**Evaluation of Supply Restriction due to a Huge Disaster**

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# Abstract

The equilibrium output model of the Input-Output analysis is demand oriented. It assumes that the supply side is always adjustable to the change of the demand side. A classic example of such analyses is an analysis of economic ripple effect of big events such as Olympic Games or World EXPOs. The additional demand is assumed to be supplied somehow. On the other side a large scale unpredicted natural disaster such as the Great East Japan Earthquake of March 3, 2011 exposes the limitations of the supply side. The disruption of production in the devastated area proved to be a more complex situation than a mere “decrease in demand”. This paper studies how to describe such supply side limitations under the framework of Input-Output analysis.

# 1. Introduction: supply-side limitations of the disaster

We receives mane graces from nature, but the powerlessness of humans against large scale natural disasters was felt with full force after the Great East Japan Earthquake of March 3rd, 2011 (hereinafter “the Earthquake”), where more than 20,000 people died and more than 200,000 people lost their homes. The Economic loss has been enormous, and the direct impact caused by damage of stock has been estimated to exceed 15 trillion yen[[5]](#footnote-5).

The disruption in production of the devastated area’s businesses affected the input-output structures of the downstream businesses, causing constraints in their production activity. The massive indirect damages from such output constraints can be regarded as one of the features of the economic damage caused by the earthquake.

Input-output table is a statistical table that records the linkage structures of intermediate inputs among industries. It is the equilibrium output model of the Input-Output analysis that was developed using such a feature. The typical application of this model is an analysis of economic ripple effect on big events, such as Olympic Games and World EXPOs. The equilibrium output model assumes that what is demanded is supplied, or that there is no bottleneck in supply chains in the intermediate transaction. However, the main effect of the earthquake was not “decrease of the demand” within the devastated area but “supply constraint” which caused disruption of production within the area. This paper discusses how to describe that supply constraint.

Talking of economic damage by the earthquake, those to non-manufacturing sectors such as voluntary restraint on the leisure sector, the decrease in tourism, and demand decrease in agricultural products by harmful rumors about the safety cannot be neglected. In this paper, however, due to the data constraint and intent to focus on indirect ripple damage caused by supply constraint, the focus of the analysis will be set mainly on the manufacturing sectors. Also, the main goal of this paper was not to estimate the value of the indirect ripple damages caused by the Earthquake; rather the main goal was to study validity and features of various alternative analytical models to estimate the indirect ripple damages.

The paper is structured as follows. In Section 2, we look at the trend of production index by area and industry to summarize the damages and recovery process in the manufacturing sectors. Section 3 presents four models for measuring indirect economic damages caused by the earthquake. In Section 4, based on models from the third chapter we make simulation of the ripple effect economic damage after the earthquake, and an empirical study of each model. The fifth chapter summarizes the conclusions and tasks for the future.

# 2 Overview of devastation and industrial output after the earthquake

## 2-1 Overview of devastation of the manufacturing sectors

The area of devastation affected by the Earthquake is an extensive area that includes the pacific coast of Tohoku region and the north part of Kanto region. The shares of food products, electronic components, electronic circuit and devices, chemical industries are relatively high in the shipments of manufacturing sectors in four heavily damaged prefectures, which are Iwate, Miyagi, Fukushima and Ibaraki. In addition, many manufacturing plants producing such basic materials as silicon wafers or chemical products, and such electronics related parts as semi-conductors or LCD panels were located in this area. Among them there are enterprises which hold large share not only domestically in Japan but also in the world[[6]](#footnote-6). It was observed that devastation in such important areas that supply materials and parts, Tohoku and north Kanto, caused a decrease in economic activities of the outside the devastated areas. Economic and Public Finance White Paper for 2011 analyzes the effects of the disruption of the supply chain by calculating “dependency ratio” on Tohoku region of other regions by industry. According to the article, the dependency of passenger automobile manufacturing on Tohoku region, for example, is very large since there exist many suppliers for “tires and rubber products”, “electronic components” and “telecommunication and related equipment” in the devastated are. And this article argues that complete disruption of the car manufacturing in Japan occurred since automobile manufacturing requires many custom and indispensable products that are non-substitutable by other products like microcontrollers that consist from “electronic components”.

The speed of recovery, on the other hand, was remarkable and has proceeded faster than initially expected. According to the surveys that the Ministry of Economy, Trade and Industry (METI) held after the Earthquake, the ratio of manufacturing establishments that answered “already recovered” had been 60% as of April 2011, while the same ratio increased 60% as of June 2011[[7]](#footnote-7). The number of establishments that answered that “there are some parts or materials that I can find no alternate suppliers” had been 12% in basic materials industries and 48% in processing and assembling industries as of April, while their numbers decreased to 0% in basic materials industries, and to 18% in processing and assembling industries as of June, 2011. As to “alternate suppliers”, 69% of questionee answered “I have alternate suppliers within Japan” and those suppliers are mainly such west Japan regions as Chugoku region (10 firms), Kinki region (8 firms), Shikoku and Kyushu region (7 firms). And 56% of questionee answers “I have alternate suppliers from abroad”, which includes China (14 firms), Asian countries other than China (7 firms), and, North America (4 firms).

It is also very interesting that the share of the questionee that answered “I will return to original supplier after the original domestic suppliers are restored” reaches 83%. However, on the other hand, there are answers “I will continue to receive supply from domestic alternate suppliers” and “I will continue to receive supplies from foreign alternate suppliers” (even after restoration of original suppliers). Those answers reach about 58% and 42% each[[8]](#footnote-8). Obviously, the acquisition and selection of alternative suppliers and relation with them after restoration, depends on the products and business partners.

## 2-2 Transition of the industrial output index

Here we take a look at the change in economic activities by region by through the transition of the Index of Industrial Production (IIP). Figure1 demonstrates the transition of Japan’s IIP by region. Japan’s IIP experienced an unprecedented drastic decline during the world economic crisis triggered by so-called Lehman Shock in 2008. And in March 2011, the Great East Japan Earthquake caused the second large-scale output decrease in 3 years. Some marked difference, however, can be seen from the both events. First, the speed of the recovery of output was much faster after the Earthquake than that after the Lehman Shock. Second, the output decrease after the Lehman Shock was almost uniform among all regions in Japan, while that after the Earthquake was variable among regions in Japan.

IIP decline in directly devastated Tohoku region was the worst with 35 points from February to March (or 28 points from February to April). The decline was also deep in Kanto and Chubu regions, hitting the bottom at 73.5 in March in Kato and at 76.6 in April in Chubu. The Chubu region has recovered at a slower pace compared with Kanto region. Other areas that were not directly affected by the Earthquake like Hokkaido, Kinki, Chugoku, Kyushu, experienced a modest IIP decline of around 5 to 10 points.

Figure 1 Transition of Indices of Industrial Production (IIP) by Region



Source: Indices of Industrial Production (seasonally adjusted), Ministry of Economy, Trade and Industry

Next, we look at the IIP transition by industries. Table 1 shows the transition of the IIP for manufacturing by types of industries. The values were converted so that value for February 2011 is equal 100. Shortly after the Earthquake, the maximum output decrease was recorded in transportation equipment industry. From March to April, the output decreased by 50%. Iron and steel industry, electronic components and devices industries, experienced an IIP decrease below 90 even during August 2011. The recovery has been notably slow for these sectors.

Table 1 Transition of IIP by industry (Feb. 2011=100, whole of Japan)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sector Classification | weight | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. |
| Manufacturing | 9979 | 98.3 | 100.0 | 84.5 | 85.8 | 91.2 | 94.6 | 95.0 | 95.7 |
| Iron and Steel | 600 | 98.2 | 100.0 | 89.8 | 87.9 | 86.0 | 86.9 | 86.3 | 88.5 |
| Non-Ferrous Metals | 212 | 98.9 | 100.0 | 83.5 | 86.1 | 87.7 | 90.1 | 91.2 | 93.4 |
| Fabricated Metals | 567 | 96.5 | 100.0 | 89.3 | 91.1 | 94.2 | 97.0 | 94.7 | 94.9 |
| General Machinery | 1318 | 96.7 | 100.0 | 85.5 | 95.7 | 101.1 | 100.2 | 100.7 | 101.2 |
| Electrical Machinery | 607 | 97.7 | 100.0 | 89.8 | 93.7 | 95.9 | 100.3 | 100.1 | 100.8 |
| Info. & Com. Electronics Eq. | 433 | 112.7 | 100.0 | 92.0 | 76.6 | 87.0 | 100.0 | 115.8 | 103.3 |
| Electronic Parts and Devices | 799 | 99.6 | 100.0 | 93.4 | 81.6 | 81.1 | 85.3 | 82.4 | 83.4 |
| Transport Equipment | 1686 | 95.2 | 100.0 | 53.3 | 52.3 | 71.4 | 85.3 | 90.0 | 95.9 |
| Precision instruments | 102 | 99.1 | 100.0 | 87.1 | 99.0 | 100.7 | 110.7 | 117.1 | 114.8 |
| Ceramics, clay and stone prod. | 293 | 102.0 | 100.0 | 94.9 | 95.1 | 93.4 | 93.9 | 94.8 | 95.9 |
| Chemicals | 1181 | 98.2 | 100.0 | 97.7 | 97.6 | 108.3 | 108.0 | 101.2 | - |
| Petroleum and coal prod. | 100 | 99.5 | 100.0 | 87.7 | 87.4 | 88.2 | 93.2 | 94.4 | 94.0 |
| Plastic prod. | 384 | 99.8 | 100.0 | 88.1 | 92.2 | 96.9 | 94.8 | 94.4 | 94.7 |
| Pulp, paper and paper prod. | 241 | 98.5 | 100.0 | 91.7 | 91.4 | 89.9 | 91.7 | 89.6 | 91.2 |
| Textiles | 201 | 98.6 | 100.0 | 98.2 | 97.3 | 96.5 | 96.9 | 97.2 | 98.9 |
| Foods and tobacco | 721 | 96.5 | 100.0 | 91.3 | 97.8 | 98.7 | 95.7 | 97.7 | - |
| Other manufacturing | 534 | 100.2 | 100.0 | 90.6 | 96.1 | 96.6 | 95.9 | 95.2 | 95.2 |

Note: The decreasing 10% points or more but less than 20% points is light gray cell shading, decreasing 20% points or more but less than 30% is dark gray cell shading, and decreasing 30% points or more is black cell shading as of Feb. 2010.

Source: Ministry of Economy, Trade and Industry, processed by author.

# 3 Analytic Model of Indirect Damages Caused by Disaster

## 3-1 Previous Studies

As for estimation of the indirect damages caused by disasters, there are two types of estimation: damage anticipation before a certain disaster and damage evaluation after a disaster. The former case includes those by Central Disaster Prevention Council of the Cabinet Office (CDPC) and by Hasebe (2002) and the latter case includes that by Chugoku Region Development Bureau of the Ministry of Land, Infrastructure and Transport (MLIT) (2005).

The CDPC has studied on damage provision for various anticipated earthquake, like the Tokai earthquake, the South-Eastern Sea and South Sea earthquake, as well as an epicentral earthquake at the capital Tokyo. For example, in “Expert Panel on South-Eastern Sea, South Sea earthquake”, the economic damage related to inland earthquake in Uemachi fault zone was estimated in 74 trillion yen where direct damages are estimated in 61 trillion yen and indirect damages of 13 trillion yen[[9]](#footnote-9). The methodology used in this study is composed of the following two steps. The first step is to estimate the volume of production reduction based on the estimated production function with the decrease of production factors (capital and labor) in the devastated area. Next step is to estimate the ripple effect by applying equilibrium output model to METI’s interregional input-output table. This method estimates the backward linkage of production disruption caused by the earthquake.

Hasebe (2002) estimated the output decrease caused by epicentral earthquake at the capital Tokyo using the Tokyo based input-output table. Hasebe (2002) first estimate the production function by industry in Tokyo region to obtain the output decrease caused by the earthquake during the period of “impossible to supply”. And Hasebe (2000) estimates the ripple effect of this output decrease assuming the non-substitutable Leontief type production function.

Chugoku Regional Development Bureau MLIT (2005) measured the effect of typhoon No. 18 which made a landfall in the Chugoku region on September 2004. The damage estimation for the Hiroshima prefecture was based on a questionnaire study and, as for indirect damages, the input-output table for the Hiroshima prefecture was used to obtain the ripple effect. In this case, the estimation of indirect damage is the backward linkage effect and the forward linkage effect is not estimated “due to the difficulty in estimation technique”.

## 3-2 Study of the analytic model

### (1) Demand model (Leontief model)

In order to estimate the ripple caused by demand decrease by the devastation of the earth quake, we use the Leontief type model. We think of an economy consisting of 3 areas, where the area 3 is assumed to be the devastated area, Tohoku. The equilibrium output for the areas 1 and 2 is described as follows when the area 3 is treated as an exogenous area.

$\left[\begin{matrix}A\_{11}&A\_{12}\\A\_{21}&A\_{22}\end{matrix}\right]\left[\begin{matrix}x\_{1}\\x\_{2}\end{matrix}\right]+\left[\begin{matrix}A\_{13}x\_{3}+f\_{1}\\A\_{23}x\_{3}+f\_{2}\end{matrix}\right]=\left[\begin{matrix}x\_{1}\\x\_{2}\end{matrix}\right]$(1)

$ A\_{ij}$ stands for the fixed “input coefficient” matrix from area *i* by area *j*, $x\_{i}$ stands for the output of the area *i*, and $f\_{i}$ expresses the final demand vector for goods of the area *i.* When we solve equation (1) by $x\_{1}$, $x\_{2}$, equilibrium output is obtained as

$\left[\begin{matrix}x\_{1}\\x\_{2}\end{matrix}\right]=\left[I-\left[\begin{matrix}A\_{11}&A\_{12}\\A\_{21}&A\_{22}\end{matrix}\right]\right]^{-1}\left[\begin{matrix}A\_{13}x\_{3}+f\_{1}\\A\_{23}x\_{3}+f\_{2}\end{matrix}\right]$(2)

Here if we assume that the output of the area 3 decreased by $∆x\_{3}$, by the Earthquake, the output change in the area 1 and 2 can be obtained from following equation. $ A\_{i3}∆x\_{3}$ expresses intermediate demand decrease for goods in the area *i* caused by the Earthquake.

$\left[\begin{matrix}∆x\_{1}\\∆x\_{2}\end{matrix}\right]=\left[I-\left[\begin{matrix}A\_{11}&A\_{12}\\A\_{21}&A\_{22}\end{matrix}\right]\right]^{-1}\left[\begin{matrix}A\_{13}∆x\_{3}\\A\_{23}∆x\_{3}\end{matrix}\right]$(3)

Equation (3) measures the backward linkage effect of output decrease in the devastated area.

### (2) Supply model (Ghosh model)

 In the Leontief type model, demand determines supply. It is possible, however, to construct a model where supply determines demand. In this section we call this supply driven model “Ghosh type model” following Miller and Blair (2009). In Ghosh type of model, we define that “output coefficient” from one industry to another and the exogenous variable is the volume of the value-added and. The production level is determined as the total of the value-added and intermediate inputs.

Let’s think of the 3 region model as we used in the previous section. To measure the ripple of output decrease caused by the disaster of the supply side, we use Ghosh model, where devastated area, Tohoku, is exogenous. Then the output for areas 1 and 2 can be described by the following equation:

$\left[\begin{matrix}x\_{1}^{'}&x\_{2}^{'}\end{matrix}\right]=\left[\begin{matrix}x\_{1}^{'}&x\_{2}^{'}\end{matrix}\right]\left[\begin{matrix}G\_{11}&G\_{12}\\G\_{21}&G\_{22}\end{matrix}\right]+\left[\begin{matrix}x\_{3}^{'}G\_{31}+v\_{1}^{'}\\x\_{3}^{'}G\_{32}+v\_{2}^{'}\end{matrix}\right]$(4)

$G\_{ij}$ stands for output coefficient matrix from area *i* toarea *j*, and $v\_{i}$ is value added vector of area *i*. When solve (8) by $x\_{1}^{'}$ and$x\_{2}^{'}$, we obtain the following equation.

$\left[\begin{matrix}x\_{1}^{'}&x\_{2}^{'}\end{matrix}\right]=\left[I-\left[\begin{matrix}G\_{11}&G\_{12}\\G\_{21}&G\_{22}\end{matrix}\right]\right]^{-1}\left[\begin{matrix}x\_{3}^{'}G\_{31}+v\_{1}^{'}\\x\_{3}^{'}G\_{32}+v\_{2}^{'}\end{matrix}\right]$(5)

If the output of the area 3 decreased by $∆x\_{3}$ because of the Earthquake, then the output change of areas 1 and 2 can be obtained from the following equation.

$\left[\begin{matrix}∆x\_{1}^{'}&∆x\_{2}^{'}\end{matrix}\right]=\left[I-\left[\begin{matrix}G\_{11}&G\_{12}\\G\_{21}&G\_{22}\end{matrix}\right]\right]^{-1}\left[\begin{matrix}∆x\_{3}^{'}G\_{31}\\∆x\_{3}^{'}G\_{32}\end{matrix}\right]$(6)

In equation (6), $∆x\_{3}^{'}G\_{3j}$ is output decrease in the area *j* caused by output decrease from the of area 3 commodity decrease amount. Equation (6) measures the forward linkage effect output decrease in the devastated area caused by.

Incidentally, how Ghosh type model has a reality relevant? The advocate of the model, Ghosh himself, kept the government controlled and planned economy with excess demand in his mind[[10]](#footnote-10). Such situation supposed by Ghosh would be rare and cannot be applied to ordinary market economies. Hasebe (2002) outlines two problematic issues with the Ghosh model; 1) its assumption of a constant output coefficient is unrealistic, 2) it implicitly assumes perfect substitution in production function in all the industries. In other studies, Oosterhaven (1988) state that it is unrealistic to assume that demand is perfectly determined from supply side, even though he suggests output coefficient would be stable if the growth rate of output among industrirs is equal and the input index is stable.

### (3) Demand and supply hybrid model (Hybrid model)

The supply model assumes that the share of the sales destination is fixed by product, it is natural, however, to assume that sales destination is adjustable unlike technological relation of the product. In other words, the relation described in equation (5) is not necessarily valid. We assume, therefore, that the forward linkage effect expressed in Ghosh model will function only on the first step and after that the backward linkage effect expressed in Leontief model will function.

Similarly as before, we look at the idea in 3 area model where the area 3 is exogenous. Now, suppose that the output in the area 3 decreased by $∆x\_{3}$ because of the Earthquake. On the initial step, the output decrease of the area 2 and 3 are respectively $G\_{31}^{'}∆x\_{3}$ and $G\_{32}^{'}∆x\_{3}$ if the forward linkage effect of Ghosh model works. But the forward linkage process in Ghosh model will last longer and from the next step the backward linkage effect of Leontief model works. Then, the output decreases in the area 2 and 3 is calculated as a product of Leontief’s inverse matrix and $G\_{31}^{'}∆x\_{3}$ and $G\_{32}^{'}∆x\_{3}$ as shown in the equation (7). Here we call model (7) as “demand and supply hybrid model” or simply “hybrid model”.

$\left[\begin{matrix}∆x\_{1}\\∆x\_{2}\end{matrix}\right]=\left[I-\left[\begin{matrix}A\_{11}&A\_{12}\\A\_{21}&A\_{22}\end{matrix}\right]\right]^{-1}\left[\begin{matrix}G\_{31}^{'}∆x\_{3}\\G\_{32}^{'}∆x\_{3}\end{matrix}\right]$(7)

Here let us summarize the three models that we introduced so far in Figure 2. Starting point of analysis is commonly the output decrease of Tohoku area (grayed cell). In Leontief model(Model i), Tohoku area’s output decrease causes a decrease of demand for intermediate goods in the area 1 and 2 by Tohoku area (vertical arrow of solid line), and this demand decrease furthermore decreases an output decrease in the area 1 and 2. On the other hand, in Ghosh model (Model ii), Tohoku area’s output decrease causes a decrease of supply of intermediate goods to the area 1 and area 2 (horizontal arrow of solid line), and this again causes a decrease supply in the area 1 and area 2. In hybrid model(model iii), supply of intermediate goods to area 1 and area 2 decreases, which is the same as in Ghosh model on the first step, but on the following steps, output decrease in area 1 and area 2 causes a decrease of intermediate demand in the same area (horizontal arrow of dotted line) and these afterwards backward linkage effect will continue[[11]](#footnote-11).

Figure 2 Path of ripple effects of each model



Source: Authors compilation

### (4) Bottle neck model

What occurred after the Earthquake is production halt in, for example, in automobile industry by devastation of microcontroller plant in Tohoku and North Kanto area. Such powerful bottleneck effect functioned in various sectors. Here we refer to the model proposed in Hasebe (2002) which introduces an idea of non-substitution in inputs but substitution in regions concerning the same input.

Let us show an example of 2 areas (A, B) and 2 goods (1, 2) as is shown in Figure 3.

Figure3 Inter-regional Input-Output Table

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Region A | Region B |
|  |  | Sector 1 | Sector 2 | Sector 1 | Sector 2 |
| Region A | Sector 1 | $$x\_{11}^{AA}$$ | $$x\_{12}^{AA}$$ | $$x\_{11}^{AB}$$ | $$x\_{12}^{AB}$$ |
| Sector 2 | $$x\_{21}^{AA}$$ | $$x\_{22}^{AA}$$ | $$x\_{21}^{AB}$$ | $$x\_{22}^{AB}$$ |
| Region B | Sector 1 | $$x\_{11}^{BA}$$ | $$x\_{12}^{BA}$$ | $$x\_{11}^{BB}$$ | $$x\_{12}^{BB}$$ |
| Sector 2 | $$x\_{21}^{BA}$$ | $$x\_{22}^{BA}$$ | $$x\_{21}^{BB}$$ | $$x\_{22}^{BB}$$ |
| Value Added | $$v\_{1}^{A}$$ | $$v\_{2}^{A}$$ | $$v\_{1}^{B}$$ | $$v\_{1}^{B}$$ | $$v\_{2}^{B}$$ |
| Output | $$x\_{1}^{A}$$ | $$x\_{2}^{A}$$ | $$x\_{1}^{A}$$ | $$x\_{1}^{B}$$ | $$x\_{2}^{B}$$ |

Source: Authors compilation

If we assume production function of non-substitution, the production function of each goods of region A and area B can be described as following.

$x\_{j}^{A}=Min\left[\frac{x\_{ij}^{AA}+x\_{ij}^{BA}}{a\_{ij}^{A}},\frac{v\_{j}^{A}}{τ\_{j}^{A}}\right](i=1,2) $ (8a)

$x\_{j}^{B}=Min\left[\frac{x\_{ij}^{AB}+x\_{ij}^{BB}}{a\_{ij}^{B}},\frac{v\_{j}^{B}}{τ\_{j}^{B}}\right](i=1,2) $ (8b)

where $a$ is input coefficient, $τ$ is value added coefficient.

Now, suppose that a disaster struck the region A and quantity of the primary inputs (labor and/or capital) decreased by the rate of $α\_{1}$ and $α\_{2}$ in each sector respectively. Primary inputs of the region A will be $v\_{1}^{A}\left(1-α\_{1}\right)$ and $v\_{2}^{A}\left(1-α\_{2}\right)$ in each sector respectively, and the output of area A decrease to $v\_{1}^{A}\left(1-α\_{1}\right)/τ\_{1}^{A}$ and $v\_{2}^{A}\left(1-α\_{2}\right)/τ\_{2}^{A}$ in each sector respectively. The output decrease in the region A affects the output of the region B. The size of this change depends how the output is allocated by the region A. Suppose that allocation ratio is the same as before the disaster, then the region B’s outputs can be described as follows:

$x\_{1}^{B}=Min\left\{\frac{{b\_{11}^{AB}v\_{1}^{A}\left(1-α\_{1}\right)}/{τ\_{1}^{A}}+x\_{11}^{BB}}{a\_{11}^{B}},\frac{{b\_{21}^{AB}v\_{2}^{A}\left(1-α\_{2}\right)}/{τ\_{2}^{A}}+x\_{21}^{BB}}{a\_{21}^{B}},\frac{v\_{1}^{B}}{τ\_{1}^{B}}\right\} $ (9a)

$x\_{2}^{B}=Min\left\{\frac{{b\_{12}^{AB}v\_{1}^{A}\left(1-α\_{1}\right)}/{τ\_{1}^{A}}+x\_{12}^{BB}}{a\_{12}^{B}},\frac{{b\_{22}^{AB}v\_{2}^{A}\left(1-α\_{2}\right)}/{τ\_{2}^{A}}+x\_{22}^{BB}}{a\_{22}^{B}},\frac{v\_{2}^{B}}{τ\_{2}^{B}}\right\} $ (9b)

where $b$ is allocation coefficient defined as

$ b\_{ij}^{AB}={x\_{ij}^{AB}}/{x\_{i}^{A}} (i,j=1,2) $ (10)

Here, let us name this model described in equation(9) as “Bottle neck model”.

# 4 Simulations

## 4-1 Estimation assumptions

### (1) Input Output Table

For the purpose of the analysis on regional supply constraint, we use METI’s interregional input-output table from. This METI’s table divides Japan into such nine areas as Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku, Kyushu, and Okinawa[[12]](#footnote-12). We use the original 53 sector classification of the METI’s table.

### (2) Imported intermediate inputs

METI’s inter-regional table is of “competitive import and non-competitive domestic in-transfer” type. Zero-output of a product in certain regions, however, is one of the problems when we use regional tables since we cannot calculate input coefficient or output coefficient. In order avoid this problem, we restructured the original inter-regional table to “non-competitive import and non-competitive domestic in-transfer type” with a well-known assumption that import rates are same within the cells of same row sectors.

### (3) Initial output decrease by the Earthquake

As we mentioned in Section 3, the amount of output decrease in the devastated area is usually estimated either by labor and/or capital inputs in the production function in the devastated area or by ex-post surveys on the damages in the devastated area. If the estimation of the indirect damages of the Earthquake is the primary objective of this paper, we need to gather more detailed information. Our objective is, however, rather comparison of estimation method, we applied a simplified method. First, we calculate the average of the industrial output index (IIP) in Tohoku area by industry for the period of March to May 2011 as the post-Earthquake output. Second, we calculated the decline rate of output by the ration of the above mentioned post-Earthquake output on the IIP on February 2011. Third, we calculated the decreased amount of output by multiplying this ratio and the amount of output for the corresponding sector in METI’s interregional input-output table where we assume that all the output decrease was caused only by the Earthquake. As to non-manufacturing, the output decrease at the initial stage is considered zero for simplification of the analysis.

### (4) The period while indirect damages last

As we mentioned in Section 2 the recovery of businesses in the devastated areas is remarkable in general although the recovery of businesses varies among sectors. We, therefore, identify the period from March to May, 2011 as the period when supply constraint had dominant effects on the output in Japanese economy. The indirect damage ripple value was estimated for the same period of time.

## 4-2 Simulation results

Table 2 shows the output decrease based on the models described in Section 3. The rows 1 to 30 show the total output decrease in 8 regions by sector. The row 31 represents the total for manufacturing sectors, the row 32 represents the total for the non-manufacturing sector, and the row 33 is the total for all sectors. Rows 34 to 41 are aggregated values of output (decrease) for manufacturing sectors by region. Rows 42 to 47 show top 6 largest sectors in Chubu. Finally, rows 48 to 53 contain similar values for the Kinki area. The third column from the right contains the “initial output decrease”, which is initial output decrease amount obtained from industrial output index on Tohoku area of the inter-regional table for 2005.

### (1) Demand model (Leontief model) and supply model (Ghosh model)

The Output decrease in whole Japan in Leontief model is 7.6 trillion yen while that in Ghosh model is 8.0 trillion yen. The total value is almost same since the difference is no more than 418 billion yen. On the other hand, when we take a look at manufacturing(31) and non-manufacturing(32) separately, the difference is larger in manufacturing since that in manufacturing is 344 billion yen and that in non-manufacturing is only 74 billion yen.

As a general tendency the output decrease in manufacturing by Ghosh model is larger than that by Leontief model but it is interesting to compare in industry level. The output decrease by Ghosh model is larger in automobile industry (25) with 161 billion yen, general machinery (17) with 110 billion yen, and food processing and beverages (1) with 77 billion, while the output decrease in Leontief is larger in iron and steel industries (14) with 125 billion yen, coal and petroleum products (11) with 76 billion yen, and basic chemical products (7) with 71 billion yen. As, we explained in the previous section, Leontief model measures the “backward linkage effect”, meanwhile Ghosh model measures the “forward linkage”, it is plausible that a larger effect was found in final goods sectors in using Ghosh model and that a larger effect was found in material sectors in using Leontief model.

Let us compare the effects of these two models by region. The output decrease in Kanto (36) by Ghosh model is considerably large. The output decrease by Ghosh model is as much as 1 trillion 79 billion yen, while that by Leontief model is no more than 688 billion yen. This reflects the fact that Tohoku is the largest parts supplier for the Kanto region.

### (2) Hybrid model

The output decrease in hybrid model is 8.3 trillion yen in whole Japan(33) and 6.9 trillion yen in manufacturing. This is a little larger than those in Ghosh model and Leontief model. There are, however, the output decrease is in between Ghosh model and Leontief model like automobiles(25).

### (3) Bottle neck model

The output decrease estimated in Bottle neck model is extremely large comparing with other tree models. The total output decrease(33) is 44.8 trillion yen which is five to six times larger than those in other models while decrease in manufacturing(31) is relatively small 16.7 trillion yen. Using any of the other 3 models, the decrease value for manufacturing is 5 times to 6 times higher than that of non-manufacturing (32). The main feature in bottle neck model is that the output decrease in non-manufacturing is much large than that in bottle neck model. On the other hand, the output decrease in manufacturing is larger in the previous three models. The main reason of this asymmetric result is the assumption of non-substitutability of all the inputs.

As for comprehensive assessment of hybrid model, it is believed that for manufacturing such as automobiles, the output decrease is plausible to some extent. there are, however, many cases where the estimation result is not realistic for non-manufacturing,

Table 2 Output decrease estimated by each model



Source: Authors’ calculations based on METI interregional I-O table.

# 5 Conclusion

In this paper we presented the characteristic and the validity of four types of models to measure indirect damage of supply constraint caused by the Great East-Japan Earthquake. The main results obtained in this study and simulations are listed as follows:

(1)As for the aggregate value of ripple of economic damages across Japan, there is large difference between the backward linkage effect of Leontief Model and the forward linkage effects of Ghosh Model. We observed, however, rather large difference regarding the effect on individual sectors. Though government agencies, METI or MLIT, used to apply Leontief model in estimating indirect damages of disasters by I-O analysis, Leontief model may not evaluate the indirect damages, especially damages by area or by industrial sector, when supply constraint is the problem.

(2)When using Bottleneck Model, the size of direct and indirect damages for manufacturing is two times as large as those in Leontief Model or Ghosh Model. Although Leontief Model or Ghosh Model cannot explain the drastic output decline by bottleneck of intermediate input like the passengers cars, it is possible to some extent for Bottleneck Model to track such a phenomenon. However, the condition that Bottleneck Model has seems to be too strong in the respect that it allows all the intermediates input to be a bottleneck. Some inputs, in particular non-manufacturing inputs, may not be indispensable and impossible to substitute inputs which work as a bottleneck.

This research was the first step in studying on estimation models for indirect damages under the supply constraint. Further studies will be accomplished along the following direction.

(1)The definition of devastated area should be more specific. We assumed that the devastated area was only Tohoku area where the initial output decrease occurred. But it is well known that the shutdown of semi-conductor or electronic components plants located in North Kanto had a large effect on industrial output in Japan. We need to take output capacity decrease in this area into account in order to get more realistic simulation results.

(2)Decrease of output capacity in non- manufacturing sector should be considered. We assumed that decrease of output capacity occurred only in manufacturing sector. Impacts in economic activity caused by the Earthquake, however, reached other sectors such as agriculture, fishery, commerce, energy supply, transportation infrastructure, and recreation facilities. One of the most important issues to be considered among them is the capacity constraint for electricity supply. No nuclear power plant operates as of May 5th though there are 50 nuclear plants in Japan.

(3)More detailed study is required on the treatment of the time axis. The equilibrium output that I-O analysis brought is the destination that the ripple finally reaches with a certain period. The focus of this study was mainly on the effects of supply constraint, that is why, the period for analysis was assumed to be three months immediately after the earthquake. Whether or not a new equilibrium could be achieved in this short period of time is a topic for furthers discussion. And it is also to be considered that the speeds of ripple effect differ between forward linkage and backward linkage[[13]](#footnote-13).

(4)Analysis on long term effect is also required. Long-term analysis should incorporate not only the problem of supply constraint but also an analysis for demand change through the change in economic structure[[14]](#footnote-14).

We realized through this study that it is difficult to explain the real output change using economic models because the substitutability or accessibility of intermediate inputs has a great variability among sectors and enterprises. The primary objective of this research is to study the estimation method of indirect damage under supply constraint. One of the next challenges is to pick up behaviors of enterprises or business establishments in order to reflect them in economic models.

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5. Direct damages are estimated, according to Cabinet Office (2011) at nearly 16.9 trillion yen, according to Development Bank of Japan (2011) at nearly 16.4 trillion yen. [↑](#footnote-ref-5)
6. For more details refer to for example Japan External Trade Organization (2011). [↑](#footnote-ref-6)
7. METI(2011a) “Industrial situation after Great East Japan Earthquake urgent survey” and METI(2011b) “Industrial situation after Great East Japan Earthquake urgent survey-2” [↑](#footnote-ref-7)
8. Because of the multiple choice answers the total is not equal to 100%. [↑](#footnote-ref-8)
9. Central Disaster Prevention Council (2008) “On results of damage anticipation of inland earthquake in Chubu area and Kinki area: economic damage”. “Uemachi” is an area name in Osaka city. [↑](#footnote-ref-9)
10. See Ghosh(1958). [↑](#footnote-ref-10)
11. In hybrid model, production spillover is measured from “step forward and turn back”, it is necessary to pay attention to possibility of occurrence of double count. [↑](#footnote-ref-11)
12. We aggregate Kyushu and Okinawa, since the economic size of Okinawa is small comparing with other regions. [↑](#footnote-ref-12)
13. If ignore existence of stock, then supply disruption of parts and materials would immediately affect upstream production. In this meaning, it is thought that the speed of ripple of forward relation effect is faster. [↑](#footnote-ref-13)
14. Ashiya (2005) using Hyogo prefecture input-output table for 1990, 1995, 2000, analyzed in detail the change of economic structure before and after of Great Hanshin earthquake. [↑](#footnote-ref-14)