Bottleneck 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

The Great East Japan Earthquake（GEJE）in 2011 caused damages to auto parts plants in the Tohoku and northern Kanto regions of Japan, which in turn caused parts supply disruptions that halted production at vehicle assembly plants across the country. This phenomenon is caused by the fact that intermediate inputs are at least in the short run completely non-substitutable, and is referred to as the bottleneck effect in this paper. The demand driven model (Leontief model) and supply driven model (Ghosh model) presented in the first presentation cannot handle such phenomena adequately. In this presentation, we introduce a model that emphasizes the idea of complete non-substitutability among inputs of production, while the demand driven model also assumes non-substitutability among factors. The difference between them is that this idea is used on the demand side of the input good in the demand driven model, while in the bottleneck model the idea is used on the production side. The idea of this model is new and has never been presented at an international conference before, and we believe it is important to introduce this model at IIOA because of its significant academic contribution.

In the Leontief model, the production function can be expressed as the ratio of the quantity of intermediate input goods divided by the input coefficient for each material, the smallest of which is the output. When TM (TM) is hit by an earthquake, supply of intermediate inputs from TM to the other region decreases. Since the numerator of each element of the Leontief type production function becomes smaller, the amount of production will decrease. We estimate the decrease of output of the other region based on TM two-regional Input-Output table.

However, the magnitude of the change depends on how TM's output is distributed among industries in other regions. In this presentation, we assume that the distribution ratio is the same as before the earthquake, although this is a strong assumption. Therefore, there is a problem that the bottleneck effect may be too strong in this model.

1. Introduction

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.”

On the other hand, Hasebe (2002) 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.

2. Bottleneck model

As stated in the previous section, what actually happened in the GEJE was an abrupt supply shortage of intermediate inputs whereby the damaged parts plants in Tohoku and north Kanto stopped nationwide automobile production. The conventional Input-Output models may not able to appropriately handle such a situation.

Therefore, this study introduces a model that assumes perfect non-substitutability with regard to intermediate inputs with reference to Hasebe (2002). Figure 2 is a simplified interregional input–output table with two regions (Region A and Region B) and two products (Goods 1 and Goods 2).

		Region A		Region B	
		Goods 1	Goods 2	Goods 1	Goods 2
Region A	Goods 1	x_{11}^{AA}	x_{12}^{AA}	x_{11}^{AB}	x_{12}^{AB}
	Goods 2	x_{21}^{AA}	x_{22}^{AA}	x_{21}^{AB}	x_{22}^{AB}
Region B	Goods 1	x_{11}^{BA}	x_{12}^{BA}	x_{11}^{BB}	x_{12}^{BB}
	Goods 2	x_{21}^{BA}	x_{22}^{BA}	x_{21}^{BB}	x_{22}^{BB}
Value added		v_1^A	v_2^A	v_1^B	v_2^B
Production		x_1^A	x_2^A	x_1^B	x_2^B

Figure 1 Simplified Interregional Input–Output table

Source: authors compilation

With the assumption of complete non-substitutability among inputs[1], the production functions of the products in Region A and Region B can be expressed in the following equations (1A) and (1B), respectively. The parameter a is the input coefficient and τ is the added-value coefficient in the equations.

$$x_j^A = \mathrm{Min}\left\{\frac{x_{1j}^{AA} + x_{1j}^{BA}}{a_{1j}^A}, \frac{x_{2j}^{AA} + x_{2j}^{BA}}{a_{2j}^A}, \frac{v_j^A}{\tau_j^A}\right\} (j = 1,2) \tag{1A}$$

$$x_j^B = \mathrm{Min}\left\{\frac{x_{1j}^{AB} + x_{1j}^{BB}}{a_{1j}^B}, \frac{x_{2j}^{AB} + x_{2j}^{BB}}{a_{2j}^B}, \frac{v_j^B}{\tau_j^B}\right\} (j = 1,2) \tag{1B}$$

Here, it is assumed that a disaster has occurred in Region A and that labor and capital input have decreased. For this reason, the value-added of both goods in Region A decrease at the rate of α_1 and α_2, respectively. In this case, the value-added in Region A are $v_1^A(1-\alpha_1)$ and $v_2^A(1-\alpha_2)$, respectively. Production in

1 It is assumed that the same type of inputs are substitutable even if the production areas are different,

Region A decreases at the same rates of $v_1^A(1-\alpha_1)/\tau_1^A$ and $v_2^A(1-\alpha_2)/\tau_2^A$, respectively. The decrease in production in Region A decreases the production in Region B that requires intermediate goods from Region A while the extent of decrease depends on how the Region A products are distributed. Assuming that the distribution ratio is the same as prior to the disaster, production in Region B can be expressed as the following equation (2):

$$x_j^B = \mathrm{Min}\left\{\frac{b_{1j}^{AB} v_1^A(1-\alpha_1)/\tau_1^A + x_{1j}^{BB}}{a_{1j}^B}, \frac{b_{2j}^{AB} v_2^A(1-\alpha_2)/\tau_2^A + x_{2j}^{BB}}{a_{2j}^B}, \frac{v_j^B}{\tau_j^B}\right\} \quad (j = 1, 2) \qquad (2).$$

The parameter b_{ij}^{AB} is the distribution coefficient, which is defined in the following equation (3):

$$b_{ij}^{AB} = x_{ij}^{AB}/x_i^A \quad (i, j = 1,2) \qquad (3).$$

As is shown in the equation (2), the intermediate input will limit the product to the minimum that can be produced in the bottleneck model. In the simulation performed in the next section, the calculation is made by replacing the initial amount of decrease of production with $v_j^A(1-\alpha_1)$ $(j = 1,\ 2)$.

3. Simulation

3-1 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.[2] 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.

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

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.[3]

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 CY2015, 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.

3 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.

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 four 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	Bottleneck model
Tokyo	Agriculture / mining	111	0	0	0	0
	Manufacturing	8,857	0	0	0	0
	Construction	8,346	0	0	0	0
	Electricity, gas, etc.	2,505	0	0	0	0
	Commerce	24,143	0	0	0	0
	Service	114,365	0	0	0	0
	Headquarters	30,707	-3,071	-3,071	-3,071	-3,071
Outside of Tokyo	Agriculture / mining	13,624	-1	-36	-45	-422
	Manufacturing	292,489	-43	-947	-932	-9,064
	Construction	52,491	-1	-178	-99	-1,627
	Electricity, gas, etc.	31,576	-32	-82	-125	-858
	Commerce	71,336	-5	-541	-547	-2,211
	Service	397,975	-155	-1,470	-1,452	-11,149
	Headquarters	51,543	-13	-46	-233	0
A TM Total		189,035	-3,071	-3,071	-3,071	-3,071
B Outside of TM		911,034	-250	-3,301	-3,433	-25,330
C Japan Total		1,100,069	-3,320	-6,372	-6,504	-28,401
A Rate of decrease			-1.6%	-1.6%	-1.6%	-1.6%
B Rate of decrease			0.0%	-0.4%	-0.4%	-2.8%
C Rate of decrease			-0.3%	-0.6%	-0.6%	-2.6%

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.

In the bottleneck model shown in the fourth column of Tables2, the production decrease outside Tokyo is approximately 25 trillion yen, which is much larger than those in the three other models. The bottleneck model assumes complete non-substitutability among intermediates inputs. In other words, when the input from headquarters decreases at a certain rate, the production of all other industries decreases with the same rate. However, the bottleneck model allows interregional substitutability, then even if headquarters in Tokyo were totally lost, production outside Tokyo would not reach zero as long as headquarters outside Tokyo survives. However, even if headquarters outside Tokyo can substitute the headquarters functions, the impact of 10% decrease from the headquarters in

Tokyo is extremely large in the bottleneck model and the production outside of Tokyo would decrease by 2.8% compared to before the earthquake.

(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 four 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, approximately 3.6 trillion yen in the supply-based model and hybrid model, and approximately 33.9 trillion yen in the bottleneck 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 strong backward linkage effect on average in comparison to headquarters whose backward linkage effect is weak.

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.

As with the case in Table 2, the production decrease in the bottleneck model outside of Tokyo is an order of magnitude larger than those in the three other models.

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	Bottleneck
Tokyo	Agriculture / mining	111	-5	-5	-5	-5
	Manufacturing	8,857	-995	-995	-995	-995
	Construction	8,346	0	0	0	0
	Electricity, gas, etc.	2,505	-389	-389	-389	-389
	Commerce	24,143	-2,481	-2,481	-2,481	-2,481
	Service	114,365	-6,543	-6,543	-6,543	-6,543
	Headquarters	30,707	0	0	0	0
Outside of Tokyo	Agriculture / mining	13,624	-78	-44	-60	-522
	Manufacturing	292,489	-1,021	-1,257	-1,256	-12,549
	Construction	52,491	-10	-226	-144	-1,415
	Electricity, gas, etc.	31,576	-120	-93	-138	-1,507
	Commerce	71,336	-175	-239	-222	-2,313
	Service	397,975	-508	-1,526	-1,456	-13,349
	Headquarters	51,543	-533	-204	-343	-2,242
A TM Total		189,035	-10,412	-10,412	-10,412	-10,412
B Outside of TM		911,034	-2,445	-3,590	-3,618	-33,897
C Japan Total		1,100,069	-12,858	-14,002	-14,030	-44,310
A Rate of decrease			-5.5%	-5.5%	-5.5%	-5.5%
B Rate of decrease			-0.3%	-0.4%	-0.4%	-3.7%
C Rate of decrease			-1.2%	-1.3%	-1.3%	-4.0%

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 except for the bottleneck model, 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. On the other hand, regarding the bottleneck model, this relationship does not hold. In the bottleneck model, only the production of goods with the largest change in input ratio explains the output change. Non-linearity of the results is due to that the intermediate inputs with the largest change in input ratio are different in each case.

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	Bottleneck
Tokyo	Agriculture / mining	111	-5	-5	-5	-5
	Manufacturing	8,857	-995	-995	-995	-995
	Construction	8,346	0	0	0	0
	Electricity, gas, etc.	2,505	-389	-389	-389	-389
	Commerce	24,143	-2,481	-2,481	-2,481	-2,481
	Service	114,365	-6,543	-6,543	-6,543	-6,543
	Headquarters	30,707	-3,071	-3,071	-3,071	-3,071
Outside of Tokyo	Agriculture / mining	13,624	-79	-80	-105	-529
	Manufacturing	292,489	-1,064	-2,204	-2,188	-12,549
	Construction	52,491	-11	-405	-243	-1,627
	Electricity, gas, etc.	31,576	-152	-175	-263	-1,507
	Commerce	71,336	-180	-781	-768	-2,313
	Service	397,975	-663	-2,996	-2,908	-14,193
	Headquarters	51,543	-546	-250	-576	-2,242
A TM Total		189,035	-13,483	-13,483	-13,483	-13,483
B Outside of TM		911,034	-2,695	-6,891	-7,051	-34,960
C Japan Total		1,100,069	-16,178	-20,374	-20,534	-48,443
A Rate of decrease		—	-7.1%	-7.1%	-7.1%	-7.1%
B Rate of decrease		—	-0.3%	-0.8%	-0.8%	-3.8%
C Rate of decrease		—	-1.5%	-1.9%	-1.9%	-4.4%

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

4. 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. This estimated damage is close to the that in the bottleneck model in this study, where the estimated damage is 48.4 trillion yen in the case TEE gives damages to all sectors including headquarters in TM and 43.1 trillion yen in the case TEE gives damages to non-headquarters in TM. 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 is higher in this research. However, it is notable that CDMC and this research give similar estimation as for Transportation machinery that includes automobile industry.

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

	CDMC estimates	Demand model	Supply model	Hybrid model	Bottleneck model
Agri. / forestry / fishery	500	78	77	99	507
Mining	100	6	9	11	26
Construction	3,200	11	405	243	1,627
Wholesale / retail	12,500	2,661	3,261	3,249	4,794
Finance / insurance	4,800	904	1,176	1,178	1,889
Real estate	6,900	814	979	963	2,797
Trans. / comm.	1,900	3,626	3,921	4,025	5,822
Electricity / gas / water	2,200	541	564	652	1,896
Service sector	2,800	1,862	3,463	3,285	10,228
Transport machinery	2,600	307	622	502	2,536
Other manufacturing	10,500	1,752	2,577	2,681	11,009
Headquarters	—	3,616	3,321	3,646	5,312
Total（Excluding HQ）	—	12,562	17,053	16,888	43,130
Total（including HQ）	47,900	16,178	20,374	20,534	48,443

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

5. Conclusion

In this paper, four types of models have been presented to measure the indirect damage 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 discuss these issues.

First, the production decrease in Kobe after the Great Hanshin Earthquake was used as the assumed damage estimate for each industry, but this was just a placeholder for the preliminary calculation. It goes without saying that Kobe and Tokyo have different industry structures, and that TM may have different preparations in terms of earthquake-proofing during 25 years after the Great Hanshin Earthquake. A possible direction is to use the same production function-based method as the Central Disaster Management Council used, but this will be an arduous task in terms of data preparation.

Second, while it was suggested that the bottleneck model was potentially the most realistic explanation of the damage when looking at the preliminary calculations both in Shimoda and Fujikawa (2012) and in this research, it is necessary to make revisions that reflect the actual situation. For example, in the bottleneck model in this paper, there is no consideration for replacement supply by international or domestic imports. Even in the case of production suspension in the Tohoku region, replacement supply from the other regions did take place after the Great East Japan Earthquake. It is necessary to sophisticate the model to take the such cases into account.

Third, it is necessary to consider the handling of headquarters functions. As stated before, headquarters functions are vastly different from normal services in that they cannot be replaced using different companies. In this paper, headquarters services were handled in the same way as other services, but it is impossible for companies that have head offices in Tokyo to purchase headquarters services of other companies outside Tokyo. It would be required to construction a model that reflects such special characteristics of headquarters. In addition, on the other hand we also need to consider whether it is appropriate to handle headquarters services as completely non-substitutable inputs

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