 80%. As we set the exogenous values for the year 2011 as a whole, we will take Case 1, which is a more moderate case than Case 2, for the exogenous values of the simulation in this paper.

The Research Institute of Economy, Trade and Industry (RIETI) publishes the Japanese real capital stock data. Table 2-6 shows the damage to Japan's capital stock calculated by using the capital stock data in 2011 of RIETI (2013) and the damage ratio presented by the Cabinet Office (2011).

Table 2-6 Amount of damage to Japan's capital stock caused by the Great East Japan Earthquake and its ratio to the total capital stock

Total capital stock (2010, trillion yen)		1449.2
Amount of damage to Japan's total capital stock (trillion yen)	Case 1	16
	Case 2	25
Damage ratio in Japan's capital stock (percentage)	Case 1	1.10%
	Case 2	1.73%

Source: Cabinet Office (2011) "Methodology on the estimation of the amount of capital stock damage caused by the Great East Japan Earthquake," Research Institute of Economy, Trade and Industry (2013) "JIP2013."

3. Structure of substitution between capital and energy goods in the GTAP-E model

Section 3 discusses the structure of substitution between capital and energy goods in the GTAP-E model. In this model, substitution parameters concerning capital and energy composite take positive values. These values are approximately means of those taken from previous studies. In the GTAP-E model, the elasticity of substitution in energy subproduction (between electricity and non-electricity energy goods) and that in non-coal energy subproduction take the value of 1, while that in capital-energy subproduction (between capital and energy goods) and that in non-electricity energy subproduction take the value of 0.5.

However, Burniaux and Truong (2002) explain in GTAP Technical Paper No.16 that the values of the final elasticity of substitution (also known as the "outer" elasticity of substitution) between capital and energy goods can be estimated using the formula for the case of a nested CES structure derived from Keller (1980). This formula uses the given substitution elasticity (also known as the "inner" elasticity of substitution) between capital and energy, the substitution elasticity for the value-added-energy composite, the cost share of the capital-energy composite, as well as that of the value-added-energy composite, as shown in the next page.

$$\sigma_{KE-outer} = [\sigma_{KE-inner} - \sigma_{VAE}] / S_{KE} + \sigma_{VAE} / S_{VAE}$$

$\sigma_{KE-outer}$	: outer substitution elasticities between K and E
$\sigma_{KE-inner}$	: inner substitution elasticities between K and E
σ_{VAE}	: substitution elasticity for the value-added-energy composite
S_{KE}	: the cost share of the KE-composite
S_{VAE}	: the cost share of the value-added-energy composite

As we see in Table 3-1, the GTAP Technical Paper No. 16, which is based on the GTAP 4.0 database, shows that although most industries are characterized by an overall complementary relationship between energy and capital, "electricity" in the United States and "electricity," "ferrous metals," and "chemical, rubber, plastic products" in Japan are characterized by overall substitutional relationships.

Table 3-1 Relationship between inner and outer elasticities of energy-capital substitution for the cases of Japan and the US in Burniaux and Truong (2002)

Sector			Japan			USA		
	$\sigma_{KE-inner}$	σ_{VAE}	S_{VAE}	S_{KE}	$\sigma_{KE-outer}$	S_{VAE}	S_{KE}	$\sigma_{KE-outer}$
Coal	0.0	0.20	0.49	0.11	−1.50	0.67	0.16	−0.97
Crude Oil	0.0	0.20	0.64	0.24	−0.52	0.69	0.34	−0.30
Gas	0.0	0.84	0.97	0.95	−0.02	0.81	0.55	−0.49
Petroleum, coal products	0.0	1.26	0.68	0.59	−0.28	0.91	0.88	−0.04
Electricity	0.5	1.26	0.83	0.71	0.45	0.84	0.71	0.43
Ferrous metals	0.5	1.26	0.51	0.34	0.27	0.43	0.18	−1.35
Chemical, rubber, plastic products	0.5	1.26	0.42	0.26	0.05	0.50	0.30	−0.05
Other manufactuing; trade, transport	0.5	1.45	0.46	0.16	−2.65	0.51	0.18	−2.45
Agriculture, forestry and fishery	0.0	0.23	0.58	0.20	−0.77	0.46	0.26	−0.38
Commercial/public services, dwellings	0.5	1.28	0.62	0.30	−0.58	0.63	0.23	−1.41

Source: Burniaux, Jean-Marc and Truong P. Truong (2002)"GTAP-E: An Energy-Environmental Version of the GTAP Model," GTAP Technical Paper No.16, Center for Global Trade Analysis, Purdue University.

One of the reasons that "electricity," "ferrous metals," and "chemical, rubber, plastic products" in Japan are characterized as having overall substitutional relationships in the GTAP-E model could be that in Japan energy-efficient investments were promoted after the first oil shock. Previous studies have pointed out the importance of energy-efficient investments in Japan after the first oil shock. In this regard, Nemoto (1984) analyzed the ceramic and mineral products industry, which is energy intensive, the paper and pulp industry, as well as the food industry in Japan. This study concluded that although energy-capital complementarity or independence was observed in Japan before the first oil shock, strong energy-capital substitutability was noticed after the shock.

The Economic Planning Agency (1981) analyzed the energy- and oil-efficient investments in Japan's manufacturing industries and noticed that these investments were especially remarkable in energy-intensive industries, such as the raw materials industry. This study also points out that previously these investments primarily concerned the change of the operation system or improvement of the equipment, which did not need considerable change. However, gradually they became large-scale investments, which concerned the renewal or construction of the production equipment. Thus, energy-efficient investments in Japan are considered to have played an important role for the energy-capital substitutability.

Table 3-2 shows the relationship between inner and outer elasticities of energy-capital substitution for Japan calculated using the data extracted from the GTAP 8.1 database and aggregated into 28 sectors for the simulation of this paper. Compared with Table 3-1, we can see that in several industries shown in Table 3-2, not only the cost share of the capital-energy composite but also the values of substitution elasticities for the value-added-energy composite are largely different from those in Table 3-1. Additionally, in these industries the values of the "outer" elasticity of substitution between capital and energy in Table 3-2 rather differ from those in Table 3-1. Nevertheless, we can still observe an overall substitutional relationship between energy and capital in "electricity," "ferrous metals," and "chemical, rubber, plastic products" in Table 3-2.

Table 3-2 Relationship between inner and outer elasticities of energy-capital substitution for Japan based on the GTAP 8.1 database

	Sectors		Japan			
		$\sigma_{KE-inner}$	σ_{VAE}	S_{VAE}	S_{KE}	$\sigma_{KE-outer}$
1	Agriculture, forestry and fishery	0.5	0.24	0.54	0.22	1.61
2	Coal	0.0	4.00	0.49	0.09	-35.81
3	Crude Oil	0.0	0.40	0.51	0.14	-2.15
4	Gas	0.0	0.00	0.50	0.27	0.00
5	Petroleum, coal products	0.0	1.26	0.94	0.93	-0.02
6	Electricity	0.5	1.26	0.72	0.62	0.53
7	Minerals nec	0.5	0.20	0.39	0.21	1.97
8	Food processing	0.5	1.12	0.33	0.19	0.18
9	Textiles	0.5	1.26	0.26	0.05	-11.39
10	Chemical, rubber, plastic products	0.5	1.26	0.38	0.25	0.29
11	Mineral products nec	0.5	1.26	0.49	0.28	-0.15
12	Ferrous metals	0.5	1.26	0.30	0.21	0.66
13	Metals nec	0.5	1.26	0.21	0.11	-0.89
14	Metal products	0.5	1.26	0.42	0.12	-3.49
15	Motor vehicles and parts	0.5	1.26	0.16	0.04	-12.94
16	Transport equipment nec	0.5	1.26	0.28	0.09	-3.93
17	Electronic equipment	0.5	1.26	0.26	0.08	-4.72
18	Machinery and equipment nec	0.5	1.26	0.33	0.11	-3.30
19	Manufactures nec	0.5	1.26	0.40	0.17	-1.31
20	Construction	0.5	1.40	0.44	0.08	-8.79
21	Trade	0.5	1.68	0.63	0.24	-2.18
22	Transport nec	0.5	1.68	0.62	0.30	-1.18
23	Water transport	0.5	1.68	0.48	0.27	-0.82
24	Air transport	0.5	1.68	0.37	0.23	-0.61
25	Communication	0.5	1.26	0.55	0.33	0.00
26	financial services and insurance	0.5	1.26	0.61	0.33	-0.23
27	Other services	0.5	1.26	0.61	0.41	0.23
28	Public services	0.5	1.26	0.70	0.21	-1.82

Source: the author.

4. Methodology for analyzing the economic impacts of electric supply shortage in Japan caused by earthquakes

4.1. Overview of previous studies

Previous studies attempted to evaluate the impacts of earthquakes in Japan using the CGE model. Hagiwara (2001) evaluated the impacts of the Great Hanshin-Awaji Earthquake that occurred in 1995 using the Kobe CGE model (2 regions and 22 sectors). The study estimated the damage to capital stock in Kobe City and analyzed the impact of change in capital stock and the final demand on production in Kobe city from 1995 to 1997. It concluded that the damage caused by the supply side, that is the reduction of the capital stock, is particularly serious in electricity, gas, and water sector. The result of this study also shows that the machinery equipment sector, transport equipment sector, and electricity, gas, and water sector did not benefit from the increase in final demand.

With regard to industrial resiliency, Tadano et al. (2007) analyzed the impact of catastrophic disaster damages to lifeline facilities such as electric power, water, and gas services on community life and business activity in the case of the Niigata-Chuetsu Earthquake that occurred in 2004, referring to other similar studies, mainly Rose and Liao (2005). This study sets labor, capital, and utilities (electricity, water, and gas) as factor endowments and considers the effect of rather short terms for lifeline disruption—3 days for electricity, 12 days for water, and 30 days for gas.

As for the studies that analyze the impacts of the reduced use of electric power in Japan using the CGE model, we can refer to the following three studies: Ishikura and Ishikawa (2011); Yamazaki and Ochiai (2011); and Tachi and Ochiai (2011). All of these studies analyzed the case of the Great East Japan Earthquake.

Ishikura and Ishikawa (2011) analyzed the impact of the reduced use of electric power for the whole of Japan and for the Tokyo metropolitan area, by using the spatial CGE (SCGE) model. They investigated the effect of a shock to the productivity of the electricity sector in the Tokyo metropolitan area, resulting from the reduced electric supply capacity caused by the Great East Japan Earthquake.

Yamazaki and Ochiai (2011) analyzed the impact of restricted electric supply in the Kanto area on the whole of Japan and on eight Japanese regions, following the Great East Japan Earthquake. They used the Japanese multi-regional CGE model developed by the Japan Center for Economic Research. For setting the exogenous values of the simulation, they reduced the quantity of endowment commodities (capital and labor) and demand for electricity of households in the Kanto area.

Tachi and Ochiai (2011) also used the Japanese multi-regional CGE model developed by the Japan Center for Economic Research, but modified the production function of the electricity sector in order to give exogenous conditions to nuclear, hydroelectric, and thermal power to analyze the case in which the nuclear electric power is completely discontinued in Japan.

4.2. Methodology for analyzing the economic impacts of electric supply shortage caused by earthquakes using the GTAP-E model

Referring to the previous studies, this paper sets exogenous values for two variables; capital stock in Japan, qo (“capital,” “JPN”) and the productivity in Japan’s electricity sector, aoall (“electricity,” “JPN”) . Exogenous values are taken from the data as observed in Section 2.

As capital stock is exogenous in the basic closure of the GTAP-E model, we can directly determine the exogenous value of the change in Japan’s capital stock in 2011, which is -1.1%. The productivity in the electricity sector is also exogenous in the basic closure of the GTAP-E model, but the information on change in productivity in the electricity sector is not available. In this paper, we will attempt to determine the exogenous value of the change in productivity in the Japanese electricity sector in 2011 by using the change in Japanese electricity sales in 2011, which is -4.57%.

Two simulations are necessary to analyze the impact of the Great East Japan Earthquake, using the exogenous value of the productivity of Japan’s electricity sector and that of the Japanese capital stock in 2011. In the first simulation, the basic closure will be changed by setting aoall (“Electricity,” “JPN”) as endogenous and qo (“Electricity,” “JPN”) as exogenous. By setting the reduction rate of Japan’s electricity sales in 2011 taken from the survey in Section 2 as qo (“Electricity,” “JPN”) and that of capital stock in 2011 as qo (“capital,” “JPN”), we can obtain the rate at which productivity in the Japanese electricity sector decreased in 2011.

In the second simulation which uses the basic closure, by setting the reduction rate of productivity in the Japanese electricity sector in 2011 (taken from the first simulation) as aoall (“Electricity,” “JPN”) and that of capital stock in 2011 (used in the first simulation as the exogenous value) as qo (“capital,” “JPN”), we can estimate the impacts of decreased productivity in the Japanese electricity sector and damage to capital stock, both on account of the Great East Japan Earthquake in 2011. Thus, we simulate the impact of the two ways through which earthquakes affect the economy.

As for the investment allocation in the simulation, it is well known that two options concerning investment allocation are possible in the GTAP and the GTAP-E models. When RORDELTA (binary coefficient to switch mechanism of allocating investment funds) = 1, investment funds are allocated across regions to equate the changes in the expected rates of return. When RORDELTA = 0, investment funds are allocated across regions to maintain the existing composition of capital stocks. This paper uses the exogenous values that are taken from the Japanese data for the year 2011 as a whole. Considering that the analysis period of this paper would be rather medium- or long-term and not short-term, it adopts the option that investment funds are allocated across regions to equate the changes in the expected rates of return (RORDELTA = 1)[3].

4.3. Aggregation of regions and sectors

The revised GTAP-E model was developed using the aggregation of nine regions and eight sectors. This paper attempts to analyze the impacts of the Great East Japan Earthquake, a natural disaster that occurred in Japan only, and had relatively little impact on other regions. Therefore, the regional aggregation in this paper remains at the rather small size of 12 regions, after adding some new Asian regions to the original aggregation; Korea, ASEAN Net Energy Exporters, and Other ASEAN Countries (Table 4-1).

Concerning the sectoral aggregation, as this paper aims to analyze the impact of both the change in productivity of the electricity sector and the damage to capital stock in Japan taking into consideration the effect of the substitution between capital and energy goods, the manufacturing sectors become important. Thus, this paper attempts a rather large sectoral aggregation of 28 sectors[4] (Table 4-2).

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[3] Higashi-Shiraishi (2014) adopts the option in which investment funds are allocated across regions to maintain the existing composition of capital stocks (RORDELTA = 0) in the simulation in which the electric supply in Japan is reduced by 1%. In the case of Japan, when RORDELTA = 1, capital and investment decreases and increases respectively, and as a result, the impacts of reduced electric power usage become less serious. When RORDELTA = 0, both the capital and investment decrease, and as a result, the impacts of reduced electric power usage become more serious.

[4] Regional and sectoral aggregation used in this paper is the same as those in Higashi-Shiraishi (2014).

Table 4-1 Regional disaggregation

No.	Code	Region Description	Comprising GTAP 8.1 Countries/Regions
1	JPN	Japan	Japan
2	KOR	Korea	Korea
3	CHN	China	China
4	AEEx	ASEAN Net Energy Exporters	Indonesia, Malaysia, Vietnam
5	OASN	Other ASEAN Countries	Cambodia, Lao People's Democratic Republic, Philippines, Singapore, Thailand, rest of Southeast Asia
6	IND	India	India
7	USA	United States	United States of America
8	EU27	EU27	Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom, Bulgaria, Romania
9	OEEx	Other Net Energy Exporters	Mexico, Argentina, Bolivia, Colombia, Ecuador, Venezuela, Islamic Republic of Iran, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Egypt, rest of North Africa, Nigeria, Central Africa
10	EEFSU	Eastern Europe and FSU	Albania, Belarus, Croatia, Russian Federation, Ukraine, rest of Eastern Europe, rest of Europe, Kazakhstan, Kyrgyzstan, rest of the FSU, Armenia, Azerbaijan, Georgia
11	RoA1	Other Annex 1 Countries	Australia, New Zealand, Canada, Switzerland, Norway, rest of the EFTA countries
12	ROW	Rest of the World	Rest of Oceania, Hong Kong, Mongolia, Taiwan, rest of East Asia, Bangladesh, Nepal, Pakistan, Sri Lanka, rest of South Asia, rest of North America, Brazil, Chile, Paraguay, Peru, Uruguay, rest of South America, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, rest of Central America, Caribbean, Bahrain, Israel, Turkey, rest of Western Asia, Morocco, Tunisia, Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Nigeria, Togo, Senegal, rest of Western Africa, South Central Africa, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Tanzania, Uganda, Zambia, Zimbabwe, rest of Eastern Africa, Botswana, Namibia, South Africa, rest of South African Customs, rest of the World

Source: the author.

Table 4-2 Sectoral disaggregation

No.	Code	Sector Description	Comprising GTAP 8.1 Sectors
1	AGR	Agriculture	Paddy rice, wheat, cereal grains nec, vegetables, fruit, nuts, oil seeds, sugarcane, sugar beet, plant-based fibers, crops nec, bovine cattle, sheep and goats, horses, animal products nec, raw milk, wool, silk-worm cocoons, forestry, fishing
2	Coal	Coal	Coal
3	Oil	Oil	Oil
4	Gas	Natural gas extraction	Gas, gas manufacture, distribution
5	Oil_Pcts	Petroleum, coal products	Petroleum, coal products
6	Electricity	Electricity	Electricity
7	OMN	Minerals nec	Minerals nec
8	PFD	Food processing	Bovine cattle, sheep and goat meat products, meat products, vegetable oils and fats, dairy products, processed rice, sugar, food products nec, beverages and tobacco products
9	TXL	Textiles	Textiles, wearing apparel
10	CRP	Chemical, rubber, plastic products	Chemical, rubber, plastic products
11	NMM	Mineral products nec	Mineral products nec
12	I_S	Ferrous metals	Ferrous metals
13	NFM	Metals nec	Metals nec
14	FMP	Metal products	Metal products
15	MVH	Motor vehicles and parts	Motor vehicles and parts
16	OTN	Transport equipment nec	Transport equipment nec
17	ELE	Electronic equipment	Electronic equipment
18	OME	Machinery and equipment nec	Machinery and equipment nec
19	OMF	Manufactures nec	Leather products, wood products, paper products, publishing, manufactures nec
20	CNS	Construction	Construction
21	TRD	Trade	Trade
22	OTP	Transport nec	Transport nec
23	WTP	Water transport	Water transport
24	ATP	Air transport	Air transport
25	CMN	Communication	Communication
26	OFR	Financial services	Financial services nec, insurance
27	OSP	Other services	Water, business services nec, recreational and other services, ownership of dwellings
28	OSG	Public services	Public administration, defense, education, health

Source: the author.

5. Economic impacts of electric supply shortage in Japan caused by earthquakes

5.1. Macroeconomic changes

We estimate the impact of earthquakes in Japan through two channels: the decrease in productivity in the electricity sector and the damage to capital stock, both on account of the Great East Japan Earthquake that occurred in 2011. To analyze the impact of earthquakes on the economy, it would be useful to examine the total effects of both the channels and the individual effect of each channel. For this reason, we set three cases: in Case1, both the decrease in productivity in the electricity sector and the damage to capital stock occur; in Case 2, only the decrease in productivity in the electricity sector occurs; and in Case 3, only the damage to capital stock occurs.

Table 5-1 shows the simulation results of macroeconomic changes caused by the decrease in productivity in the electricity sector and the damage to capital stock in Japan in 2011. The simulation result with respect to the percentage change in Japan's real GDP (-0.65%) is not overly different from that observed in the actual 2011 data (-0.50%). Furthermore, the simulation result regarding the change in real imports is -0.19%, whereas in the actual data, this change was recorded as +11.1% in 2010, +5.9% in 2011, +5.3% in 2012, and +3.4% in 2013; these numbers indicate that the growth rate of Japan's real imports continues to fall. Considering this tendency, it could be said that the simulation result of the GTAP-E model follows the tendency of Japanese imports in the post-2011 years.

As for the change in real exports, the simulation result of the GTAP-E model is -1.26%, whereas in the actual data, this change was recorded as +22.4% in 2010, -0.4% in 2011, -0.1% in 2012, and +1.6% in 2013. Regarding the real exports data as well, it could be said that the simulation results derived from the GTAP-E model align relatively well with the tendency of Japan's real exports during the post-2011 years.

As we can see in Table 5-2, Cases 2 and 3 show rather different tendencies. The growth rate of Japan's real GDP attains -0.19% in Case 2 and -0.47% in Case 3, which shows that the effect of the damage to capital stock is estimated stronger than that of decreased productivity in the electricity sector.

In Case 2, we notice that the decrease in real imports (-0.32%) is larger than in Case 1, and that real exports increase by 0.84% while this figure decreases in Case 1. In Case 2, the productivity in the electricity sector decreases, but the capital stock is not damaged. Thus, it could be considered that as the capital used in the electricity sector before the shock would be demanded in other sectors, in some sectors the production increases. In the whole of Japan, however, the decrease of productivity in the electricity sector causes a decrease in the overall industrial production and private consumption, and therefore imports would decrease. In this scenario, the increased production in some sectors would be exported, and therefore exports would increase.

In Case 3, in which only the damage to capital stock occurs, real imports show a tendency to increase (+0.13%) and the rate of decrease of real exports (-2.08%) becomes larger than that in Case 1. When the capital stock is damaged, the overall production would decrease and the demand for imports tends to increase while that for exports tends to decrease.

Thus, the two channels of the impact of earthquakes on the Japanese economy, namely, the decrease in productivity in the electricity sector and the damage to capital stock, show rather different tendencies and the total impact is decided through these two channels.

Table 5-1 Macroeconomic changes caused by the decrease in productivity in the electricity sector and the damage to capital stock (Case 1) in Japan in 2011

	Change in Real GDP		Change in Real Imports		Change in Real Exports		Change in Equivalent Variation
	percentage	millions USD	percentage	millions USD	percentage	millions USD	millions USD
JPN	-0.65	-28,636	-0.19	-1,313	-1.26	-9,966	-20,058
KOR	0.00	-34	-0.05	-208	0.01	61	-124
CHN	0.00	-120	-0.06	-605	0.00	-54	-331
AEEx	0.00	-27	-0.02	-59	0.03	96	-104
OASN	0.00	-19	-0.02	-85	0.02	91	-103
IND	0.00	-9	-0.02	-60	0.04	87	-26
USA	0.00	-31	-0.05	-1,078	0.07	1,031	-397
EU27	0.00	50	-0.01	-441	0.04	2,465	-178
OEEx	0.00	-40	-0.03	-272	0.03	397	-247
EEFSU	0.00	-11	-0.01	-71	0.02	133	-59
RoA1	0.00	-51	-0.01	-105	0.04	451	-146
ROW	0.00	-23	-0.03	-376	0.04	549	-234

Source: the author.

Table 5-2 Macroeconomic changes caused by the decrease in productivity in the electricity sector (Case 2) and the damage to capital stock (Case 3) in Japan in 2011

	Change in Real GDP (%)		Change in Real Imports (%)		Change in Real Exports (%)		Change in Equivalent Variation (millions USD)	
	Case2	Case3	Case2	Case3	Case2	Case3	Case2	Case3
JPN	-0.19	-0.47	-0.32	0.13	0.84	-2.08	-9,325	-10,804
KOR	0.00	0.00	0.01	-0.07	-0.02	0.03	6	-130
CHN	0.00	-0.01	0.02	-0.08	-0.02	0.02	151	-485
AEEx	0.00	-0.01	0.00	-0.02	-0.04	0.06	46	-150
OASN	0.00	0.00	0.00	-0.02	-0.02	0.04	14	-118
IND	0.00	0.00	0.02	-0.04	-0.04	0.08	32	-58
USA	0.00	0.00	0.04	-0.09	-0.09	0.16	297	-690
EU27	0.00	0.00	0.01	-0.02	-0.05	0.09	147	-327
OEEx	0.00	0.00	0.03	-0.06	-0.04	0.07	278	-525
EEFSU	0.00	0.00	0.02	-0.04	-0.02	0.04	105	-164
RoA1	0.00	0.00	0.01	-0.02	-0.05	0.09	149	-295
ROW	0.00	0.00	0.02	-0.05	-0.04	0.08	165	-398

Source: the author.

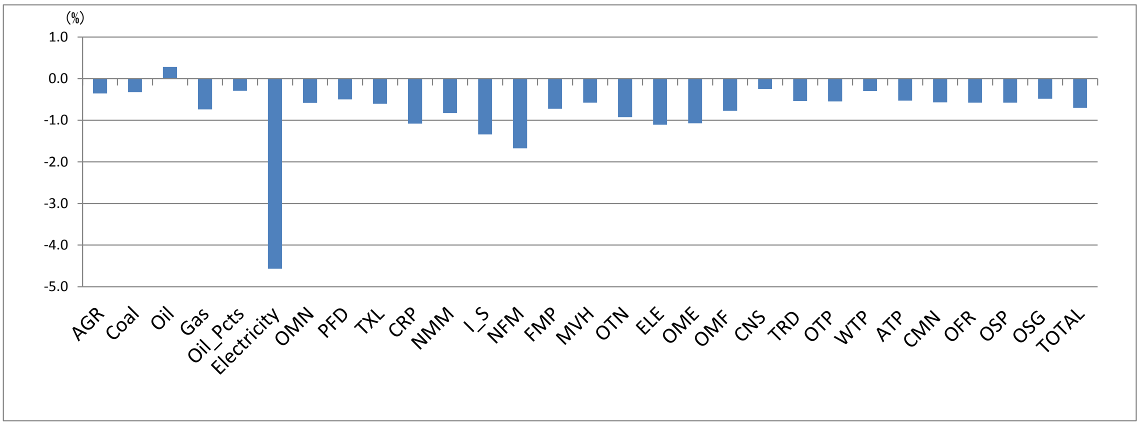
5.2. Changes in industrial output

As the changes in real GDP for other regions are quite small, the industry-level analysis concentrates on the simulation results of Japan. In all sectors besides the oil sector, the industrial output decreases and percentage changes in the manufacturing sectors are higher than those in the service sectors. Apart from the electricity sector, the reduction rate is large in NFM (metals nec), I_S (ferrous metals) and CRP (chemical, rubber, plastic products).

Figures 5-1 and 5-2 show the impacts on Japan's industrial output owing to the decrease in productivity in the electricity sector and damage to capital stock (Case 1) in Japan in 2011 in percentages and in millions USD, respectively.

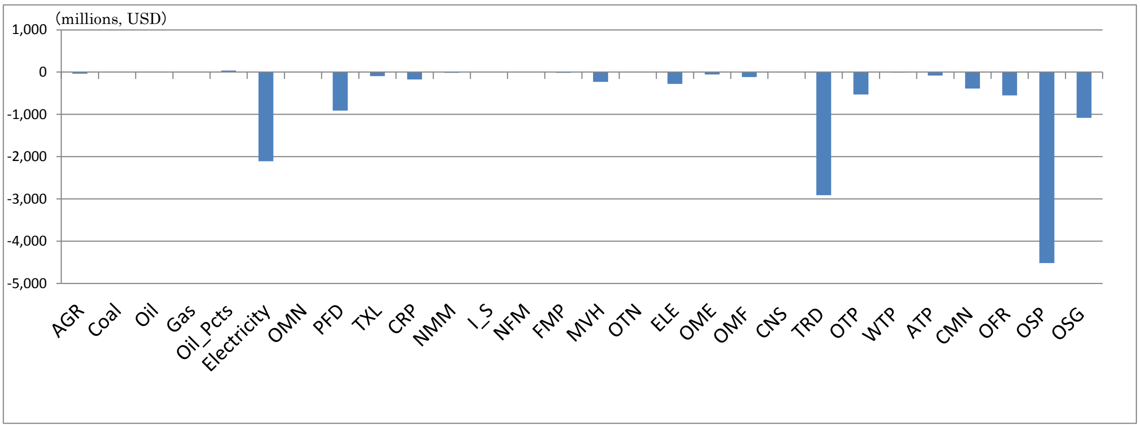
Although the percentage changes in the service sectors are lesser than those in the manufacturing sectors, the changes evaluated in terms of millions of USD are greater for the service sectors than for the manufacturing sectors. The change in OSP (other services) attains USD 10.2 billion, that in TRD (trade) attains USD 5.8 billion, and that in OSG (public services) attains USD 5.7 billion. With respect to the energy and manufacturing sectors, the change in the oil sector remains USD 1.15 million, while that in OME (machinery and equipment nec) attains USD 4.5 billion, that in CRP (chemical, rubber, plastic products) attains USD 4.3 billion, that in ELE (electronic equipment) attains USD 3.7 billion, and that in I_S (ferrous metals) attains USD 3.4 billion.

Figure 5-1 Impacts on Japan's industrial output caused by the decrease in productivity in the electricity sector and damage to capital stock (Case 1) in 2011 (percentage)



Source: the author.

Figure 5-2 Impacts on Japan's industrial output caused by the decrease in productivity in the electricity sector and damage to capital stock (Case 1) in 2011 (millions, USD)



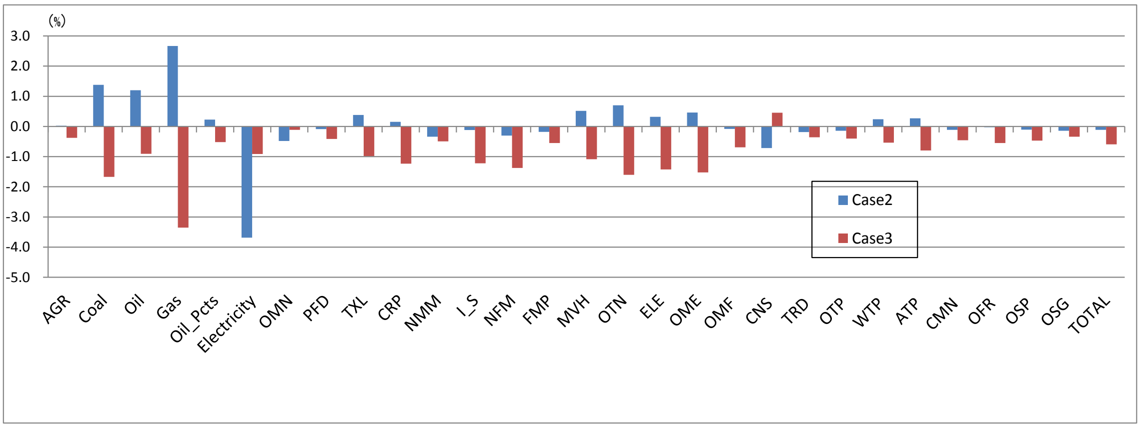
Source: the author.

Figure 5-3 shows the impacts on Japan's industrial output owing to the decrease in productivity in the electricity sector (Case 2) and the damage to capital stock (Case 3) in 2011 (percentage).

In Case 2, we find both the sectors in which production decreases and those in which production increases. In this case, the productivity in the electricity sector decreases but the capital stock is not damaged, and in some sectors, the production increases using the capital demanded before in the electricity sector. Reflecting this tendency, the result suggests that in energy sectors, apart from the electricity sector, the production increases. The production decreases mainly in sectors such as OMN (minerals nec), NMM (mineral products nec), I_S (ferrous metals), and NFM (metals nec); these sectors are classified as energy-intensive industries in Burniaux and Truong (2002). The production decreases, too, in other manufacturing sectors, such as PFD (food processing), FMP (metal products), and OMF (manufactures nec), as well as in other service sectors, such as CNS (construction), TRD (trade), OTP (transport nec), CMN (communication), OFR (Financial services), OSP (other services), and OSG (public services).

In Case 3, in all industries except construction, the production decreases, mainly in energy sectors such as Coal (coal) and GAS (gas), in energy-intensive sectors such as CRP (chemical, rubber, plastic products), I_S (ferrous metals), and NFM (metals nec), as well as in other manufacturing sectors such as MVH (motor vehicles and parts), OTN (transport equipment nec), ELE (electronic equipment), and OME (machinery and equipment nec).

Figure 5-3 Impacts on Japan's industrial output caused by the decrease in productivity in the electricity sector (Case 2) and the damage to capital stock (Case 3) in Japan in 2011 (percentage)



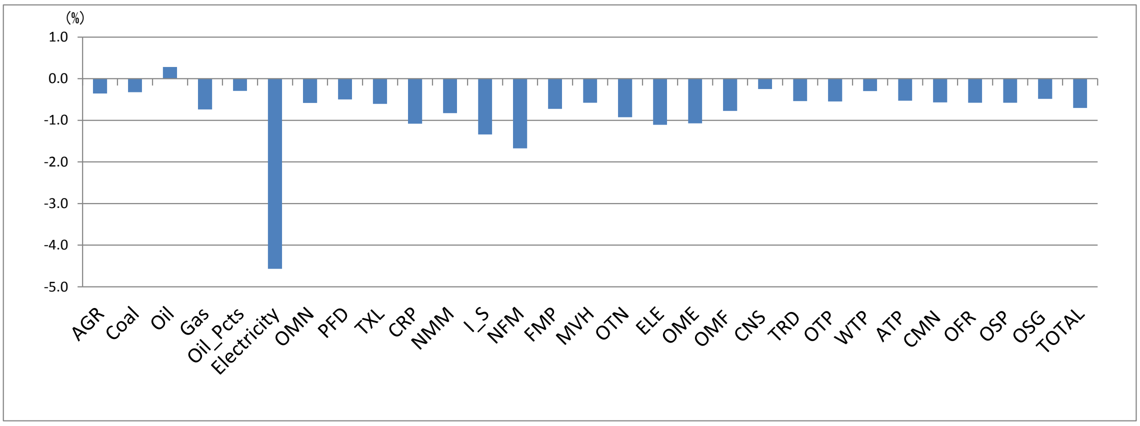
Source: the author.

5.3. Changes in private consumption

According to the simulation result of Case 1, which is shown in Figure 5-4, the change in the consumption of electricity is much larger than that in other commodities; it decreases by 5.0%. Apart from energy commodities other than electricity, private consumption in Japan decreases in all sectors by -0.1%～-0.8%. Concerning energy commodities other than electricity, private consumption increases by +0.1%～+0.2%. Apart from the electricity sector, the reduction rate is large in NFM (metals nec), I_S (ferrous metals), and CRP (chemical, rubber, plastic products).

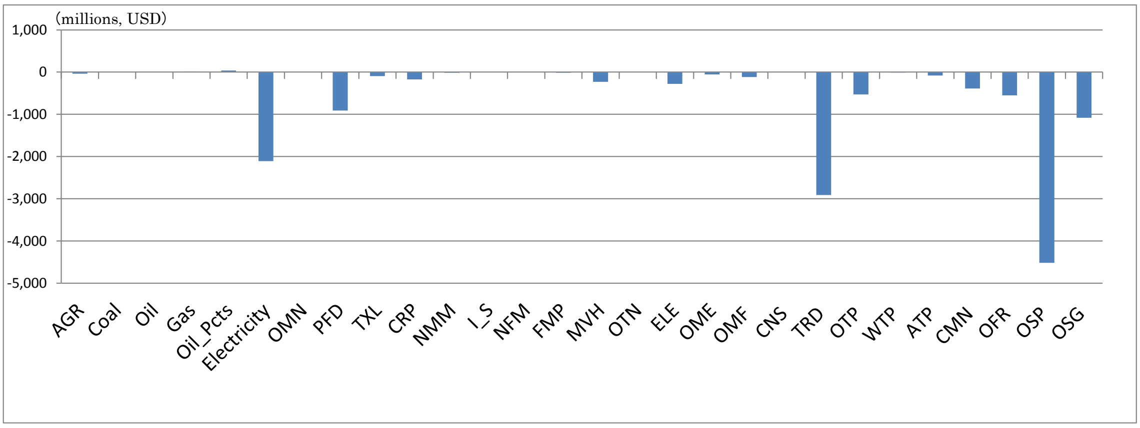
When we observe the simulation results of changes in private consumption evaluated in terms of USD millions as shown in Figure 5-5, the impact is much larger for service commodities than for manufacturing ones. The decrease in OSP (other services) attains USD 4.5 billion and that in TRD (trade) attains USD 2.9 billion, while that in electricity remains USD 2.1 billion. In manufacturing sectors, the largest decrease is observed in PFD (food processing) which attains 900 million. The increase in energy goods remains modest; increase in coal and oil goods is almost nil, and the sum of the increase in both gas and petroleum and coal products attains USD 39 million.

Figure 5-4 Impacts on Japan's private consumption owing to the decrease in productivity in the electricity sector and damage to capital stock (Case 1) in Japan in 2011 (percentage)



Source: the author.

Figure 5-5 Impacts on Japan's private consumption owing to the decrease in productivity in the electricity sector and damage to capital stock (Case 1) in Japan in 2011 (millions, USD)

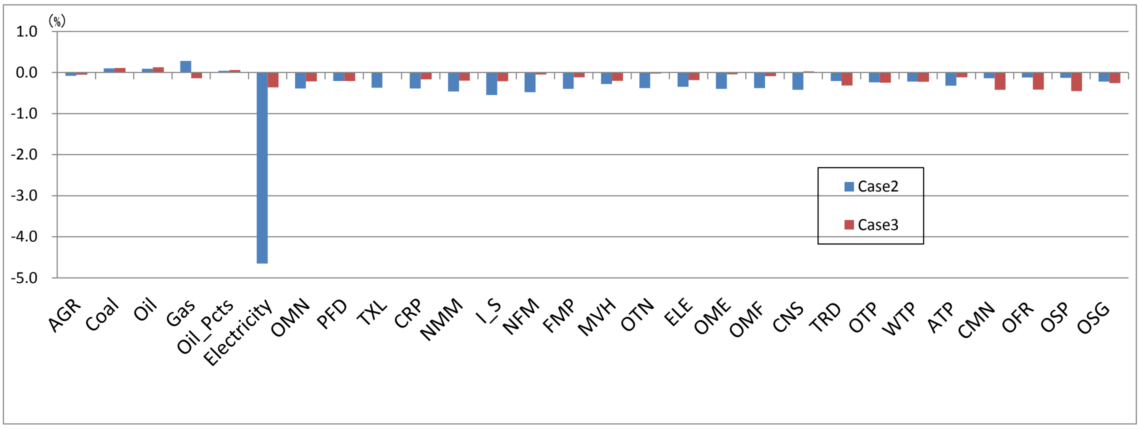


Source: the author.

Figure 5-6 shows the simulation results of changes in private consumption of both Case 2 and Case 3. In Case 2, the consumption of electricity decreases by 4.7%, which shows that the change of the consumption of electricity in Case 1 is mainly attained by the change in productivity in the electricity sector. The magnitude of change in other goods except energy goods is much smaller than that in electricity; it ranges from -0.1% to -0.6%. As in Case 1, in energy commodities except electricity, private consumption does not decrease in Case 2; private consumption of coal and oil increases by 0.1%, that of gas increases by 0.3 %, and that of petroleum and coal products increases almost by 0 %.

In the simulation results of private consumption as well, the tendency of Case 3, in which no exogenous value is assigned to the electricity sector, is rather different from that of Case 2. In most of the sectors private consumption decreases, and the reduction rate of consumption of electricity is -0.4%, at the same rate as for other goods. Concerning energy goods other than electricity, while the amount of consumption of coal, oil, and petroleum and coal products increases, that of gas, however, decreases.

Figure 5-6 Impacts on Japan's private consumption owing to the decrease in productivity in the electricity sector (Case 2) and the damage to capital stock (Case 3) in Japan in 2011 (percentage)

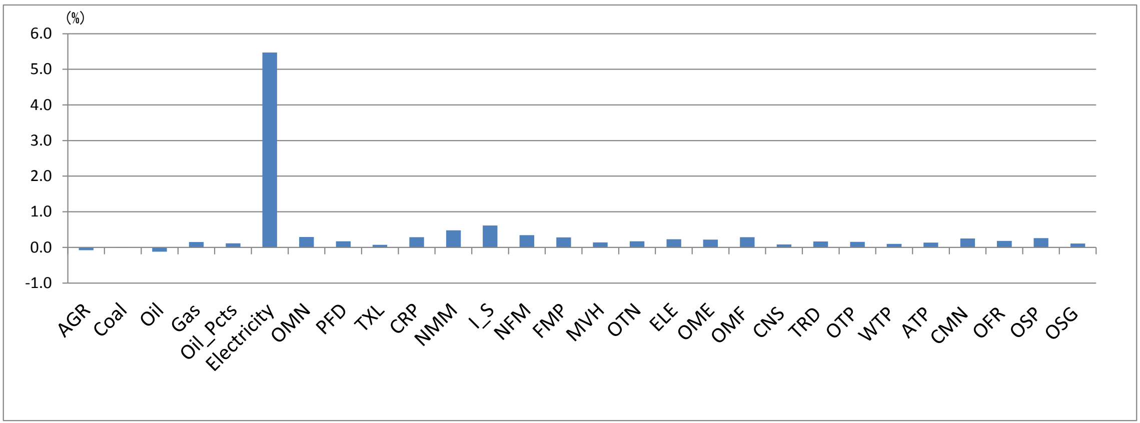


Source: the author.

5.4. Changes in supply price

Figure 5-7 shows the simulation results concerning changes in Japan's supply price (Case 1). According to the simulation results, apart from agriculture and oil, in which supply price decreases slightly by -0.1%, the supply price increases in all sectors. The increase rate of supply price in the electricity sector, in which the productivity decreases, is especially high; the supply price in the electricity sector increases by 5.5%. In other sectors, the increase ranges from +0.1% to +0.6%, showing modest increase compared with that in the electricity sector.

Figure 5-7 Impacts on Japan's supply price owing to the decrease in productivity in the electricity sector and damage to capital stock (Case 1) in Japan in 2011 (percentage)

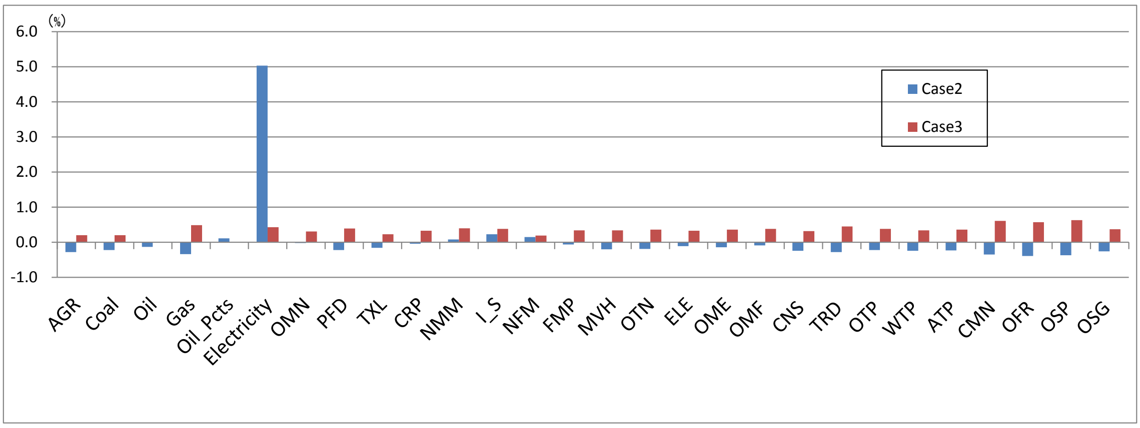


Source: the author.

Figure 5-8 shows the simulation results concerning the changes in Japan's supply price for Cases 2 and 3. In Case 2, the supply price of electricity shows a high increase rate as observed in Case 1; it attains 5.0% and would cause a serious decrease in the consumption of electricity, as shown in Figure 5-6. In other sectors, changes in supply price range from -0.4% to +0.2%. In this case, the capital stock is not damaged. Capital stock formerly used in electricity sector becomes surplus and is used in other sectors; therefore, the price of capital stock decreases. Reflecting this tendency, the supply price decreases in many sectors in Case 2. The supply price increases mainly in energy-intensive sectors in which industrial output decreases in Case 2, such as mineral products nec, ferrous metals, and metals nec.

The simulation results of Case 3 seem rather different from those of Case 2. The increase rate of supply price of electricity remains at +0.4%, and changes of supply price in other sectors range from 0.0% to +0.6%. Case 3 does not reflect the decrease in productivity in the electricity sector, and it could be concluded that the increase in supply price of electricity shown in Case 1 is mainly caused by the decrease in productivity in the electricity sector.

Figure 5-8 Impacts on Japan's supply price owing to the decrease in productivity in the electricity sector (Case 2) and the damage to capital stock (Case 3) in Japan in 2011 (percentage)



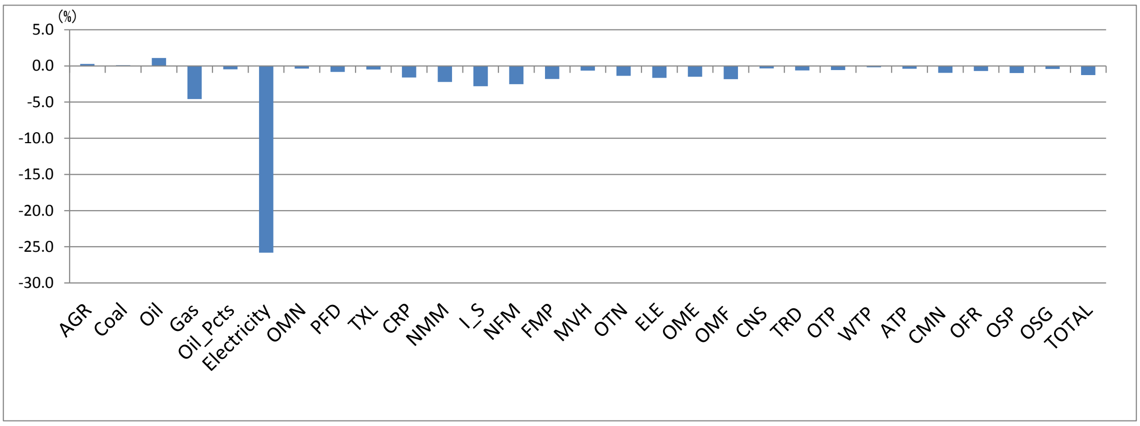
Source: the author.

5.5. Changes in exports

Figure 5-9 shows the simulation results of Case 1 concerning changes in Japanese exports, evaluated in percentage. As we have already seen, industrial output in all sectors decreases in Case 1 because of the impact of an earthquake, and supply price increases, thus increasing the export price, which causes a decrease in exports. Exports decrease mainly in manufacturing sectors, and large reduction rates are observed in energy-intensive sectors such as mineral products nec (-2.2%), ferrous metals (-2.8%), and metals nec (-2.8%).

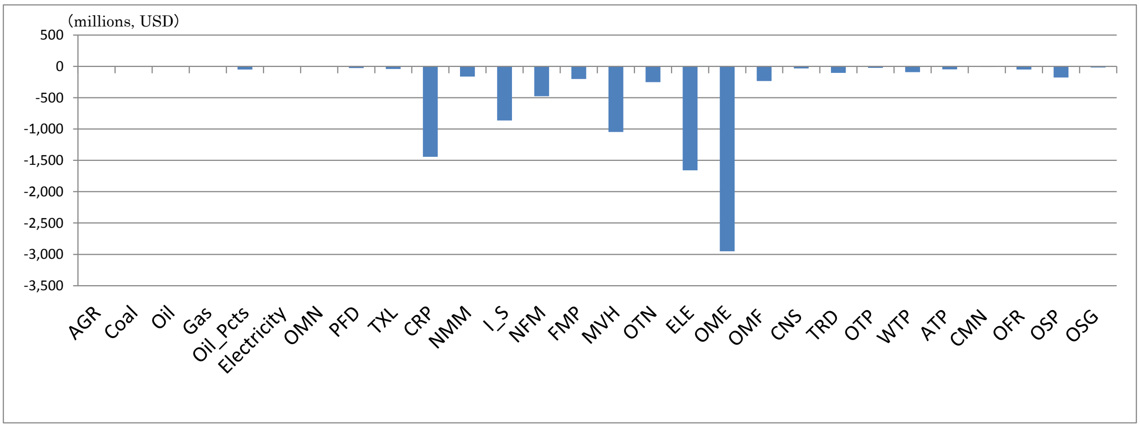
Figure 5-10 shows the simulation results of Case 1 concerning changes in Japanese exports, evaluated in USD million. Although percentage changes in agriculture, oil, and coal increase, changes evaluated in terms of USD millions equal almost zero in oil and coal and remains 3 million USD in agriculture. Exports decrease largely in machinery and equipment nec (approximately 3 billion USD), electronic equipment (approximately 1.7 billion USD), chemical, rubber, plastic products (approximately 1.4 billion USD), and motor vehicles and parts (approximately 1 billion USD).

Figure 5-9 Impacts on Japan's exports owing to the decrease in productivity in the electricity sector and damage to capital stock (Case 1) in Japan in 2011 (percentage)



Source: the author.

Figure 5-10 Impacts on Japan's exports owing to the change in productivity in the electricity sector and the damage to capital stock (Case 1) in Japan in 2011 (millions, USD)

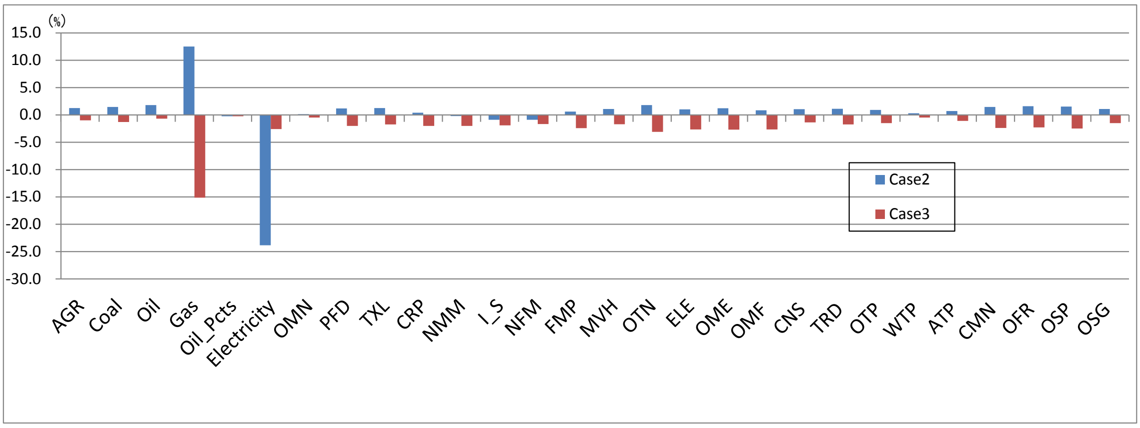


Source: the author.

Figure 5-11 shows the simulation results of changes in exports for both Case 2 and Case 3. In Case 2, the supply price decreases in many sectors, and thus export price decreases in many sectors simultaneously. As a result of this tendency in export price, exports increase slightly in many sectors, apart from petroleum and coal products, electricity, and energy-intensive sectors such as mineral products nec, ferrous metals, and metals nec. Evaluated in terms of USD million, while exports of petroleum and coal products, mineral products nec, ferrous metals, and metals nec decrease, those of other goods increase, and thus the total amount of exports increases slightly.

In Case 3, the supply price increases in all sectors, and thus the export price increases in all sectors, which causes a decrease in exports. The simulation results concerning Japanese exports in Case 3 show rather different tendency than those of Case 2. Evaluated in percentage change, the results of Case 3 show that the changes are relatively large in gas (-15.1%), transport equipment nec (-3.1%), electronic equipment (-2.6%), machinery and equipment nec (-2.6%), and manufactures nec (-2.7%). When the simulation results of Case 3 are evaluated in USD million, a significant decrease of exports is observed in machinery and equipment nec (5.3 billion USD), motor vehicles and parts (2.7 billion USD), electronic equipment (2.6 billion USD), and chemical, rubber, plastic products (1.8 billion USD).

Figure 5-11 Impacts on Japan's exports owing to the decrease in productivity in the electricity sector (Case 2) and the damage to capital stock (Case 3) in Japan in 2011 (percentage)



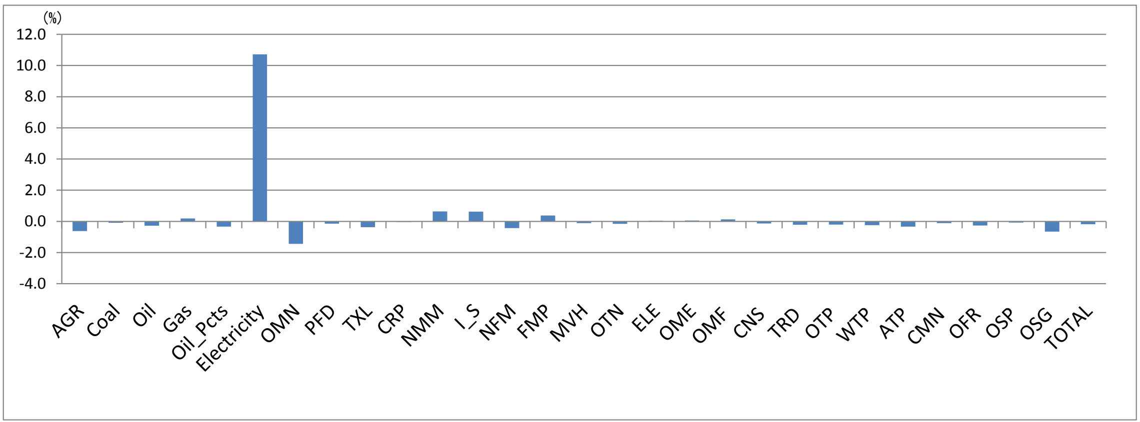
Source: the author.

5.6. Changes in imports

Figure 5-12 shows the simulation results of Case 1 concerning changes in Japan's imports, evaluated in percentage. Because of the effect of an earthquake, industrial output and private consumption of many goods decrease in Japan, as we have already seen in the previous parts. On the other hand, imports increase slightly in energy goods such as gas, energy-intensive goods such as mineral products nec and ferrous metals, and manufacturing goods such as metal products, electronic equipment, machinery and equipment nec, and manufactures nec. For other goods, imports decrease moderately.

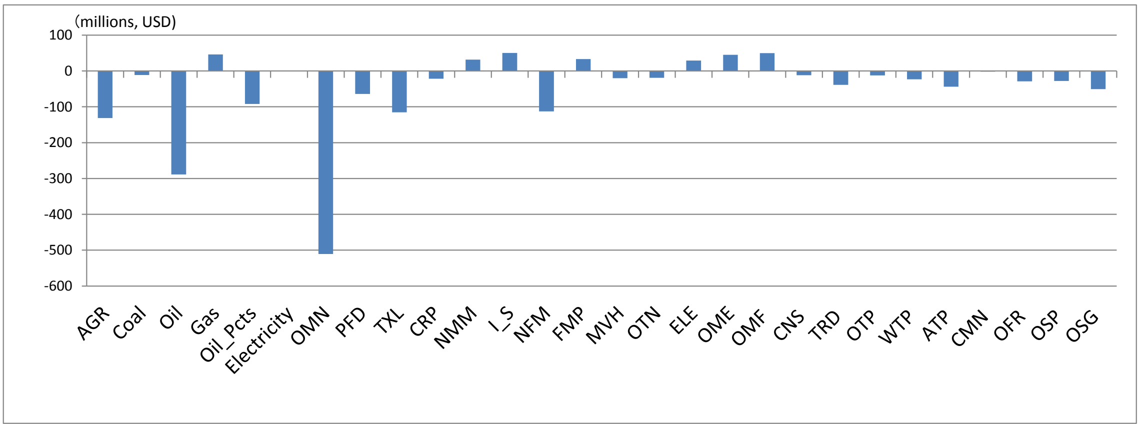
Figure 5-13 shows the simulation results of Case 1 concerning changes in Japanese imports, evaluated in millions USD. The decrease in imports overweighs the increase in imports, and Japan's total imports decrease by -0.19%. Simulation results from the GTAP-E model are based on real values, and it is difficult to compare them with Japan's imports data by commodity; most of the commodities are based on nominal values. Further data analysis is required for the comparison of the simulation results and Japanese imports data by commodity.

Figure 5-12 Impacts on Japan's imports owing to the decrease in productivity in the electricity sector and damage to capital stock (Case 1) in Japan in 2011 (percentage)



Source: the author.

Figure 5-13 Impacts on Japan's imports owing to the change in productivity in the electricity sector and the damage to capital stock (Case 1) in Japan in 2011 (millions USD)

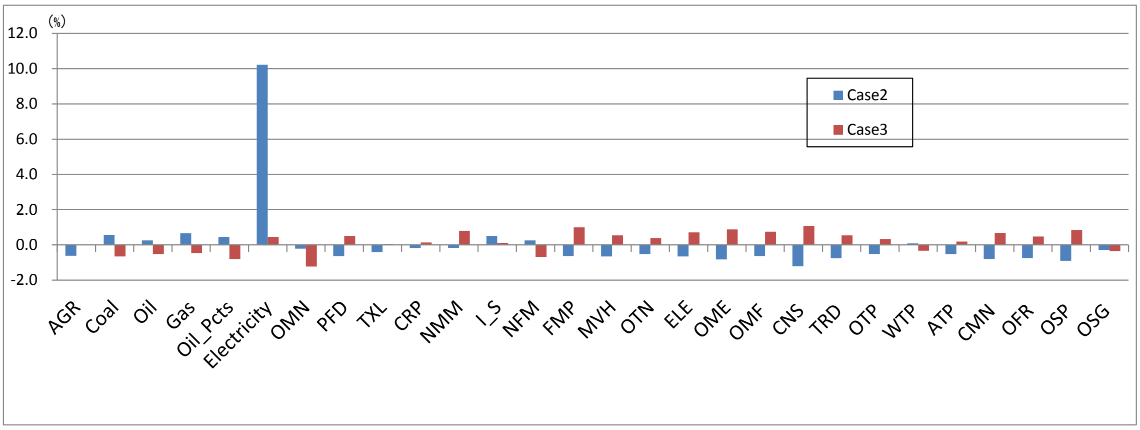


Source: the author.

Figure 5-14 shows the simulation results of changes in imports for both Case 2 and Case 3. In Case 2, which does not take into account the damage to capital stock, the decrease in industrial output is not as serious as in Case 1 and Case 3. As industrial output increases in several sectors, the dependence on imported goods reduces. On the other hand, imports of energy-intensive goods whose industrial output decreases in Case 2 tend to increase, and the total imports decrease by -0.32%.

In Case 3, industrial output decreases in all sectors, and thus total imports increase slightly, as many sectors tend to depend on imported goods. Another feature of Case 3, in which industrial output decreases in all sectors, is that the imports of energy goods do not increase but the total imports increase, showing the opposite trend of Case 2.

Figure 5-14 Impacts on Japan's imports owing to the decrease in productivity in the electricity sector (Case 2) and the damage to capital stock (Case 3) in Japan in 2011 (percentage)



Source: the author.

5.7. Effects of energy substitution by sectors

In order to evaluate the effects of energy substitution in the GTAP-E model, we set the same exogenous values to both the GTAP and GTAP-E models, and compare the results of these two models. Exogenous values are assigned in each sector regarding the reduction in productivity in each sector caused by the decrease of industrial output by -4.57% and reduction of capital stock by -1.1%. Table 5-3 compares the simulation results concerning the changes of real GDP, real imports, and real exports (percentage) in the GTAP model, which does not include the structure of substitution between capital and energy goods, and those of the GTAP-E model, which includes the substitutional structure between capital and energy goods.

We can observe a significant difference between the simulation results of the two models when exogenous values are assigned to electricity, followed by those when exogenous values are assigned to other energy goods, petroleum and coal products. Another feature of the case of electricity and petroleum and coal products is that the signs of exports and imports are reversed between the simulation results of the GTAP model and those of the GTAP-E model.

When we set exogenous values to each sector in Japan, in most cases the difference between the simulations results of the GTAP model and those of the GTAP-E model is rather small. It is shown, however, that in energy goods such as electricity and petroleum and coal products, the difference in the simulation results between the GTAP model and the GTAP-E model could become relatively large.

Table 5-3 Macroeconomic changes caused by the decrease in productivity in each sector and the damage to capital stock in Japan in 2011 (GTAP model and GTAP-E model)

	Agriculture		Coal		Oil		Natural gas extraction		Petroleum, coal products	
	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP
Change in Real GDP (%)	−0.63	−0.63	−0.47	−0.47	−0.47	−0.47	−0.47	−0.47	−0.69	−0.83
Change in Real Import (%)	0.48	0.49	0.13	0.10	0.13	0.10	0.13	0.10	−0.24	0.27
Change in Real Export (%)	−1.31	−1.18	−2.08	−1.96	−2.08	−1.96	−2.08	−1.95	−1.29	−0.03

	Electricity		Minerals nec		Food processing		Textiles		Chemical, rubber, plastic products	
	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP
Change in Real GDP (%)	−0.65	−1.36	−0.50	−0.57	−0.80	−0.80	−0.48	−0.48	−0.62	−0.62
Change in Real Import (%)	−0.19	−0.13	0.07	−0.26	0.51	0.52	0.13	0.11	−0.13	−0.09
Change in Real Export (%)	−1.26	0.45	−1.76	−1.45	−1.31	−1.18	−2.03	−1.90	−1.70	−1.56

	Mineral products nec		Ferrous metals		Metals nec		Metal products		Motor vehicles and parts	
	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP
Change in Real GDP (%)	−0.55	−0.55	−0.66	−0.65	−0.49	−0.48	−0.61	−0.60	−0.58	−0.57
Change in Real Import (%)	−0.06	−0.05	−0.47	−0.40	0.04	0.03	−0.16	−0.12	−0.22	−0.20
Change in Real Export (%)	−1.50	−1.37	−1.41	−1.24	−2.04	−1.91	−1.04	−0.90	−2.13	−2.00

	Transport equipment nec		Electronic equipment		Machinery and equipment nec		Manufactures nec		Construction	
	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP
Change in Real GDP (%)	−0.48	−0.47	−0.55	−0.55	−0.57	−0.57	−0.70	−0.69	−0.98	−0.97
Change in Real Import (%)	0.10	0.08	−0.09	−0.07	−0.30	−0.26	0.21	0.27	−1.59	−1.45
Change in Real Export (%)	−2.05	−1.92	−1.71	−1.57	−1.61	−1.45	−0.63	−0.49	3.26	3.43

	Trade		Transport nec		Water transport		Air transport		Communication	
	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP
Change in Real GDP (%)	−2.29	−2.29	−1.77	−1.76	−0.54	−0.54	−0.49	−0.48	−1.03	−1.02
Change in Real Import (%)	−1.90	−1.67	−1.26	−0.99	0.06	0.05	0.13	0.11	−0.15	−0.12
Change in Real Export (%)	1.99	2.18	1.66	1.88	−2.28	−2.15	−2.07	−1.94	−1.64	−1.50

	Financial services		Other services		Public services	
	GTAP-E	GTAP	GTAP-E	GTAP	GTAP-E	GTAP
Change in Real GDP (%)	−1.62	−1.61	−3.41	−3.45	−1.82	−1.81
Change in Real Import (%)	−0.65	−0.47	−1.91	−1.53	−0.37	−0.31
Change in Real Export (%)	−0.34	−0.19	1.89	2.21	−1.46	−1.35

Source: the author.

6. Systematic sensitivity analysis concerning substitution parameters between capital and energy goods

6.1. Systematic sensitivity analysis concerning substitution parameters between capital and energy

Section 6 undertakes Systematic Sensitivity Analysis (SSA)[5] concerning the substitution parameters (1) between capital and energy and (2) between energy goods in all Japanese industries.

The substitution parameter between capital and energy is named ELFKEN and is fixed at the value of 0.5 for all sectors except non-electricity energies, in which it is fixed at zero. Here, we vary the value of ELFKEN in all Japanese sectors except non-electricity energies from the base value in the range of a 50% reduction and a 50% increase, that is, from 0.25 to 0.75. Then we analyze the change in the value of the real GDP as an example of macroeconomic variables, and that in the value of Japan's industrial output and private consumption as examples of industry-specific variables, using the confidence interval derived from Chebyshev's inequality.

In the SSA results concerning the real GDP, standard deviation is calculated as 0.0011, and we can be 95% confident that the rate of change of real GDP lies between -0.66% and -0.65%, which shows that the simulation result changes very little against the change in the value of ELFKEN. It could be concluded that the simulation results of macroeconomic variables are relatively robust against the change in the value of the substitution parameter between capital and energy.

[5] Systematic Sensitivity Analysis is an analysis tool available in RunGTAP. In this analysis, means (M) and standard deviations (SD) of each variable are calculated when particular parameters are varied from the base value in the range of a fixed percentage (in this paper it is fixed at 50%) reduction and increase. Using Chebyshev's inequality, in which we can be 95% confident that the value of variables lies between $M-\sqrt{20}\times SD$ and $M+\sqrt{20}\times SD$, we calculate the confidence interval for each variable.

Table 6-1 Simulation result of the change in real GDP by SSA concerning the change in the value of ELFKEN in the range of a 50% reduction and a 50% increase

	Mean	Standard Deviation	Lower limit (95% confidence level)	Upper limit (95% confidence level)
JPN	−0.65	0.0011	−0.66	−0.65
KOR	0.00	0.0000	0.00	0.00
CHN	0.00	0.0001	0.00	0.00
AEEx	0.00	0.0001	0.00	0.00
OASN	0.00	0.0001	0.00	0.00
IND	0.00	0.0000	0.00	0.00
USA	0.00	0.0000	0.00	0.00
EU27	0.00	0.0000	0.00	0.00
OEEx	0.00	0.0001	0.00	0.00
EEFSU	0.00	0.0001	0.00	0.00
RoA1	0.00	0.0001	0.00	0.00
ROW	0.00	0.0000	0.00	0.00

Source: the author.

As for the results concerning industrial output, the largest value of standard deviation is observed in electricity, which is 0.089, and we can be 95% confident that the rate of change of industrial output lies between -4.97% and -4.17%, while the mean is -4.57%. The standard deviation tends to become large for energy sectors; the standard deviation for the coal sector is 0.062 and that for the gas sector is 0.068.

In sectors other than energy sectors, standard deviations remain less than 0.02. This result suggests that the simulation results of industrial output are relatively robust against the change in the value of the substitution parameter between capital and energy.

In the results of private consumption, the largest value of standard deviation is observed for energy goods as well. The standard deviation in oil attains 0.0070 and that in coal attains 0.0065[6]. Other goods for which standard deviations are relatively large are construction (0.0044), textiles (0.0036), metals nec (0.0036), and transport equipment nec (0.0035). These results suggest that the simulation results of industrial output are robust enough against the change in the value of the substitution parameter between capital and energy.

[6] It should be noted that the private consumption of coal and oil is nearly zero.

Table 6-2 Simulation result of change in industrial output by SSA concerning the change in the value of ELFKEN in the range of a 50% reduction and a 50% increase

	Mean	Standard Deviation	Lower limit (95% confidence level)	Upper limit (95% confidence level)
AGR	−0.35	0.003	−0.37	−0.34
Coal	−0.33	0.062	−0.60	−0.05
Oil	0.28	0.036	0.12	0.45
Gas	−0.74	0.068	−1.04	−0.43
Oil_Pcts	−0.29	0.034	−0.44	−0.14
Electricity	−4.57	0.089	−4.97	−4.17
OMN	−0.58	0.003	−0.59	−0.57
PFD	−0.50	0.003	−0.51	−0.49
TXL	−0.60	0.012	−0.66	−0.55
CRP	−1.08	0.016	−1.15	−1.01
NMM	−0.83	0.003	−0.84	−0.81
I_S	−1.34	0.015	−1.41	−1.27
NFM	−1.68	0.018	−1.75	−1.60
FMP	−0.73	0.004	−0.74	−0.71
MVH	−0.58	0.014	−0.64	−0.51
OTN	−0.92	0.021	−1.02	−0.83
ELE	−1.11	0.018	−1.19	−1.03
OME	−1.07	0.020	−1.16	−0.98
OMF	−0.77	0.007	−0.80	−0.74
CNS	−0.25	0.013	−0.30	−0.19
TRD	−0.54	0.001	−0.55	−0.53
OTP	−0.55	0.003	−0.56	−0.53
WTP	−0.30	0.009	−0.34	−0.26
ATP	−0.53	0.010	−0.57	−0.49
CMN	−0.57	0.003	−0.58	−0.56
OFR	−0.58	0.006	−0.60	−0.55
OSP	−0.58	0.003	−0.59	−0.56
OSG	−0.48	0.002	−0.49	−0.48

Source: the author.

Table 6-3 Simulation result of change in private consumption by SSA against the change in the value of ELFKEN in the range of a 50% reduction and a 50% increase

	Mean	Standard Deviation	Lower limit (95% confidence level)	Upper limit (95% confidence level)
AGR	−0.13	0.0004	−0.13	−0.13
Coal	0.21	0.0065	0.18	0.24
Oil	0.22	0.0070	0.19	0.25
Gas	0.14	0.0027	0.13	0.15
Oil_Pcts	0.10	0.0059	0.07	0.12
Electricity	−4.99	0.0005	−5.00	−4.99
OMN	−0.61	0.0006	−0.61	−0.60
PFD	−0.42	0.0004	−0.42	−0.41
TXL	−0.38	0.0036	−0.40	−0.37
CRP	−0.56	0.0019	−0.56	−0.55
NMM	−0.66	0.0013	−0.66	−0.65
I_S	−0.76	0.0014	−0.77	−0.75
NFM	−0.53	0.0036	−0.54	−0.51
FMP	−0.51	0.0023	−0.52	−0.50
MVH	−0.48	0.0010	−0.49	−0.48
OTN	−0.41	0.0035	−0.42	−0.39
ELE	−0.53	0.0014	−0.54	−0.53
OME	−0.44	0.0034	−0.46	−0.43
OMF	−0.47	0.0027	−0.49	−0.46
CNS	−0.39	0.0044	−0.41	−0.37
TRD	−0.52	0.0005	−0.52	−0.52
OTP	−0.49	0.0004	−0.49	−0.48
WTP	−0.45	0.0009	−0.45	−0.44
ATP	−0.43	0.0025	−0.44	−0.42
CMN	−0.56	0.0017	−0.57	−0.55
OFR	−0.53	0.0015	−0.54	−0.53
OSP	−0.59	0.0018	−0.59	−0.58
OSG	−0.47	0.0001	−0.47	−0.47

Source: the author.

6.2. Systematic sensitivity analysis concerning substitution parameters between energy goods

The substitution parameters between energy goods are named ELFENY (substitution parameters between electricity and non-electricity energy goods), ELFNELY (substitution parameters between coal and non-coal energy goods), and ELFNCOAL (substitution parameters between oil, gas, and petroleum and coal products). ELFENY is fixed at the value of 1.0 for all sectors except energy goods. ELFNELY is fixed at the value of 0.5 for all sectors except non-electricity energy goods. ELFNCOAL is fixed at the value of 1.0 for all sectors except non-electricity energy goods. Here, we vary the values of ELFENY and ELFNELY from 0.5 to 1.5 and from 0.25 to 0.75, respectively, in all Japanese sectors except energy goods. We also vary the value of ELFNCOAL in all sectors except non-electricity energy goods from 0.5 to 1.5. Then, we analyze the change in the value of the real GDP as an example of macroeconomic variables, and that in the value of Japanese industrial output and private consumption as examples of industry-specific variables, using the confidence interval derived from Chebyshev's inequality, as shown in 6.1.

The SSA results concerning the real GDP suggest that the standard deviation is calculated as 0.0015, and we can be 95% confident that the rate of change of real GDP lies between -0.66% and -0.65%, which shows that the simulation results are similar to those of the precedent case. It could be concluded that simulation results of macroeconomic variables are relatively robust against the change in the value of the substitution parameters between energy goods as well.

Table 6-4 Simulation result of change in real GDP by SSA concerning changes in the values of ELFENY, ELFNELY, and ELFNCOAL in the range of a 50% reduction and a 50% increase

	Mean	Standard Deviation	Lower limit (95% confidence level)	Upper limit (95% confidence level)
JPN	−0.65	0.0015	−0.66	−0.65
KOR	0.00	0.0001	0.00	0.00
CHN	0.00	0.0000	0.00	0.00
AEEx	0.00	0.0001	0.00	0.00
OASN	0.00	0.0000	0.00	0.00
IND	0.00	0.0001	0.00	0.00
USA	0.00	0.0000	0.00	0.00
EU27	0.00	0.0001	0.00	0.00
OEEx	0.00	0.0001	0.00	0.00
EEFSU	0.00	0.0001	0.00	0.00
RoA1	0.00	0.0000	0.00	0.00
ROW	0.00	0.0000	0.00	0.00

Source: the author.

As for the SSA results concerning industrial output, their values are larger for energy goods compared with the simulation results of the precedent case. The largest value of standard deviation is observed in electricity, which attains 0.137, and we can be 95% confident that the rate of change of industrial output in electricity lies between -5.18% and -3.96%, while the mean is -4.57%. Standard deviation tends to become large for energy sectors; the value for the coal sector is 0.182 and that for the gas sector is 0.081. It is notable that the rate of change of industrial output of coal changes the sign between the 95% confidence interval; we can be 95% confident that the rate of change of industrial output of coal lies between -1.14% and +0.49%. In the case of the petroleum and coal products as well, the rate of change of industrial output is about to change the sign; we can be 95% confident that the rate of change of industrial output lies between -0.58% and 0%.

For sectors other than energy sectors, standard deviations tend to be less than those in the simulation results of the precedent case. It is shown that the simulation results of industrial output are in general robust against the change in the value of the substitution parameters between energy goods.

Table 6-5 Simulation result of changes in industrial output by SSA concerning changes in the values of ELFENY, ELFNELY, and ELFNCOAL in the range of a 50% reduction and a 50% increase

	Mean	Standard Deviation	Lower limit (95% confidence level)	Upper limit (95% confidence level)
AGR	−0.35	0.002	−0.36	−0.34
Coal	−0.33	0.182	−1.14	0.49
Oil	0.28	0.037	0.12	0.45
Gas	−0.74	0.081	−1.10	−0.37
Oil_Pcts	−0.29	0.065	−0.58	0.00
Electricity	−4.57	0.137	−5.18	−3.96
OMN	−0.58	0.001	−0.59	−0.58
PFD	−0.50	0.002	−0.51	−0.49
TXL	−0.60	0.008	−0.64	−0.57
CRP	−1.08	0.010	−1.13	−1.04
NMM	−0.83	0.003	−0.84	−0.81
I_S	−1.34	0.011	−1.39	−1.29
NFM	−1.68	0.011	−1.72	−1.63
FMP	−0.73	0.003	−0.74	−0.71
MVH	−0.58	0.009	−0.62	−0.54
OTN	−0.92	0.013	−0.98	−0.87
ELE	−1.11	0.012	−1.16	−1.06
OME	−1.07	0.013	−1.13	−1.02
OMF	−0.77	0.003	−0.78	−0.76
CNS	−0.25	0.006	−0.27	−0.22
TRD	−0.54	0.001	−0.55	−0.53
OTP	−0.55	0.001	−0.55	−0.54
WTP	−0.30	0.004	−0.31	−0.28
ATP	−0.53	0.005	−0.55	−0.50
CMN	−0.57	0.001	−0.57	−0.56
OFR	−0.58	0.000	−0.58	−0.58
OSP	−0.58	0.000	−0.58	−0.58
OSG	−0.48	0.001	−0.49	−0.48

Source: the author.

Regarding the results of private consumption, we do not find cases in which the sign of variables changes between 95% confidence intervals. The largest value of standard deviation is observed for energy goods; the standard deviation for oil is 0.0045 and that for petroleum and coal products is 0.0035. These results suggest that the simulation results of private consumption are robust enough against the changes in the values of the substitution parameters between energy goods.

Table 6-6 Simulation result of changes in private consumption by SSA concerning changes in the values of ELFENY, ELFNELY, and ELFNCOAL in the range of a 50% reduction and a 50% increase

	Mean	Standard Deviation	Lower limit (95% conficdence)	Upper limit (95% conficdence)
AGR	−0.13	0.0001	−0.13	−0.13
Coal	0.21	0.0018	0.20	0.22
Oil	0.22	0.0045	0.20	0.24
Gas	0.14	0.0008	0.13	0.14
Oil_Pcts	0.10	0.0035	0.08	0.11
Electricity	−4.99	0.0009	−5.00	−4.99
OMN	−0.61	0.0010	−0.61	−0.60
PFD	−0.42	0.0005	−0.42	−0.41
TXL	−0.38	0.0012	−0.39	−0.38
CRP	−0.56	0.0005	−0.56	−0.55
NMM	−0.66	0.0009	−0.66	−0.65
I_S	−0.76	0.0014	−0.77	−0.75
NFM	−0.53	0.0012	−0.53	−0.52
FMP	−0.51	0.0006	−0.51	−0.51
MVH	−0.48	0.0006	−0.49	−0.48
OTN	−0.41	0.0011	−0.41	−0.40
ELE	−0.53	0.0004	−0.53	−0.53
OME	−0.44	0.0010	−0.45	−0.44
OMF	−0.47	0.0007	−0.48	−0.47
CNS	−0.39	0.0016	−0.40	−0.39
TRD	−0.52	0.0012	−0.53	−0.52
OTP	−0.49	0.0009	−0.49	−0.48
WTP	−0.45	0.0004	−0.45	−0.45
ATP	−0.43	0.0009	−0.43	−0.43
CMN	−0.56	0.0015	−0.57	−0.55
OFR	−0.53	0.0015	−0.54	−0.53
OSP	−0.59	0.0016	−0.59	−0.58
OSG	−0.47	0.0012	−0.48	−0.47

Source: the author.

7. Conclusion

This paper analyzed the impact of earthquakes on the Japanese economy using the GTAP-E model. The simulation results show that the GTAP-E model can reproduce the effects of a real-world earthquake—in this case, the Great East Japan Earthquake. The results are not overly different from the actual Japanese 2011 macroeconomic data with respect to the percentage change from the previous year. Two channels have been utilized to analyze the impact: the decrease in productivity in the electricity sector and the damage to capital stock. Each of these channels has an impact of a rather different tendency on the economy. As there might be other channels through which earthquakes affect an economy, further analysis would be important in order to improve the methods to evaluate the impacts of earthquakes on the economy.

The Japanese electricity sector is a rather exceptional case in that it is characterized by a substitutional relationship between energy and capital, as shown in previous studies. This paper analyzed the substitutional relationship between capital and energy goods based on GTAP 8.1 database, and found that this relationship continues to exist between capital and energy goods in Japan's electricity sector. Thus, the GTAP-E model would be a useful tool to analyze Japan's electricity sector, as the model allows one to take into account the effect of energy substitution.

The results of systematic sensitivity analysis show that the simulation results are rather robust against changes in the value of the substitution parameters between capital and energy and those among energy goods. It is noted, however, that when the number of varied parameters increases, the change in the simulation results of energy goods could become considerable.

After the Great East Japan Earthquake, Japan has experienced sudden changes in its electric supply; the structure of electric supply source has radically changed by a drastic reduction and even complete discontinuation of nuclear power, which caused an increase in electricity price. For further analysis of the effects of earthquakes on the economy, it is necessary to examine the possibility of other channels through which earthquakes affect the economy. It is also necessary to reflect in the analysis the latest trends of Japanese electric supply structure in detail, and for this purpose, classifying GTAP electricity data by source will be highly useful.

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