Conventional I-O model to estimate indirect economic damage of earthquakes: Taking a Tokyo Epicentral Earthquake as an example

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List of Abbreviation

CDMC	Central Disaster Management Council
GEJE	Great East Japan Earthquake
GH	Great Hanshin Earthquake
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
TEE	Tokyo Epicentral Earthquake
TM	Tokyo Metropolitan

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Abstract
This presentation is the first presentation in the organized session, "An Input-Output Analysis for Disaster Damage: A Case Study on the Tokyo Epicentral Earthquake".
An earthquake of magnitude seven or greater in the southern Kanto region, including Tokyo, is expected to cause more direct damage than the Great East Japan Earthquake in 2011. A reduction in economic activity in Tokyo would cause significant economic damage to the rest of the country since Tokyo is the center of logistics. This session will focus on such indirect damage, where Tokyo is assumed as the disaster area and exogenous to measure the production decrease caused by the disaster in Tokyo. The entire Japan is divided into two regions, Tokyo and the rest of Japan, and we estimate the extent to which the damage in Tokyo extends beyond Tokyo based on Tokyo metropolitan two-regional Input-Output table.

In this research, we present a demand-oriented model, a supply-oriented model, and a hybrid demand. This presentation is important in the sense that the results obtained can be compared with those obtained with other models in the same session although the ideas of these models are relatively well known and the models themselves do not have much novelty. In the demand-oriented model, the exogenous variable is the decrease in intermediate demand from Tokyo due to the production decrease in Tokyo. The resulting decrease in production outside of Tokyo is the damage caused by the earthquake. In other words, this is the backward linkage effect of the decrease in production in Tokyo, which is estimated by Leontief model. In the supply-oriented model, we apply the Ghosh model, in which production is determined as the sum of inputs (intermediate goods and value added). What is considered fixed in this model is the allocation coefficient from one industry to others. The Tokyo disaster reduces inputs to the rest of the country. The model measures the forward linkage effect of the decrease in production in Tokyo, which is then considered as the damage. The hybrid model uses both. In the first step, the forward linkage effect expressed by the Gauche model is activated, and from the second step, the backward linkage effect by the Leontief model is activated.

1. Introduction

Ten years have passed since the Great East Japan Earthquake (GEJE) that occurred on March 11, 2011. Humans receive countless blessings from nature, but this earthquake again confirmed that Japan is an earthquake-prone country. The Great East Japan Earthquake resulted in 20,000 fatalities, and the loss of 200,000 homes. In addition, the amount of direct damage to infrastructure and buildings is estimated to have reached more than 15 trillion yen.[1] At the same time, businesses in the disaster area were also affected and transportation was severed, causing production activities to be suspended; even the production activities at business locations downstream of the affected businesses were limited. One of the main characteristics of the economic damage from the Great East Japan Earthquake was the large-scale indirect damage that occurred due to supply constraints.

Currently, there are concerns about the occurrence of earthquakes in the South Kanto area (Tokyo area).[2] The Kanto area is the axis of distribution and information in Japan, which means that if a major earthquake were to occur in this region, it is easy to image that there would be supply constraints across an incredibly large area. This would have an enormous impact on the Japanese economy.

Incidentally, people are surprisingly unaware of the fact that there are two groups of Kanto area earthquakes, one group being major earthquakes of around Magnitude 8 (M8) and the other group being large earthquakes of around Magnitude 7 (M7).[3] The most recent major M8 earthquakes were the 1703 Genroku Earthquake (M8.2) and the 1923 Great Kanto Earthquake (M7.9). Going further back, there was the Meio Kanto Earthquake (1495). The Kamakura

1 Estimates of direct damage include that of the Cabinet Office (2011) (approx. 16.9 trillion yen), and that of the Development Bank of Japan (2011) (approx. 16.4 trillion yen).

2 Earthquake types include “deep earthquakes” that occur at the borders of tectonic plates, and “inland earthquakes” that cause the earth’s crust to move upward due to the pressure and that occur at fault lines. The scope of this paper covers the latter.

3 Magnitude is an index that shows the scale of energy of an earthquake. The relationship is $\log(E)=4.8+1.5M$ where E signifies the energy of the earthquake (joules), M represents the magnitude and log is the common logarithm. The increments of 1 in magnitude are increments of 1.5 in the common logarithm, which means the difference is approximately 30 times greater. Generally, earthquakes that exceed Magnitude 7 are called large earthquakes and those that exceed Magnitude 8 are called major earthquakes. The greatest earthquake on record in Japan was the Great East Japan Earthquake, which was Magnitude 9.0. The Great Kanto Earthquake was Magnitude 7.9, while the 1995 Great Hanshin Earthquake was Magnitude 7.3. An earthquake with a magnitude of around 7 that occurs under Tokyo would cause immense damage.

Earthquake (1293) may also have been a major M8 earthquake. Such major M8 earthquakes occur approximately every 200 years.

The other group is large M7 earthquakes that occur between the major M8 earthquakes. Between the 1703 Genroku Earthquake and the 1923 Great Kanto Earthquake, the following eight large M7 earthquakes occurred: 1) 1782 Tenmai Odawara Earthquake (M7.0); 2)1853 Kaei Odawara Earthquake (M6.7); 3) 1855 Ansei Edo Earthquake (M6.9); 4) 1894 Meiji Tokyo Earthquake (M7.0); 5)1894 Tokyo Bay Earthquake (M6.7); 6)1895 South Ibaraki Earthquake (M7.2); 7)1921 South Ibaraki Earthquake (M7.0); 8)1922 Uraga Channel Earthquake (M6.8). However, these eight earthquakes did not occur at regular intervals. Figure 1 depicts the eight earthquakes within the first and latter half of the 200-year period between the Genroku Earthquake and the Great Kanto Earthquake. As a result, it can be understood that only the Tenmai Odawara Earthquake occurred in the first half, while the seven other earthquakes occurred 150 years or more after that major earthquake.

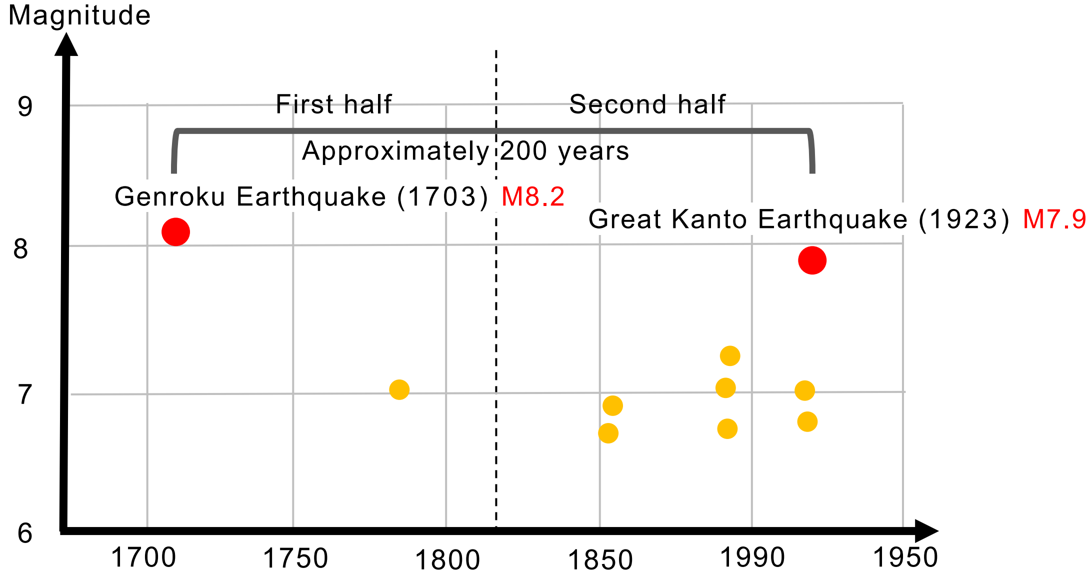

Figure 1 Large earthquakes in Kanto after 1700

Source: Created by the authors based on NHK News Web (2019.11.25)
https://www3.nhk.or.jp/news/special/saigai/natural-disaster/natural-disaster_14.html

Nearly 100 years have passed since the Great Kanto Earthquake occurred in 1923, meaning that the coming 100-year period will correspond to the latter-half of the mid-cycle of major M8 earthquakes that occur in intervals of 200 years, while also being a period of activity of large M7 earthquakes. Conclusively, there is a roughly a 70% probability that a Tokyo Inland Earthquake will occur in the next 30 years.

In the sense of the economic damage from earthquakes, the most visible aspect of this may be the reduction of assets in terms of damage to existing structures (infrastructure/buildings). However, this is not the topic of this paper, as this is considered to be the job of government agencies that hold such information. In this paper, the focus is placed on the indirect ripple-effect damage due to supply constraints that are corollary to the damage to existing structures (infrastructure/ buildings). The clear objective of this study is to consider the characteristics and validity of various analytical models that can be chosen when estimating indirect damage, which is the primary purpose of this paper. However, another idea that is kept in mind is the presentation of the estimation of the amount of indirect damage caused by a Tokyo Inland Earthquake in the future.

In the analysis in this paper, a Tokyo Metropolitan (TM) input–output table is used. An input–output table is a statistical table that describes the intermediary structures related to each industry. These characteristics have been used to develop a technique called the equilibrium level of output model for the input–output analysis, which is an economic ripple-effect analysis typically used for major events such as the Olympics and the International Exposition. As will be described below, with the equilibrium level of output model, it is hypothesized that “what is in demand can be supplied,” that is, that there is no bottleneck to the supply chain; however, what was brought into sharp focus by the impact of the Great East Japan Earthquake was that, rather than there being a “reduced demand” in the disaster area, there were “supply constraints” because production in the disaster region came to a stop. In this paper, multiple trials are carried out to consider how to model such supply constraints.

The structure of this paper is as follows. In Section 2, the prior studies related to disaster analysis are introduced. In Section 3, four types of models are presented to measure the indirect economic damage caused by disasters. In Section 4, on the basis of the models from Section 3, the ripple effects of economic damage immediately after earthquakes are simulated, and an empirical study of the characteristics of each model is made. In Section 5, the conclusion and future issues are presented.

2. Literature review

There are two kinds of estimation regarding indirect damage caused by a disaster, pre-disaster damage estimates and post-disaster damage estimations. The former includes the damage estimates by the Central Disaster Management Council (CDMC) (2008) and Hasebe (2002), while the latter includes those by the

Ministry of Land, Infrastructure, Transport and Tourism (MLIT) Chugoku Regional Development Bureau (2005).

CDMC(2011) has made damage estimates of "Uemachi fault zone earthquake", which is expected to give damage to Osaka area. The total economic damage was estimated approximately 74 trillion yen, of which direct damage would comprise approximately 61 trillion yen and indirect damage would comprise approximately 13 trillion yen. As to the direct damage, production function in the disaster area is estimated as the initial step, and the loss of the amount of production caused by the decrease in capital and labor is estimated for each industry as the final step. As to the indirect damage, the direct damage obtained from production functions is applied to interregional input–output table issued by the Ministry of Economy, Trade and Industry (METI). This estimate is a backward linkage effect from the suspension of production caused by the earthquake.

On the other hand, The MLIT Chugoku Regional Development Bureau (2005) measured the impact on the regional economy centering on indirect damage using a model case of Typhoon No 18 that struck the Chugoku region in September 2004. The damage estimation in this case was based on a questionnaire survey among businesses in Hiroshima Prefecture, and the estimation of indirect damage was made by the input–output analysis based on the Hiroshima Prefecture input–output table. The estimation of the ripple effect of indirect damage in this case was limited to the backward linkage effect, and there was no estimation of the forward linkage effect due to the "difficulty of establishing estimation techniques."

Hasebe (2002) also made an estimation of the amount of decrease in production caused by Tokyo epicentral Earthquake based on the TM input–output table. The procedure involved calculating the percentage of decrease with consideration for the duration of the supply outage after finding the percentage of decrease in production in each industry in Tokyo based on the production function, and then to estimate the amount of damage on areas outside of Tokyo. Hasebe's bottleneck mode, while being based on the Leontief production function, is characterized by the inclusion of parameters for the percentage of decrease in production components, the influx of assets from other regions and countries, resource distribution between sectors.

Shimoda and Fujikawa (2012), using four different models, namely, a demand-based model, a supply-based model, a demand/supply-hybrid model, and a bottleneck model, estimated the indirect damage given to the outside of the Tohoku region from the Great East Japan Earthquake (GEJE) to clarify the characteristics of each model. From the results of the calculation, it was confirmed that the first three models are insufficient when it comes to explaining the production decrease that actually occurred after the earthquake. Only bottleneck model was able to explain the sharp decline in production in those days. Although this model follows the decreases in the production of such manufacturing sectors as automobiles, the damage seems to be overestimated in non-manufacturing sectors since input items that are not necessarily essential to production form bottlenecks.

This study builds on the work by Shimoda and Fujikawa (2012) that treated the GEJE and aims to provide a preliminary estimation on the indirect damage Tokyo Epicentral Earthquake (TEE) in the future while also studying the analytical techniques.

3. Models

3-1 Demand-based Model

In this paper, a model in which the Tokyo disaster area is exogenous is used to measure the ripple effect of the disaster on the demand-side of a production decrease. With the idea that two regions, that is, Regions 1 and 2 form an economy, the disaster area shall be given as Region 2. If Region 2 is the "exogenous" region, the supply–demand equilibrium in Region 1 can be represented in equation (1) as follows:

$$\mathbf{x_1} = \mathbf{A_{11}}\mathbf{x_1} + [\mathbf{A_{12}}\mathbf{x_2} + \mathbf{f_1}] \tag{1}$$

$\mathbf{A_{ij}}$ shows the input coefficient matrix from Region *i* by Region *j*, which is assumed to be fixed in place in the demand model. The production vector in Region *i* is shown by $\mathbf{x_i}$, while $\mathbf{f_i}$ shows the final demand vector against products from Region *i*. Solving equation (1) for $\mathbf{x_1}$, the equilibrium output becomes as shown in the following equation (2):

$$\mathbf{x_1} = (\mathbf{I} - \mathbf{A_{11}})^{-1}[\mathbf{A_{12}}\mathbf{x_2} + \mathbf{f_1}] \tag{2}$$

In the case that the amount of production in Region 2 due to the disaster decreasing only by $\Delta\mathbf{x_2}$; the change in the amount of production in Region 1 can be found using the following equation (3):

$$\Delta\mathbf{x_1} = (\mathbf{I} - \mathbf{A_{11}})^{-1}[\mathbf{A_{12}}\Delta\mathbf{x_2} + \mathbf{f_1}] \tag{3}$$

The reduction in the demand for Region 1 products by Region 2 is shown by $\mathbf{A_{12}}\Delta\mathbf{x_2}$ in equation (3), which measures the backward linkage effect brought about by the decrease in production in the disaster area.

3-2 Supply-based Model

In the Leontief model, demand determines supply, but it is also possible to have a model in which estimates are made where supply determines demand; in this paper, in line with Miller and Blair (2009), the model is called the Ghosh Model. With the Ghosh Model, the amount of added-value is given exogenously, and production is determined as the sum total of input items (intermediate goods and added-value). In this model, the distribution coefficient from one industry to other industries is fixed.[4]

In this paper, a Ghosh model is used in which the Tokyo disaster area is exogenous in order to measure the ripple effect of the disaster on the supply-side of a production decrease. With the idea of two regions forming an economy, as per the demand-based model, Region 2 shall be exogenous. If the distribution coefficient is assumed to be fixed, production in Region 1 and Region 2 can be given according to the following equation (4):

$$\mathbf{x}_1' = \mathbf{x}_1'\mathbf{G}_{11} + [\mathbf{x}_2'\mathbf{G}_{21} + \mathbf{v}_1'] \quad (4)$$

The distribution coefficient matrix from Region *i* to Region *j* is shown as $\mathbf{G_{ij}}$, and $\mathbf{v_i}$ is the added-value vector of Region *i*. Solving equation (4) for $\mathbf{x}_1'$, gives the following equation (5):

$$\mathbf{x}_1' = [\mathbf{x}_2'\mathbf{G}_{21} + \mathbf{v}_1'](\mathbf{I} - \mathbf{G}_{11})^{-1} \quad (5)$$

In the case that the amount of production in Region 2 due to the disaster decreases only by Δx_2, the change in the amount of production in Region 1 can be found using the following equation (6):

$$\Delta\mathbf{x}_1' = [\Delta\mathbf{x}_2'\mathbf{G}_{21} + \mathbf{v}_1'](\mathbf{I} - \mathbf{G}_{11})^{-1} \quad (6)$$

The reduction in input in Region 1 products by Region 2 is shown by $\Delta\mathbf{x}_2'\mathbf{G}_{21}$ in equation (6), which measures the forward linkage effect brought about by the decrease in production in the disaster area.

To what extent is the Ghosh Model shown above valid in reality? In terms of a case to which this model can be applied, Ghosh, who invented the model, had in

4 This is often called the "output coefficient" but in this paper it is referred to as the "distribution coefficient."

mind the idea of a planned economy producing excessive demand where the government regulates distribution.[5] However, this is a specific case, and it cannot be applied to general market economies. Hasabe (2002) identified two issues with the Ghosh Model: (1) It is unrealistic to make fixed assumptions about the distribution coefficient and (2) It is assumed that there is complete replaceability of the production function, which is logically inconsistent with the input–output theory. Oosterhaven (1988) also pointed out the unfeasibility of demand being completely determined by the supply-side, even though he did show that the distribution coefficient is stable when the input coefficient is also stable, as long as there is a uniform production growth rate between divisions on the basis of the mathematical relationship between the input and distribution coefficients.

3-3 Demand/Supply-Hybrid Model

In the demand-based model, the fixed coefficient was given as the input structure of intermediate goods, while in the supply-based model; the fixed coefficient was given as the market structure of intermediate goods. However, in contrast to the technical relationship of intermediate goods at the time of production, market share is considered to be adjustable, and so there may be a certain amount of validity to the idea that it is not realistic for the steps of the ripple effects expressed in equation (6) to continue in the long-term. Below, a model is considered in which the forward linkage effect from the Ghosh model is applied to the first step, while the backward linkage effect from the Leontief model is used in all other steps.

As before, this approach will be considered with a two-region model in which Region 2 is exogenous. Production in Region 2 has decreased by $\Delta \boldsymbol{x}_2$ due to the disaster. In the first step, if the forward linkage effect from the Ghosh Model is applied, the decrease in production in Region 1 will be $\mathbf{G}'_{21}\Delta \boldsymbol{x}_2$. In the Ghosh Model, it is thought that the same (forward) ripple effect process will continue thereafter. However, in this model, in the following steps, the backward linkage effect from the Leontief model is applied. The decrease in production in Region 1 at this time is found using equation (7) in which $\mathbf{G}'_{21}\Delta \boldsymbol{x}_2$ is successively multiplied by the input coefficient to find the totals; the equation is shown as follows:

$$\Delta \mathbf{x}_1 = (\mathbf{I} - \mathbf{A}_{11})^{-1}\mathbf{G}'_{21}\Delta \mathbf{x}_2 \tag{7}$$

In this paper, the model based on equation (7) is referred to as the "Demand/Supply-Hybrid Model" or simply as the "Hybrid Model."

5 See Ghosh (1958).

4. Simulation

4-1 Assumptions for simulation

Based on the model from the preceding section, we implement a simulation to estimate indirect damage caused by TEE. First, we explain the conditions and assumptions of the simulations.

The target region to estimate the indirect damage is outside of TM (46 prefectures in Japan except TM), and the 2015 TM I–O table (38 sector classification) is used for the simulation.[6] The TM I–O table has two characteristics that are not found in the input–output tables of other prefectures. Specifically, the “headquarters sector” is independently taken out, and the table specification is not a single region table but a two-region inter regional table for TM and outside of TM.

We first estimate, in the simulation, the production decrease in TM given by TEE, and next we forecast the impact on production outside of TM caused by the decrease of production in TM by I–O models.

Let us introduce the estimation by Central Disaster Management Council (CDMC) as a simulation of the economic damage caused by TEE. CDMC estimates sector wise production functions where the productions are explained by such production factors as labor, capital, and productivity indicator. CDMC predicts the damage to the production factors and thus estimates the damage to production based on the estimated production functions. It might be ideal for us to make more precise damage estimation in TM by estimating the production function by industry as CDMC. This study, however, adopts a simplified method to assume the production decrease in TM by TEE since the main purpose of this study is to compare the methods to estimate the indirect economic damage outside of TM.

The estimations of the production decrease in TM were separately made for the headquarters and non-headquarters sectors. With regard to non-headquarters sectors, we first calculate the sector wise rate of production decrease in Kobe after the Great Hanshin Earthquake (GHE) occurred in the late FY 1994 and the nationwide production change rate in the same period based on the prefectural income statistics. And we assume that the difference between these rates of change was caused by the GHE and this rate of change is applied as decrease rates of production in our TEE simulation.[7]

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6 This table has headquarters sector as the 38th sector as well as conventional 37 sectors.

7 As to sectors with a positive difference in GHE, such as the construction, we assume the output is unchanged (damage rate is zero %) to apply TEE simulation.

According to a 2021 survey by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), only 31% of companies have backup bases for headquarters functions preparing disasters. Since the average damage rate was 6.5% for the non-headquarters sectors, we assume the damage rate in the headquarters sector would be 10%, which is higher than the non-headquarters average.

The assumed production decrease in TM by TEE is shown in Table 1. The first column is the production in TM in FY2015, the second column is the assumed decrease rate of production with reference to the experiences of the GHE, and the column 3 shows the assumed decrease in production in TM by TEE. The rate of decrease is high in Chemical products, Petroleum and coal products, and Plastic and rubber products among manufacturing sectors, on the other hand, the damage rate is high in Transportation and postal services, Telecommunications among service sectors.

Table 1 Assumed production decrease in TM caused by TEE (Billion yen)

	Sectors	Pre TEE production in TM	Assumed damage rate in TM by TEE	Assumed damage in TM by TEE
1	Agriculture, forestry and fisheries	101.7	-4.5%	-4.6
2	Mining	9.5	-5.2%	-0.5
3	Food and beverage	1,161.9	-16.3%	-189.2
4	Textile and garment	82.9	-5.0%	-4.1
5	Pulp, paper and wood products	285.1	-1.7%	-4.9
6	Chemical products	511.2	-20.7%	-106.1
7	Petroleum and coal products	29.7	-38.2%	-11.3
8	Plastic and rubber products	200.5	-21.4%	-43.0
9	Ceramics and stone products	163.1	0.0%	0.0
10	Iron and Steel	166.0	-8.0%	-13.2
11	Non-ferrous metals	74.6	-8.0%	-5.9
12	Metal products	231.3	-7.2%	-16.5
13	Machinery for general use	268.5	-6.0%	-16.1
14	Production machinery	358.7	-6.0%	-21.5
15	Business machinery	543.5	-6.0%	-32.6
16	Electronic components	306.8	-5.4%	-16.4
17	Electric machinery	671.2	-5.4%	-35.9
18	Information and communication equip.	564.3	-5.4%	-30.2
19	Transport machinery	1,939.1	-8.7%	-169.6
20	Other manufacturing products	1,298.6	-21.4%	-278.2
21	Construction	8,346.0	0.0%	0.0
22	Electricity, gas and heat supply	1,393.2	-15.5%	-216.1
23	Water services	652.8	-15.5%	-101.3
24	Waste disposal	459.2	-15.5%	-71.2
25	Commerce	24,142.9	-10.3%	-2,480.8
26	Finance and insurance	11,151.6	-7.9%	-877.8
27	Real estate	14,788.4	-5.1%	-753.5
28	Transportation and postal services	7,550.3	-10.8%	-815.3
29	Telecommunications	22,538.6	-10.8%	-2,433.9
30	Public affairs	6,669.9	-0.1%	-5.0
31	Education and research	7,041.6	-3.3%	-230.5
32	Medical and welfare services	7,279.5	-3.3%	-238.3
33	Membership organization	589.6	-3.3%	-19.3
34	Business services	25,682.7	-3.3%	-840.8
35	Personal services	10,032.8	-3.3%	-328.5
36	Office supplies	289.8	0.0%	0.0
37	Not else classified	750.4	0.0%	0.0
38	Headquarters	30,707.5	-10.0%	-3,070.7
	Total	189,035.1	-7.1%	-13,483.2

Source: authors' calculation base on prefectural income statistics and TM Input-Output table 2015.

3-2 Simulation results

Here, we show the simulation results for the following three cases to identify the production declines in headquarters and non-headquarters separately

(i)The case TEE gives a damage only to the headquarters in TM.

(ii)The case TEE gives damages only to non-headquarters in TM

(iii)The case TEE gives damages to all sectors including headquarters in TM

(1) The case TEE gives a damage only to the headquarters in TM

Table 2 shows the simulation results in the case TEE gives a damage only to the headquarters in TM. The upper block shows the effects for TM and the lower block shows those for the outside of Tokyo. The figures in the tables are those aggregated to seven sectors to save space though the calculations are implemented based on the original 38 sector table. The amount of pre-TEE is same as those in the 2015 TM I–O table. The three columns on the right show the amount of production decrease estimated by each I–O model.

Table 2 Damage to TM and outside TM
(Damage to only headquarters in TM, Billion yen)

		Pre TEE production	Production decreases by TEE		
			Demand model	Supply model	Hybrid model
Tokyo	Agriculture / mining	111	0	0	0
	Manufacturing	8,857	0	0	0
	Construction	8,346	0	0	0
	Electricity, gas, etc.	2,505	0	0	0
	Commerce	24,143	0	0	0
	Service	114,365	0	0	0
	Headquarters	30,707	-3,071	-3,071	-3,071
Outside of Tokyo	Agriculture / mining	13,624	-1	-36	-45
	Manufacturing	292,489	-43	-947	-932
	Construction	52,491	-1	-178	-99
	Electricity, gas, etc.	31,576	-32	-82	-125
	Commerce	71,336	-5	-541	-547
	Service	397,975	-155	-1,470	-1,452
	Headquarters	51,543	-13	-46	-233
A TM Total		189,035	-3,071	-3,071	-3,071
B Outside of TM		911,034	-250	-3,301	-3,433
C Japan Total		1,100,069	-3,320	-6,372	-6,504
A Rate of decrease			-1.6%	-1.6%	-1.6%
B Rate of decrease			0.0%	-0.4%	-0.4%
C Rate of decrease			-0.3%	-0.6%	-0.6%

Source: authors' calculation base on TM Input-Output table

First, comparing the production decrease outside Tokyo using the demand-based model and supply-based model, while the decrease was 250 billion yen in the demand-based model, the decrease in the supply-based model was approximately 3,301 billion yen, showing that the estimated indirect damage amount in the supply-based model is 13 times greater than that in the demand model. This difference indicates that headquarters services in Tokyo have a relatively large impact downstream, while the upstream impact is limited. In other words, the forward linkage effect of headquarters services in Tokyo is relatively large while the backward linkage effect of headquarters services in Tokyo is weak.

This point is noteworthy. For example, in the manufacturing sector of outside Tokyo, the decrease in the demand-based model was 43 billion yen while the decrease in the supply-based model was 947 billion yen. Since headquarters in Tokyo purchase manufactured goods as intermediate goods from outside Tokyo to conduct their activities, the suspension of headquarters activities in Tokyo due to a disaster causes a demand decrease for manufactured goods produced outside Tokyo to some extent. The upstream impact from this demand decrease is measured as 250 billion yen estimated by the demand-based model. On the other hand, in the supply-based model, the loss of headquarters function causes disorder among business management, information gathering activities, etc., this makes it difficult to proceed usual production activities outside Tokyo. The downstream impact is measured as 3,300 billion yen by supply-based model. Comparing the differences between the two models by industry, except for the construction which has no cross-border transaction, the greatest difference between the two is in commerce (approximately 117 times greater). This reflects the fact that, while headquarters activities in Tokyo are strongly related to commercial activities outside Tokyo, headquarters activities in Tokyo are not reliant on commerce sector outside of Tokyo. In contrast to commerce, the gap was relatively small in the sector of "electricity, gas and heat supply" (hereinafter, "electricity"). The difference was less than 3 times. This may be because Tokyo headquarters have relatively large backward linkage effect to outside Tokyo because Tokyo headquarters demands electricity mainly produced outside Tokyo.

In the calculation in the Hybrid Model, the indirect damages are generally estimated greater than in the supply-based model although the degree of difference varies from industry to industry. This is mainly because the steps of the ripple effect in the Hybrid Model is larger than the other models. However, the differences are marginal since the backward linkage effect of headquarters is not large.

(2) The case TEE gives damages only to non-headquarters in TM

Next, the results of the simulation in the case of considering damage to sectors other than the head office are shown in Table 3. As production in Tokyo is an exogenous variable, the production decrease in each industry in Tokyo is the same for all three models, and the total is approximately 10.4 trillion yen. The effect on production outside of Tokyo is approximately 2.4 trillion yen in the demand-based model, and approximately 3.6 trillion yen in the supply-based model and hybrid model, respectively.

Compared to the case when considering damage only to the headquarters, the differences between production decrease outside Tokyo in the demand-based model and the supply-based model are marginal. That is, non-headquarters industries have a relatively storing backward linkage effect on average in comparison to headquarters whose backward linkage effect is week.

By industry, while the production decreases in the manufacturing industry in the demand-based model and supply-based model have similar values, the production decrease in services in the supply-based model is three times greater than that in the demand-based model. The service industry is positioned downstream of the manufacturing industry, which may be the cause of this difference.

Table 3 Damage to TM and outside of TM
(Damage to all sectors except headquarters in TM, Billion yen)

		Pre TEE production	Production decreases by TEE		
			Demand model	Supply model	Hybrid model
Tokyo	Agriculture / mining	111	-5	-5	-5
	Manufacturing	8,857	-995	-995	-995
	Construction	8,346	0	0	0
	Electricity, gas, etc.	2,505	-389	-389	-389
	Commerce	24,143	-2,481	-2,481	-2,481
	Service	114,365	-6,543	-6,543	-6,543
	Headquarters	30,707	0	0	0
Outside of Tokyo	Agriculture / mining	13,624	-78	-44	-60
	Manufacturing	292,489	-1,021	-1,257	-1,256
	Construction	52,491	-10	-226	-144
	Electricity, gas, etc.	31,576	-120	-93	-138
	Commerce	71,336	-175	-239	-222
	Service	397,975	-508	-1,526	-1,456
	Headquarters	51,543	-533	-204	-343
A TM Total		189,035	-10,412	-10,412	-10,412
B Outside of TM		911,034	-2,445	-3,590	-3,618
C Japan Total		1,100,069	-12,858	-14,002	-14,030
A Rate of decrease			-5.5%	-5.5%	-5.5%
B Rate of decrease			-0.3%	-0.4%	-0.4%
C Rate of decrease			-1.2%	-1.3%	-1.3%

Source: authors' calculation base on TM Input-Output table

(3) The case TEE gives damages to all sectors including headquarters in TM

Next, the impact in the case of damage to all sectors is shown in Table 4. In all models, the amount of decrease of production calculated here conforms to the totals of the results considering damage to the head office (Table 2) and the results considering damage to all sectors except the head office (Table 3). For example, regarding the damage for the manufacturing industry outside of Tokyo based on the demand-based model, the decrease of production is 43 billion yen in Table 2 and that is 1,021 billion yen in Table 3, which conforms to 1,064 billion yen in Table 4. Since the conventional input–output model has a characteristic of linearity between the final demand and induced production value, the total of production inducement effects calculated from different final demands is same as the production inducement effect calculated with the total of the different final demands.

Table 4 Damage to TM and outside of TM
(Damage to all sectors including headquarters in TM, Billion yen)

		Pre TEE production	Production decreases by TEE		
			Demand model	Supply model	Hybrid model
Tokyo	Agriculture / mining	111	-5	-5	-5
	Manufacturing	8,857	-995	-995	-995
	Construction	8,346	0	0	0
	Electricity, gas, etc.	2,505	-389	-389	-389
	Commerce	24,143	-2,481	-2,481	-2,481
	Service	114,365	-6,543	-6,543	-6,543
	Headquarters	30,707	-3,071	-3,071	-3,071
Outside of Tokyo	Agriculture / mining	13,624	-79	-80	-105
	Manufacturing	292,489	-1,064	-2,204	-2,188
	Construction	52,491	-11	-405	-243
	Electricity, gas, etc.	31,576	-152	-175	-263
	Commerce	71,336	-180	-781	-768
	Service	397,975	-663	-2,996	-2,908
	Headquarters	51,543	-546	-250	-576
A TM Total		189,035	-13,483	-13,483	-13,483
B Outside of TM		911,034	-2,695	-6,891	-7,051
C Japan Total		1,100,069	-16,178	-20,374	-20,534
A Rate of decrease		—	-7.1%	-7.1%	-7.1%
B Rate of decrease		—	-0.3%	-0.8%	-0.8%
C Rate of decrease		—	-1.5%	-1.9%	-1.9%

Source: authors' calculation base on TM Input-Output table

5. Discussion

Thus far, we have introduced simulations on economic indirect damage in outside of TM applying four types of I–O models. Even though the simulation results are tentative, we would like to compare our results with that given by the CDMC. Table 5 shows the comparison our results with CDMC's estimation.

The total indirect economic damage to outside of TM is 47.9 trillion yen according to CDMC's estimation. In terms of an industry-based comparison, in Wholesale / retail, Finance / insurance and Real estate, the amounts of damage are higher in CDMC, while for Transport / communications and Services, the amounts of damage are higher in this research.

Table 5 Comparison of damage estimates with CDMC (Billion yen)

	CDMC estimates	Demand model	Supply model	Hybrid model
Agri. / forestry / fishery	500	78	77	99
Mining	100	6	9	11
Construction	3,200	11	405	243
Wholesale / retail	12,500	2,661	3,261	3,249
Finance / insurance	4,800	904	1,176	1,178
Real estate	6,900	814	979	963
Trans. / comm.	1,900	3,626	3,921	4,025
Electricity / gas / water	2,200	541	564	652
Service sector	2,800	1,862	3,463	3,285
Transport machinery	2,600	307	622	502
Other manufacturing	10,500	1,752	2,577	2,681
Headquarters	—	3,616	3,321	3,646
Total（Excluding HQ）	—	12,562	17,053	16,888
Total（including HQ）	47,900	16,178	20,374	20,534

Source: CDMC (2013) and authors' calculation base on TM Input-Output table

6. Conclusion

In this paper, three types of models have been presented to measure the indirect damage from supply constraints caused by earthquakes, and preliminary calculations of the amount of indirect damage were made for Tokyo Epicentral Earthquakes while the characteristics of each model were also considered. This technique was based on Shimoda and Fujikawa (2012) that studied the Great East Japan Earthquake. Therefore, the tendencies that the models detected in this study are generally the same as those of Shimoda and Fujikawa (2012). However, as headquarters functions with major forward linkage effects are an important sector in TM, it was confirmed that there are different effects from those of the Great East Japan Earthquake, including the greater damage from the supply-based model than the demand-based model. Furthermore, while the supply constraints in the manufacturing sector were brought into relatively sharp focus when the Great East Japan Earthquake occurred, it is predicted that supply constraints in such service sectors as headquarters and telecommunications would be a more serious issue when Tokyo Epicentral Earthquake occurs. This research would be positioned as a first step in the quantitative evaluation of such issues, but numerous issues remain in order to make damage estimates more closely conformed to the reality.

Before closing this paper, we would like to talk about remaining challenges. The first point is that indirect damage estimation using conventional input-output analysis such as demand-type model, supply-type model, and hybrid-type model is significantly different from CDMC's damage estimation, although the simulation method and assumptions are different. We would like to try to solve this by using a method other than the conventional input-output analysis model.

There are some other challenges as well. For example, 1) we have estimated the direct production decrease in TM based on that in Kobe after the Great Hanshin Earthquake, 2) we did not consider a replacement supply by international or domestic imports, and 3) we treated headquarters like any other business service. We would like to also study these issues in the future papers.

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