Chapter 17
Unexpected Natural Disasters and Regional Economies: CGE Analysis Based on Inter-regional Input–Output Tables in Japan

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Abstract Japan is a country that faces many natural disasters. These disasters adversely affect the economy and are difficult to predict. This study aims to analyze the impact of such disasters on the local economy by using the Monte Carlo experiment.

In this study, we use an inter-regional input–output table consisting of two regions: Fukuoka prefecture and other prefectures. Fukuoka prefecture (Fukuoka-ken) is located on Kyushu Island where a large earthquake occurred in 2005 (Fukuoka Prefecture Western Offshore Earthquake). This region also faces frequent heavy rains and typhoons that cause severe damage.

Based on the table mentioned above, we constructed a CGE (Computable General Equilibrium) model. We then conducted simulations of natural disasters under the assumption that they will act to destroy productive inputs and efficiency. In order to establish a set of shocks representative of the sudden decrease in capital stocks and labor accompanying a natural disaster, we undertook Monte Carlo experiments. CGE simulations were then conducted using the outputs of the Monte Carlo experiments under four alternative scenarios. Results for macroeconomic and industry variables are presented, showing maximum, minimum and average effects, together with their standard deviation.

Keywords CGE Model · Inter-regional input–output table · Natural disasters · Fukuoka prefecture · Monte Carlo Experiment

JEL Classification C15, C68, D58, O53, R13

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J. R. Madden et al. (eds.), *Environmental Economics and Computable General Equilibrium Analysis*, New Frontiers in Regional Science: Asian Perspectives 41,
https://doi.org/10.1007/978-981-15-3970-1_17

17.1 Introduction

Japan is a country that faces multiple natural disasters and resulting economic effects. It is difficult to predict the occurrence of natural disasters and evaluate their impact. It is still hard to say when and where earthquakes will occur despite ongoing research on earthquake prediction. Events such as typhoons and heavy rains cause damage even though predicted routes are announced in advance. Moreover, there is further damage in the aftermath of these disasters. For instance, the accident at the Fukushima Daiichi Nuclear Power Plant, damage to the connecting bridge at Kansai International Airport, and the Hokkaido earthquake led to a power outage. The Great East Japan Earthquake in 2011 was particularly large, and the government created the Reconstruction Agency for the purpose of restoration and reconstruction. This propagated research on the recovery process from natural disasters (Tokunaga and Resosudarmo 2017). This study focuses on analyzing the regional economic impacts of unexpected natural disasters by undertaking CGE simulations of the damage to productive capacity as predicted through Monte Carlo experiments.

In this study, we use an inter-regional input–output table consisting of two regions: Fukuoka prefecture and other prefectures. Fukuoka prefecture (Fukuoka-ken) is located on Kyushu Island near the Korean peninsula. It faces the sea on three sides, bordering Saga, Oita, and Kumamoto prefectures and facing Yamaguchi prefecture across the Kanmon Straits. Fukuoka prefecture, similar to other areas, faced a big earthquake, in 2005 (Fukuoka Prefecture West Offshore Earthquake).

We proceeded by first developing a CGE (Computable General Equilibrium) model based on the inter-regional input–output table. Natural disasters are expected to affect production factors (sudden decrease in capital and labor) and logistics networks (purchase and use of intermediate goods). We analyze the impact on the regional economy when such capital, labor, and intermediate goods decrease by using Monte Carlo experiments to determine the size of the shock to be applied to the CGE model.[1]

17.2 The Model

The model in this study is based on the CGE models of economics used in various literature, mainly in Hosoe et al. (2004), the Global Trade Analysis Project (GTAP)

[1]The previous version is from Sakamoto (2019) where the method of simulation was slightly revised.

Table 17.1 Structure of inter-regional input–output table in Fukuoka prefecture

	Fukuoka	Others	Fukuoka	Others	Export	Import	Output
Fukuoka	*XM(fp,fp)*	*XM(op,fp)*	*FD(fp,fp)*	*FD(op,fp)*	*E(fp)*	*M(fp)*	*Y(fp)*
Others	*XM(fp,op)*	*XM(op,op)*	*FD(fp,op)*	*FD(op,op)*	*E(op)*	*M(op)*	*Y(op)*
Labor	*L(fp)*	*L(op)*					
Capital	*K(fp)*	*K(op)*					
Output	*Y(fp)*	*Y(op)*					

model (Hertel 1997), and an intermediate model (Rutherford 2010).[2] This study incorporated the features of the said three models to create a unique one.

Table 17.1 shows the inter-regional input–output table in Fukuoka prefecture as a variable for model development. Here, intermediate goods are written as *XM* and final demand is written as *FD*. With labor *L* and capital *K*, value-added goods *V* are produced. Intermediate goods, on the other hand, consist of those from both Fukuoka prefecture and other prefectures. These assume imperfect substitution using the CES (Constant Elasticity of Substitution) function.[3] Intermediate goods and value-added inputs are combined in constant proportions to produce domestic goods *Z*. Furthermore, the domestic goods *Z* and the import goods *M* are combined, and the final production goods (output) *Y* are produced. Domestic goods and import goods are imperfect substitutes (Fig. 17.1). Finally, production goods are divided into various final demand *FD*, intermediate goods *XM*, and export *E*.[4]

We now describe the mathematical equations. First, it is assumed that labor and capital stocks are fixed and the price fluctuates in the supply–demand relationship

[2]The model of Hosoe et al. (2004) solves an optimization problem from the production function including TFP (Total Factor of Productivity) and constructs a nonlinear model. The GTAP model also derives a cost function from the optimization problem and constructs a linear model through logarithmic conversion. The linear model is then solved using software which computes a nonlinear solution using the Euler method or similar (Harrison and Pearson 1996). Rutherford (2010) treats GTAP models as nonlinear models. This is because many researchers of CGE models use GAMS (General Algebraic Modeling System) as a computational tool. However, as shown in Fig. 17.1, while different solution methods are used for the each of the three models, the basic structure of the three models are similar. For instance, all have the same production technology and output transformation functions as depicted in Fig. 17.1.

[3]The substitution relationship is focused on whether capital and labor can be replaced in production. Needless to say, labor can replace capital equipment such as machines. Furthermore, even the same intermediate goods can be replaced if they are produced in different regions (Armington 1969). However, it is assumed that intermediate goods and value-added goods are not substitutable. The general form of the substitution relationships is a CES function. In the special case where the substitution elasticity is 1 the CES function reduces to a Cobb-Douglas function, while for a zero elasticity it reduces to a Leontief function which prevents substitution. In the case of perfect or infinite substitution, the form is $A+B$.

[4]In this study, no detailed assumptions are made for final demand, intermediate goods, and exports. A static model is assumed, and investment does not take a form that affects production in the next period. The General Equilibrium Model is constructed from the point of view that the production value should be balanced.

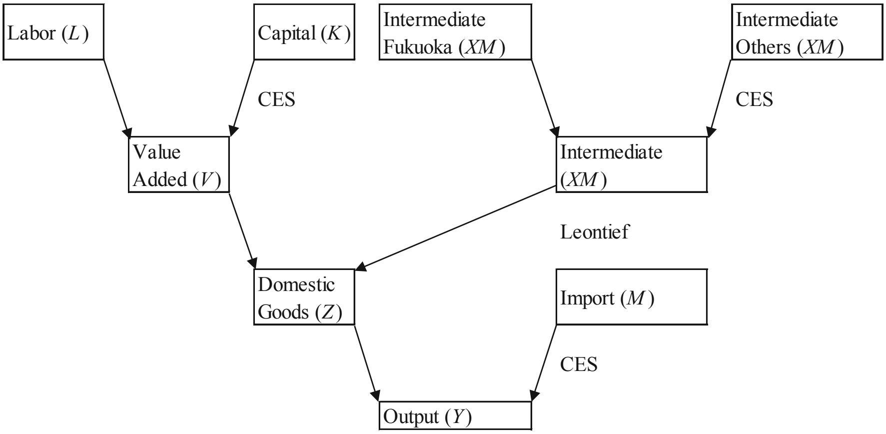

Fig. 17.1 Structure of CGE model's production technology

between labor and capital. The stock will decrease if it is damaged by a natural disaster.[5]

$$l_{r,j} = L_{r,j} \tag{17.1}$$

$$k_{r,j} = K_{r,j} \tag{17.2}$$

where l and k are endogenous variables of labor and capital stock and L and K are exogenous variables, respectively. The subscript r (s) indicates the region and j (i) indicates the industry. Since regions and industries are indicated, there will be no movement of labor and capital between regions and between industries.

Value-added goods are compounded by combining labor and capital. By constructing the optimization problem using the CES function, the cost function is expressed as follows:

$$pv_{r,j} = \left(\alpha_{r,j}^{VL} \cdot pl_{r,j}^{\left(1-\sigma_j^V\right)} + \alpha_{r,j}^{VK} \cdot pk_{r,j}^{\left(1-\sigma_j^V\right)}\right)^{\left(1 \big/ \left(1-\sigma_j^V\right)\right)} \tag{17.3}$$

[5]In reality, both the price and quantity (stock) of labor and capital fluctuate, but in the model, it is easier to construct by fixing one of them. By fixing the stock, it is impossible to indicate excess labor (employment), but in the model, excess labor is absorbed implicitly by changing prices.

Here, *pv* is the price of value-added goods, *pl* is the labor price, and *pk* is the capital price. α is a share parameter and σ is an elasticity parameter. The price of the intermediate goods combined is also shown as follows:[6]

$$pxm_{r,i,j} = \left(\sum_{s} \alpha^{XM}_{r,s,i,j} \cdot py_{s,i}^{\left(1-\sigma^X_j\right)}\right)^{\left(1 \big/ \left(1 - \sigma^X_j\right)\right)} \tag{17.4}$$

Using the Leontief function to combine value-added goods and intermediate goods, the equation is as follows:

$$pz_{r,j} = \sum_{i} \alpha^{ZM}_{r,i,j} \cdot pxm_{r,i,j} + \alpha^{ZV}_{r,j} \cdot pv_{r,j} \tag{17.5}$$

The CES function is used to combine imported goods and domestic goods. The relative price is set to 1 in the absence of a special assumption for the prices of imported goods.

$$pm_{r,j} = 1 \tag{17.6}$$

$$py_{r,j} = \left(\alpha^{YZ}_{r,j} \cdot pz_{r,j}^{\left(1-\sigma^Y_j\right)} + \alpha^{YM}_{r,j} \cdot pm_{r,j}^{\left(1-\sigma^Y_j\right)}\right)^{\left(1 \big/ \left(1 - \sigma^Y_j\right)\right)} \tag{17.7}$$

The price *p* of the consumer goods is determined by adding the indirect tax *GTAX*, the subsidy *GSUB*, and the margin *MARG* to the production goods price *py*.

$$p_{r,i} = py_{r,i} \cdot \left(1 + GTAX_{r,i} + GSUB_{r,i} + MARG_{r,i}\right) \tag{17.8}$$

We now introduce the demand function of goods. The difference between this and the previous model is that the nested demand function is summarized, which

[6] *p* is added before the variables for price variables.

makes it possible to reduce the equations to be determined on the computer. For example, the demand function for labor and capital is as follows:

$$l_{r,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pz_{r,j}}\right)^{\sigma_j^Y} \cdot \left(\frac{pz_{r,j}}{pv_{r,j}}\right)^{\sigma_j^Z} \cdot \left(\frac{pv_{r,j}}{pl_{r,j}}\right)^{\sigma_j^V} \cdot \left(\frac{pl_{r,j}}{1}\right)^{\sigma_j^L} \tag{17.9}$$

$$k_{r,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pz_{r,j}}\right)^{\sigma_j^Y} \cdot \left(\frac{pz_{r,j}}{pv_{r,j}}\right)^{\sigma_j^Z} \cdot \left(\frac{pv_{r,j}}{pk_{r,j}}\right)^{\sigma_j^V} \tag{17.10}$$

Here, the nested structure of capital demand is as follows:

$$k_{r,j} = v_{r,j} \cdot \left(\frac{pv_{r,j}}{pk_{r,j}}\right)^{\sigma_j^V}, \quad v_{r,j} = z_{r,j} \cdot \left(\frac{pz_{r,j}}{pv_{r,j}}\right)^{\sigma_j^Z}, \quad z_{r,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pz_{r,j}}\right)^{\sigma_j^Y} \tag{17.10$'$}$$

Also, there is further nesting within labor demand. Thus, the labor stock of each industry is composed of multiple types of labor, with imperfect substitution among labor types. However, the price of each labor (wage index) is assumed to be 1.[7]

Labor price (average labor price index in each industry) *pl* and capital price *pk* are determined using this demand structure and Eqs. (17.1) and (17.2).

Based on this, the demand for intermediate goods and imported goods is shown as follows:

$$xm_{r,s,i,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pz_{r,j}}\right)^{\sigma_j^Y} \cdot \left(\frac{pz_{r,j}}{pxm_{r,i,j}}\right)^{\sigma_j^Z} \cdot \left(\frac{pxm_{r,i,j}}{py_{s,j}}\right)^{\sigma_j^X} \tag{17.11}$$

$$m_{r,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pm_{r,j}}\right)^{\sigma_j^Y} \tag{17.12}$$

[7]Such forms have been applied to various fields starting from Dixit and Stiglitz (1977). For example, Fujita et al. (1999) in spatial economics and Barro and Sala-i-Martin (2004) in economic growth theory.

The supply–demand relationship of goods is shown as follows:

$$y_{r,i} = \sum_{s} fd_{s,r,i} + \sum_{s,j} xm_{s,r,i,j} + e_{r,i} + ADJ_{r,i} \tag{17.13}$$

The income (GDP) of each region is shown as the sum of labor, capital, and other added value as follows:

$$inco_r = \sum_j pl_{r,j} \cdot l_{r,j} + \sum_j pk_{r,j} \cdot k_{r,j} + \sum_j py_{r,j} \cdot y_{r,j} \cdot \left(GTAX_{r,j} + GSUB_{r,j} + MARG_{r,j}\right) \tag{17.14}$$

Finally, the final demand and the demand for export goods are indicated by the following Cobb–Douglas function (*P* is the initial value of *p*).

$$fd_{r,s,i} = P_{s.i} \cdot inco_r / p_{s,i} \tag{17.15}$$

$$e_{r,i} = P_{r.i} \cdot inco_r / p_{r,i} \tag{17.16}$$

17.3 Data and Simulation

The data uses the 2011 table of the inter-regional input–output table consisting of two regions—Fukuoka prefecture (*fp*) and other prefectures (*op*). The sector (number of industries) is 42 (Table 17.2). In this study, a model is constructed using all the information in the table. The sum of consumer spending outside a household economy (row), wages and salary, social insurance premiums (employers' costs), other salaries and allowances, was used as labor stock. For capital stock, we used capital depreciation.[8] *GTAX* is the ratio of indirect tax except customs duty, *GSUB* is the ratio of subsidy, and *MARG* is the ratio of operating surplus. On the other hand, the final demand used the sum of consumer spending outside a household economy (column), private consumption, government consumption, government investment, private investment, and inventory. Although it is assumed that the supply and demand of data are well-balanced, there is an apparent error in editing the table which is offset by an adjustment term (*ADJ* of Eq (17.13)).

Table 17.3 summarizes the actual transaction amounts shown in the Fukuoka prefecture inter-regional input–output table (2011 version). The economic scale of Fukuoka prefecture is 3.78% of the value-added in other prefectures (remaining 46

[8]Capital depreciation is not a stock value. However, assuming that the relative price of capital is 1, it can be assumed that it is capital stock. Labor stock is the same procedure.

Table 17.2 Industrial classification

	Industry		Industry
a001	Agriculture	i022	Others
a002	Forestry	i023	Construction
a003	Fishing	s024	Electricity and gas supply
i004	Mining	s025	Water supply
i005	Food products and beverages	s026	Waste treatment
i006	Textiles	s027	Wholesale and retail trade
i007	Pulp, paper, and paper products	s028	Finance and insurance
i008	Chemicals	s029	Real estate
i009	Petroleum and coal products	s030	Transport
i010	Plastic and Rubber	s031	Communications
i011	Nonmetallic mineral products	s032	Public administration
i012	Iron and steel	s033	Education and research
i013	Nonferrous metals	s034	Medical treatment, health, social security, and care
i014	Fabricated metal products	s035	Other public services
i015	License machine	s036	Business services
i016	Production machine	s037	Hotel
i017	Business machine	s038	Restaurant
i018	Electronic components	s039	Entertainment
i019	Electrical machinery, equipment, and supplies	s040	Other services
i020	Information and communication facility	s041	Stationery for an individual
i021	Transport equipment	s042	Others

Table 17.3 Actual transaction amount in the inter-regional input–output table in Fukuoka Prefecture (trillion yen)

	Fukuoka	Others	Fukuoka	Others	Export	Import	Output
Fukuoka	9.62	6.27	12.38	4.95	1.94	−1.85	33.31
Others	6.31	440.57	4.40	467.39	69.01	−81.31	906.37
Value added	17.38	459.53					
Output	33.31	906.37					

prefectures) and 3.68% of other prefectures in production. Although these figures are higher than the average size of a prefecture (2.13%), the structure is such that national economic effects are unlikely to be large unless Fukuoka prefecture achieves quite significant results in its economic policy.

Table 17.4 shows elasticity parameters. The elasticity of substitution between labor types is the logarithm of the half-power of labor stock, which could result

Table 17.4 Elasticity parameter

	σ^L (*fp*)	σ^L (*op*)	σ^V	σ^X	σ^Z	σ^Y
a001	5.177	6.856	0.26	5.00	0.00	2.50
a002	3.774	6.027	0.20	5.00	0.00	2.50
a003	4.249	6.333	0.20	2.50	0.00	1.25
i004	4.413	6.031	0.20	10.80	0.00	5.40
i005	6.146	7.701	1.12	5.04	0.00	2.52
i006	4.919	6.954	1.26	7.56	0.00	3.78
i007	5.585	7.282	1.26	6.20	0.00	3.10
i008	5.615	7.403	1.26	5.72	0.00	2.86
i009	4.171	6.239	1.26	5.72	0.00	2.86
i010	5.814	7.425	1.26	5.72	0.00	2.86
i011	5.687	7.078	1.26	7.06	0.00	3.53
i012	5.774	7.151	1.26	7.06	0.00	3.53
i013	4.728	6.895	1.26	7.06	0.00	3.53
i014	5.791	7.469	1.26	7.06	0.00	3.53
i015	5.473	7.307	1.26	8.02	0.00	4.01
i016	5.657	7.562	1.26	8.02	0.00	4.01
i017	4.465	7.075	1.26	8.02	0.00	4.01
i018	5.494	7.455	1.26	8.80	0.00	4.40
i019	5.699	7.477	1.26	8.80	0.00	4.40
i020	4.012	7.084	1.26	8.80	0.00	4.40
i021	6.128	7.849	1.26	6.40	0.00	3.20
i022	5.793	7.421	1.26	8.02	0.00	4.01
i023	6.664	8.374	1.40	3.80	0.00	1.90
s024	5.578	7.276	1.26	5.60	0.00	2.80
s025	5.207	6.660	1.26	5.60	0.00	2.80
s026	5.597	7.212	1.26	3.80	0.00	1.90
s027	7.232	8.716	1.68	3.80	0.00	1.90
s028	6.295	8.083	1.26	3.80	0.00	1.90
s029	5.930	7.611	1.26	3.80	0.00	1.90
s030	6.684	8.237	1.68	3.80	0.00	1.90
s031	6.335	8.115	1.26	3.80	0.00	1.90
s032	6.572	8.241	1.26	3.80	0.00	1.90
s033	6.881	8.438	1.26	3.80	0.00	1.90
s034	7.028	8.570	1.26	3.80	0.00	1.90
s035	5.782	7.396	1.26	3.80	0.00	1.90
s036	6.795	8.478	1.26	3.80	0.00	1.90
s037	5.178	7.051	1.26	3.80	0.00	1.90
s038	6.285	7.921	1.26	3.80	0.00	1.90
s039	5.608	7.305	1.26	3.80	0.00	1.90
s040	5.924	7.650	1.26	3.80	0.00	1.90
s041	–	–	–	3.80	0.00	1.90
s042	4.384	6.074	1.26	3.80	0.00	1.90

Note: $\sigma^L = \mathrm{Ln}(L\hat{}(1/2))$, σ^Z is a parameter of Leontief function without substitution
As no value-added data is recorded in s041 (stationery for an individual), no parameters are displayed
Source: Calculated by the author from the GTAP 8 database and the inter-regional input–output table in Fukuoka prefecture

in relatively large numbers.[9] For other elasticity parameters, for labor and capital substitution and for domestic goods and imported goods substitution, the elasticity parameters present in the GTAP 8 database are used. The degree of interregional substitution for intermediate goods is assumed to be twice that for substitution between domestic goods and imported goods. The substitution between value-added goods and intermediate goods is 0. This is assuming the use of the Leontief function.

We undertook four types of simulations in this study (Table 17.5). First, we assumed that natural disasters cause damage to specific sectors in Fukuoka prefecture. When the damage occurred, we gave a width to the size of the damage based on the premise that no damage will occur throughout Fukuoka prefecture unless it is a significant disaster. As a result, two types of probability distributions were used in the Monte Carlo experiment. Use random numbers based on the binomial distribution to set the damage that occurs for a specific sector. Here, we determined whether the damage would occur with a probability of 50%; and the magnitude is determined with uniform distribution. The width of the uniform distribution is different for production factors and intermediate goods. Among the production factors, labor stock is to be damaged up to 8% and damage to capital stock up to 40%. Regarding intermediate goods, damage to intermediate goods transactions in Fukuoka prefecture is up to 80%, and 40% for those outside. Damage to labor stock means that laborers will not be able to work due to the disaster. Since saving lives is a priority, heavy casualties are not expected. However, a substantial proportion of the capital stock is expected to become unproductive due to the destruction of properties. Although we set a relatively high number for the degree of damage, we thought that complete destruction was not a realistic possibility. Regarding intermediate goods transactions, we thought that the numbers should reflect a near extinction of these transactions because the infrastructure for logistics is expected to collapse. Therefore, the damage was set at 80%. In addition, because the disaster is assumed to be in the Fukuoka prefecture, the logistics infrastructure in other prefectures would not collapse. Therefore, we considered that the damage to intermediate goods flows within the Others region would be smaller than these flows with a Fukuoka prefecture origin or destination (Simulation 1).[10]

In the second simulation, we analyze the economic impact of damage to all sectors, not to specific sectors. Simulation 2 sets the uniform distribution which becomes the same as the damage of Simulation 1 on average.[11] For the next two simulations, the magnitude of the damage was generated in a nonuniform distribution as it is more likely that damage will be minimal. Here, a half-normal

[9]This is very rough calculation, but at least it was estimated to be higher than the substitution between labor and capital.

[10]Improving the accuracy of setting the probability of occurrence and the scale of damage will be the issue for the future. In the author's earlier study (Sakamoto 2019), we assumed a slightly higher damage than this.

[11]Given that a maximum of 40% of the damage occurs with a 50% probability and a maximum of 20% of the damage occurs with a 100% probability, the idea is that multiplying the two probabilities is equivalent.

Table 17.5 Monte Carlo experiment

	$L(fp)$	$K(fp)$	$XM(fp, fp)$	$XM(fp, op)$ and $XM(op, fp)$
Simulation 1	$L_*(1 - B(1,0.50)_* U(0,0.08))$	$K_*(1 - B(1,0.50)_* U(0,0.40))$	$XM_*(1 - B(1,0.50)_* U(0,0.80))$	$XM_*(1 - B(1,0.50)_* U(0,0.40))$
Simulation 2	$L_*(1 - U(0,0.04))$	$K_*(1 - U(0,0.20))$	$XM_*(1 - U(0,0.40))$	$XM_*(1 - U(0,0.20))$
Simulation 3	$L_*(1 - HN(0,0.04_* s))$	$K_*(1 - HN(0,0.20_* s))$	$XM_*(1 - HN(0,0.40_* s))$	$XM_*(1 - HN(0,0.20_* s))$
Simulation 4	$L_*(1 - T(0,0,0.04_* c))$	$K_*(1 - T(0,0,0.20_* c))$	$XM_*(1 - T(0,0,0.40_* c))$	$XM_*(1 - T(0,0,0.20_* c))$

Note: $B(1, 0.50)$ is a binomial distribution showing 1 at a probability of 0.50
$U(0, 0.08)$ is a uniform distribution in the range of 0–0.08
$HN(0,0.04_* s)$ is a half-normal distribution and represents the absolute value of a normal distribution with an average of 0 and a standard deviation of $0.04_* s$, $s = (\pi/8)$^(1/2)
$T(0,0,0.04_* c)$ is a triangular distribution with a minimum value of 0, a mode value of 0, and a maximum value of $0.04_* c$, $c = 3/2$

distribution showing the positive part of the normal distribution (Simulation 3) and a triangular distribution with a minimum value and a mode value of 0 (Simulation 4) is adopted. The standard deviation and the maximum value are set so that the average of the damage is the same as in Simulation 1.[12]

When damage occurs as shown in Table 17.5, the labor stock L, the capital stock K and the intermediate goods XM of Fukuoka prefecture decrease according to the probability.[13] The model is then recalculated under the changed variable. According to the equation of the model, the reduction of labor and capital stock firstly affects Eq. (17.14). The reduction in the intermediate goods transaction firstly affects Eq. (17.13). It also affects other equations and a new equilibrium solution is calculated.

17.4 Result

17.4.1 Simulation Based on Database

Table 17.6 shows the CGE results of Monte Carlo experiments for all simulations. The maximum, minimum, average, and standard deviation of output, price, nominal income (nominal GDP), and real income (real GDP) are shown. These experiments were repeated 500 times each.

In terms of output, the average damage result in Fukuoka prefecture is 0.889283 (i.e., a decrease of approximately 11% from a no-change output level of 1.000000) in Simulation 1, 0.889276 in Simulation 2, 0.889073 in Simulation 3, and 0.889244 in Simulation 4. On the other hand, in other prefectures and Japan (*jp*), the damage is less than 1% in all simulations. Along with this, the price has decreased slightly, but the average is around 1.3% at maximum. The average of nominal income in Fukuoka prefecture was 0.934199 in Simulation 1, 0.933750 in Simulation 2, 0.933932 in Simulation 3, and 0.933665 in Simulation 4. Real income is slightly higher than nominal income because prices are decreasing. As far as the average is seen, it is almost the same, consistent with the intention at the onset of the simulation.

However, the standard deviation is very different. The standard deviation of the output of Fukuoka prefecture is 0.010588 in Simulation 1, 0.004978 in Simulation 2, 0.006098 in Simulation 3, and 0.005797 in Simulation 4. The combination of the binomial distribution and the uniform distribution seems to distort the distribution of experimental results. This is because increase in the standard deviation is that for the non-damaged industry and while the various stocks do not change here, they do so for the damaged industry. The half normal and triangular distributions could also

[12] From Sakamoto (2019), Simulation 3 and Simulation 4 were added. The notes in Table 17.5 show the calculation method.

[13] The number of variables that change in a single Monte Carlo experiment is 3538 ($42_L + 42_K + 42 \times 42 \times 3_{XM} = 5376$ minus zero data 1838), and a corresponding number of random numbers are generated.

Table 17.6 Result of Monte Carlo–CGE experiments (simulation 1–4)

			Max.	Min.	Average	S.D.
Output	Simulation 1	*fp*	0.918632	0.862536	0.889283	0.010588
		op	0.996866	0.993037	0.995258	0.000695
		jp	0.993841	0.988727	0.991688	0.000933
	Simulation 2	*fp*	0.904296	0.875753	0.889276	0.004978
		op	0.996384	0.994420	0.995248	0.000344
		jp	0.993282	0.990497	0.991678	0.000459
	Simulation 3	*fp*	0.905359	0.868033	0.889073	0.006098
		op	0.996278	0.993496	0.995227	0.000428
		jp	0.993150	0.989678	0.991651	0.000561
	Simulation 4	*fp*	0.907693	0.871906	0.889244	0.005797
		op	0.996384	0.994064	0.995242	0.000401
		jp	0.993254	0.990033	0.991672	0.000536
Price	Simulation 1	*fp*	0.991876	0.981417	0.987362	0.001916
		op	0.999499	0.998792	0.999210	0.000128
		jp	0.999252	0.998290	0.998845	0.000166
	Simulation 2	*fp*	0.990140	0.985011	0.987375	0.000910
		op	0.999396	0.999058	0.999211	0.000062
		jp	0.999098	0.998646	0.998846	0.000081
	Simulation 3	*fp*	0.990536	0.983583	0.987428	0.001109
		op	0.999403	0.998959	0.999208	0.000077
		jp	0.999098	0.998548	0.998845	0.000101
	Simulation 4	*fp*	0.990310	0.984228	0.987419	0.001077
		op	0.999409	0.999007	0.999212	0.000074
		jp	0.999113	0.998606	0.998848	0.000097
Nominal Income	Simulation 1	*fp*	0.956633	0.906303	0.934199	0.008778
		op	0.998934	0.997926	0.998474	0.000188
		jp	0.997286	0.994704	0.996131	0.000430
	Simulation 2	*fp*	0.947335	0.923076	0.933750	0.004287
		op	0.998771	0.998241	0.998471	0.000093
		jp	0.996672	0.995545	0.996112	0.000213
	Simulation 3	*fp*	0.949394	0.912554	0.933932	0.005596
		op	0.998781	0.998067	0.998467	0.000115
		jp	0.996903	0.995144	0.996115	0.000274
	Simulation 4	*fp*	0.947867	0.919158	0.933665	0.005418
		op	0.998785	0.998163	0.998471	0.000111
		jp	0.996928	0.995411	0.996110	0.000265

(continued)

Table 17.6 Result of Monte Carlo–CGE experiments (simulation 1–4)

			Max.	Min.	Average	S.D.
Real income	Simulation 1	*fp*	0.967063	0.921593	0.946149	0.007847
		op	0.999442	0.999056	0.999263	0.000071
		jp	0.998200	0.996237	0.997284	0.000325
	Simulation 2	*fp*	0.959091	0.936264	0.945687	0.003828
		op	0.999375	0.999158	0.999259	0.000035
		jp	0.997753	0.996842	0.997263	0.000160
	Simulation 3	*fp*	0.959073	0.927224	0.945819	0.005070
		op	0.999378	0.999086	0.999259	0.000043
		jp	0.997839	0.996503	0.997268	0.000210
	Simulation 4	*fp*	0.958492	0.932223	0.945559	0.004892
		op	0.999375	0.999140	0.999259	0.000042
		jp	0.997812	0.996743	0.997259	0.000203

see larger standard deviations than the uniform distribution because the distribution is concentrated to the damage rate closer to zero. Generally, there are two points. First, even if a large natural disaster occurs in Fukuoka prefecture, the impact on the Japanese economy is not significant. Second, although the economy of Fukuoka prefecture suffers substantially, the situation of damage varies depending on how such damage occurs and its magnitude.

Table 17.7 shows the results of Monte Carlo experiments by industry, showing the output and prices in Fukuoka prefecture. The same trend was shown for each simulation except for the size of the result, so the result of Simulation 1 is displayed.[14]

Like Table 17.6, it can be seen from this table that the change in output is greater than the change in price. According to the table, in seven industries (i004, i007, i013, s026, s036, s041, and s042), the average output damage exceeds 30% and in 13 industries (i004, i011, i012, i013, i014, i020, i021, s026, s028, s031, s036, s041, and s042), the standard deviation of output exceeds 5%. Also, in five industries (a001, a003, i012, s029, and s042), the standard deviation of price exceeds 1%.

Figure 17.2 shows the distribution of experimental results of real income in each simulation. In creating the distribution, we used weighted frequency distribution to make it smooth.[15] Although the distribution of damage occurrence in each simulation is different, the result is close to normal distribution because the real income is the sum of each industry. Since the standard deviation is different, the

[14]Unlike Excel, random number generation in GAMS always generates random numbers with the same pattern (pseudorandom number), so it has high reproducibility due to recalculation.

[15]The frequency distribution was counted at an interval of 0.001, and a weight of 0.1 was applied to the frequency two before and two after it, a weight 0.2 was applied to the frequency one before and one after it, and a weight 0.4 was applied to the frequency.

Table 17.7 Results of Monte Carlo–CGE experiments (output and price in Fukuoka Prefecture), simulation 1

	Output				Price			
	Max.	Min.	Average	S.D.	Max.	Min.	Average	S.D.
a001	0.979844	0.755711	0.914855	0.049514	0.990185	0.899595	0.961969	0.020817
a002	0.985176	0.900891	0.957101	0.016353	0.989335	0.939143	0.972052	0.009958
a003	0.994086	0.848027	0.956017	0.027033	0.993447	0.914000	0.967226	0.016612
i004	0.912117	0.312426	0.709371	0.118429	0.998883	0.993360	0.996236	0.001456
i005	0.996993	0.847280	0.939027	0.028714	0.998344	0.985377	0.993775	0.002823
i006	0.930090	0.811035	0.876429	0.021136	1.005763	1.001377	1.003260	0.000804
i007	0.893379	0.654065	0.787898	0.047788	1.013396	1.001442	1.006645	0.002324
i008	0.957551	0.754751	0.880357	0.040744	0.997136	0.990913	0.994751	0.001165
i009	0.964753	0.773314	0.884876	0.040574	0.996056	0.982211	0.990422	0.002784
i010	0.944104	0.800366	0.877455	0.028085	0.999236	0.993891	0.997306	0.000995
i011	0.959918	0.652901	0.854091	0.055226	1.004738	0.995901	0.999149	0.001423
i012	0.983714	0.743639	0.902797	0.056404	0.994593	0.931338	0.974364	0.014244
i013	0.905222	0.628057	0.784448	0.052363	1.005099	1.000079	1.002175	0.000912
i014	0.954485	0.573317	0.823423	0.069309	1.025927	0.990843	1.005247	0.005545
i015	0.979921	0.860391	0.931449	0.024661	1.005458	0.994782	0.999845	0.001925
i016	0.986643	0.895084	0.952901	0.020951	1.001986	0.993800	0.998416	0.001426
i017	0.943719	0.751724	0.877109	0.038196	1.009702	1.000902	1.003970	0.001742
i018	0.974287	0.750587	0.882597	0.046562	0.997986	0.994377	0.996605	0.000691
i019	0.967364	0.875117	0.924434	0.019677	1.003555	0.997554	1.000510	0.000995
i020	0.952744	0.756924	0.880372	0.051353	1.002424	0.999984	1.000872	0.000647
i021	0.986045	0.769481	0.919395	0.052699	0.998679	0.994353	0.997064	0.000843
i022	0.894084	0.746960	0.831121	0.027343	1.011840	1.002764	1.006615	0.001564
i023	0.935915	0.843635	0.896619	0.017288	1.003295	0.997587	1.000748	0.000978
s024	0.929545	0.712164	0.839825	0.035447	0.981160	0.923154	0.958631	0.009262
s025	0.929035	0.775686	0.858797	0.029651	0.981377	0.945148	0.965281	0.006847
s026	0.927459	0.596379	0.796305	0.058398	1.023985	1.000146	1.008646	0.004042
s027	0.970138	0.903900	0.940783	0.011621	0.998944	0.990882	0.995527	0.001145
s028	0.917025	0.659837	0.829129	0.050362	0.994100	0.979995	0.989075	0.002304
s029	0.970561	0.919212	0.951295	0.010181	0.953575	0.875960	0.924005	0.015236
s030	0.914022	0.716515	0.830189	0.037209	0.996610	0.991261	0.994428	0.000876
s031	0.933553	0.676559	0.821115	0.051246	0.991507	0.969016	0.981826	0.004136
s032	0.962143	0.911546	0.940261	0.008404	0.991082	0.980002	0.985566	0.002043
s033	0.932831	0.793296	0.878542	0.025798	1.003026	0.997923	1.000116	0.000923
s034	0.959216	0.896472	0.931247	0.011482	0.998974	0.996221	0.997570	0.000467
s035	0.926813	0.843135	0.888973	0.013518	1.006989	1.000830	1.003735	0.001008
s036	0.876921	0.555018	0.753479	0.055139	0.991455	0.964554	0.982795	0.004195
s037	0.993957	0.982773	0.988980	0.001709	0.996946	0.993355	0.995313	0.000678
s038	0.973274	0.925744	0.954274	0.008582	0.997730	0.993053	0.995616	0.000875
s039	0.984598	0.945374	0.969055	0.008019	0.995160	0.988819	0.992123	0.001132
s040	0.969955	0.906002	0.944268	0.013469	0.992556	0.984504	0.989155	0.001519
s041	0.877834	0.455265	0.714308	0.074986	1.001842	0.999300	1.000601	0.000467
s042	0.894292	0.444707	0.719006	0.095822	0.981052	0.921173	0.959614	0.012461

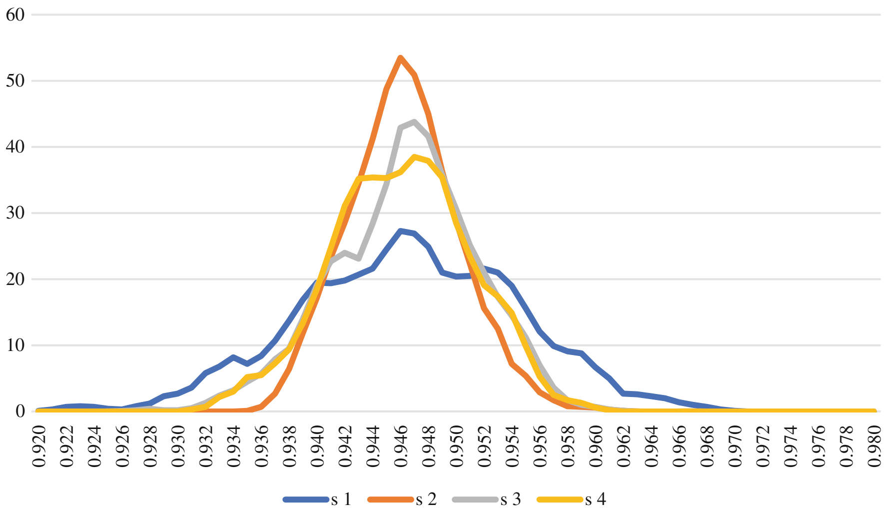

Fig. 17.2 Distribution of experimental results of real income in each simulation

shape of the distribution is also different hence showing that the distribution of Simulation 1 is the widest.

17.4.2 Comparison with Past Disasters

The Fukuoka Prefecture West Offshore Earthquake occurred in March 2005. Although this earthquake was relatively large, the damage was not so compared to the other one that introduced later. According to "Fukuoka Prefecture Main Natural Disaster Damage Statistics (after 1954)" in Fukuoka prefecture,[16] the damage amount was 31,497 billion yen. Other examples of large earthquakes include the Great Hanshin-Awaji Earthquake in January 1995, the Niigata Chuetsu Earthquake in October 2004, the Great East Japan Earthquake in March 2011, and the Kumamoto Earthquake in April 2016. According to the policy director of the Cabinet Office on "Assessing the impact of the 2016 Kumamoto earthquake",[17] the estimated damage of these large earthquakes are 9.6–9.9 trillion yen (Hanshin-Awaji Earthquake) and 1.7–3 trillion yen (Niigata Chuetsu Earthquake), 16.9 trillion yen (Cabinet Office for Disaster Prevention) and 16–25 trillion yen (Cabinet Office for Analysis) (East Japan Earthquake), 2.4–4.6 trillion yen (Kumamoto Earthquake).

[16] http://www.pref.fukuoka.lg.jp/uploaded/life/298282_53094633_misc.pdf

[17] https://www5.cao.go.jp/keizai3/kumamotoshisan/index.html

From here, we analyze the Kumamoto earthquake that occurred in Kumamoto and Oita prefectures, which are adjacent to the Fukuoka prefecture. According to “Assessing the impact of the 2016 Kumamoto earthquake,” the damage amount of Kumamoto prefecture is about 1.8–3.8 trillion yen while that of Oita prefecture is about 0.5–0.8 trillion yen. The total for both prefectures is estimated to be 2.4–4.6 trillion yen. This is the amount of loss of capital, and with respect to the capital stock of both prefectures, the estimated loss was about 63 trillion yen (34 trillion yen for Kumamoto prefecture and 28 trillion yen for Oita prefecture). If the damage amount is divided by the capital stock, the damage rate of the Kumamoto earthquake will be 3.8–7.3% (5.3–10.0% for Kumamoto prefecture, 1.8–2.9% for Oita prefecture). In addition, the impact on GDP is estimated to be about 90–127 billion yen (Kumamoto prefecture is 81–113 billion yen, Oita prefecture is 10–14 billion yen), and against each prefecture’s GDP (gross prefecture product) 55,645.6 billion yen and 43,782.32 billion yen,[18] the damage rate was 1.0–1.3% (1.5–2.0% for Kumamoto prefecture and 0.2–0.3% for Oita prefecture). In this way, when a large earthquake occurs, it can be seen that even if the stock has a relatively large impact, the flow has little impact.

Comparing this with the results in Table 17.6, the average real income was 0.946149 (about 5.4% loss) in Simulation 1. Although not introduced in the table, the average damage rate of capital was 10% in any simulation (one-half of the width of the uniform distribution is the average). This is realistic as the largest estimate of damage to capital stock in the Kumamoto earthquake is 10%. However, the average loss of real income in this study is over 5% versus 2% which is the largest estimate GDP loss in the Kumamoto earthquake. Even within the distribution of Fig. 17.2, damage within 2% (0.980) is negligible as it seems exaggerated. This study assumes that besides the loss of capital stock, there is a further loss on both labor stock and intermediate goods due to damage to logistics networks. As it is forecasting in advance, it seems better to make some pessimistic predictions.

17.5 Concluding Remarks

In this study, the adverse effects of natural disasters on the economy that cannot be easily measured are analyzed in advance through Monte Carlo experiments using CGE models aided by the inter-regional input–output table for Fukuoka prefecture and Other prefectures region. In the Monte Carlo experiment, random numbers from binomial distributions were generated as the possibility of damage occurrence, and degree of damage; random numbers with uniform distribution, half-normal distribution, and triangular distribution were generated.

[18]Cabinet Office of Japan, “Kenmin Keizai Keisan (Prefectural economic accounts),” (https://www.esri.cao.go.jp/jp/sna/sonota/kenmin/kenmin_top.html). The figures for 2016 have not been published so nominal values for 2015.

It goes without saying that the larger the scale of the damage, the greater the negative impact on the economy. However, if there are regional and industrial variations in the occurrence of damage, the standard deviation of the impact on the economy will be larger. In this study, the damage scale was set relatively large. The negative impact on the Fukuoka economy was significant, but the impact on the Japanese economy was minimal. Also, compared with the actual damage of the Kumamoto earthquake, it can be said that the assumption of the damage in this study is significant.

Since it is not easy to prevent natural disasters in advance, it is necessary to exert efforts to minimize the damage. However, since unexpected damage may still occur, the response, in this case, is in need of examination.

Acknowledgment We would like to thank Editage (www.editage.jp) for English language editing.

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