Analysis of Indirect Socioeconomic Impacts on East Asia by Recovering Fukushima Forest Watershed Quality

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The objective of this study is to assess the regional indirect effects of recovering water quality in the Fukushima forest watersheds after the Great East Japan Earthquake and the Fukushima disaster. The primary outcomes of the simulated EMEDA results are as follows. First, the tertiary sectors receive many benefits through domestic transactions after recovering the water quality in Fukushima forest watersheds. Second, the Japanese grains and crops sector enjoys approximately four times more than the rice sector that directly receives benefits by water recovery while it suffers some damages in East Asian countries.

Key words: Fukushima forest watershed, socioeconomic impacts, recovery

1. Introduction

A massive earthquake, the Great East Japan earthquake, and the subsequent tsunami on March 11, 2011, brought about the calamitous disaster at the Fukushima Daichi nuclear plant, the Fukushima disaster, leaving trace amounts of radiation in its surrounding land and sea. Exposure to harmful levels of radiation and cumulative exposure has serious health consequences, including elevated risks of various cancers. The residents within a 20-kilometer radius of the plant were evacuated, while other residents were left concerned about the likely radiation exposure.1)

The Fukushima disaster cleanup has been attempted to reduce radioactive contamination from the Fukushima disaster in the disaster affected regions.2) After the decontamination in the special decontamination areas, air dose rate has been decreased sixty, fifty-nine, thirty, and forty-four percent in residential areas, farmland, forests, and roads, respectively (MOE b).3) The latest results of post-decontamination monitoring in 2014-2018 show seventy-six, seventy-two, fifty-five, and sixty-four percent reduction compared with pre-decontamination in 2011. Over seventy percent in residential areas and farmland recovered from the contamination by the Fukushima disaster. However, forest areas have remained approximately half of them. Also, little study has assessed the indirect socioeconomic impacts of Fukushima nature recovery. Therefore, it is challenging to discuss new policies for disaster-affected regions, although people believe that it is essential for Japan’s real economy.

The objective of this study is to assess the regional indirect effects of recovering water quality in Fukushima forest watersheds after the Fukushima disaster.

Features of this research are to assess indirect socioeconomic impacts by recovering Fukushima forest watershed quality as reducing radioactive substances, and to include foreign countries in the analysis for assessing more real economies and clarifying influence on other countries, especially East Asia.

The paper is organized as follows. Section 2 discusses the simulation model and direct damages in Fukushima forest watershed; Section 3 gives the results; and Section 4 summarizes conclusions.

2. Methodology

1) Evaluation model for environmental damage and adaption (EMEDA)

EMEDA is an Evaluation Model for Environmental Damage and Adaptation, is a computable general equilibrium (CGE) model, and is developed initially to simulate future sectoral socioeconomic dynamics in the context of specific direct damages (Washida, 2011).4) There are several Fukushima prefecture are the special decontamination areas (MOE a).

1) Parts of Okuma and Futaba in Fukushima prefecture have still evacuated in 2019.
2) Especially, Tamura, Naraha, Kawauchi, Okuma, Katsurao, Kawamata, Futaba, Iitate, Tomioka, Minamisoma, and Namie in Fukushima prefecture are the special decontamination areas (MOE a).
3) The residential areas include schools, parks, cemeteries, and large-sized facilities, farmland includes an orchard, and forests include slopes, grassland, and lawn (MOE b).
4) Although an original EMEDA was developed for simulating indirect socioeconomic impacts of direct global warming impacts,
advantages to use EMEDA that EMEDA captures not only domestic economic impacts in each sector but also indirect economic impacts in sectors through international trade. Another benefit of using EMEDA is that it is relatively easy to assess regional and sectoral impacts of specific direct damage. The value-added production function for EMEDA is as:

$$V_{jr} = \pi_{jr} \left\{ \alpha_{jr} K_{jr} \left( 1 - \alpha_{jr} \right) L_{jr} \right\}^{\beta_{jr}}$$

where $V_{jr}$ is the value-added, $K_{jr}$ is capital, and $L_{jr}$ is labor. A sector $j = 1, ..., 16$ and a region $r = 1, ..., 16$. The EMEDA calibration obtains a scale parameter $\pi_{jr}$ and a distribution parameter $\alpha_{jr}$. An elasticity of substitution $\beta_{jr}$ is obtained from the GTAP9 database. In EMEDA, domestic production consists of domestic demand and total exports. Armington goods are calculated by domestic demand and total imports using constant elasticity of substitution functions. Value-added is composed of consumption, government expenditure, and investment (Washida et al., 2014).

Based on an original EMEDA, we arranged to adjust to capture indirect socioeconomic impacts on the recovery in Fukushima forest watersheds. The Fukushima disaster damages in Fukushima forest watersheds are calculated. Two scenarios are simulated in this research. “Immediately after the Fukushima disaster” scenario is calculated as a massive direct damage case after the Fukushima disaster in 2012. Another scenario is “the present,” which calculates with reduced radioactive substances in 2017. For analyzing differences between the two scenarios, we discuss indirect socioeconomic impacts after recovering the Fukushima forest watershed quality from 2012 and 2017. Table 1 shows the sixteen regions and sectors associated with EMEDA. Regional and sectoral data are taken from GTAP9.

### 2) Fukushima forest watersheds

Forest watersheds in the disaster affected regions, especially Fukushima forests, received huge damages from radioactive contamination from the Fukushima Daiichi nuclear plant. In this study, we focus on cesium-134 (Cs-134) at the bottom of a river because a half-life of it is about two years. Our target is a middle basin in the Abukumagawa-river in Nihonmatsu-city, Fukushima. Figure 1 presents the amount of Cs-134 at the bottom of the Abukumagawa-river at Takadabashi-bridge. Data is combined the Radioactive Material Monitoring in the Water Environment in and around (MOE a) and our survey.

Miyagi prefecture summarized standards of radioactive substances that 10, 50, 50, and 100 Bq/kg are the standard of Cs-134 and Cs-137 for drinking water, milk, food for babies, and regular food after April 2012, respectively (Miyagi Genshiryoku Joho Station). Provisional tolerances of Cs-134 and Cs-137 for fertilizer, cattle and horse feed, swine feed, poultry feed, and cultured fish feed are 400, 100, 80, 160, and 40

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**Table 1. Regions and sectors for EMEDA**

| Region             | Sector               |
|--------------------|----------------------|
| 1 Japan            | 1 Paddy Rice         |
| 2 China            | 2 Wheat              |
| 3 USA              | 3 Cereal Grains       |
| 4 India            | 4 Processed Rice      |
| 5 Russia           | 5 Grains and Crops    |
| 6 South Korea      | 6 Meat and Livestock  |
| 7 EU_25            | 7 Forestry            |
| 8 Oceania          | 8 Fishing             |
| 9 Other East Asia  | 9 Mining and Extraction |
| 10 Southeast Asia  | 10 Processed Food     |
| 11 South Asia      | 11 Textile and Clothing |
| 12 North America   | 12 Light Manufacturing |
| 13 Latin America   | 13 Heavy Manufacturing |
| 14 Middle East and North Africa | 14 Utilities and Construction |
| 15 Sub-Saharan Africa | 15 Transport Communication |
| 16 Rest of World   | 16 Other Services     |

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EMEDA can calculate other direct economic and non-economic impacts, e.g., biodiversity (Yamaura et al., 2017). We use EMEDA model and GTAP data to assess the recovery of the Fukushima forest watershed quality, and obtain not only domestic indirect effects by the recovery but also indirect impacts on neighbor countries through international trade as an open economy.

5) https://www.gtap.agecon.purdue.edu/databases/v9/.
6) A unit is millions of 2011 current US dollars.
Provisional tolerances of Cs-134 and Cs-137 for sludge fertilizer for a farm is 200 Bq/kg, and the standard of Cs-134 and Cs-137 for landfill disposal is 8,000 Bq/kg (100,000 Bq/kg following the disposal method in the policy). A reference value of a bathhouse is 10 Bq/kg, indicator values of Cs-134 and Cs-137 for mushroom log and bacteria bed medium are 50 and 200 Bq/kg, respectively. Since the Cs-134 in September 2011 was extremely high, which was 14,000 Bq/kg, we selected data in June 2012, which was 860 Bq/kg, for a value of “immediately after the Fukushima disaster.” We used data in September 2017 for a value of the present scenario, which was 87 Bq/kg in the Abukumagawa-river at Takadabashi-bridge.

3) Direct damages

There are various direct radioactive substance impacts (mostly damages) in our societies by the Fukushima disaster. Focusing on Fukushima forest watersheds, especially in the Abukumagawa-river, paddy fields, and health and recreation functions, including Satoyama-effects, Shinrin-yoku, which is taking in the forest atmosphere or forest bathing, camping, and other related activities such as tourism or eco-tourism. For calculating direct impacts in paddy fields in the Naka-Dori area, Fukushima, we used rice cultivation data in Fukushima and values of forest multifunction by the Science Council of Japan.

Therefore, the direct paddy field damage in the Naka-Dori area is 1.481 percent of all paddy field in Japan in 2012 and is 0.101 percent in 2017, which is 89.88 percent reduced Cs-134 case. Similarly, we calculated direct damages in health and recreation functions in 2012 and 2017.

Following Washida et al. (2014) that investigated a static EMEDA with a damage index, a value-added production function of EMEDA with direct damages is as:

\[ V_{fr} = (1 - B_{fr})\pi_{fr} \left( \alpha_{fr}K_{fr}^{\beta_{fr} - 1} + (1 - \alpha_{fr})L_{fr}^{\beta_{fr} - 1} \right) \]

where \( B_{fr} \) is the damage index, which is positive.

3. Results

A CGE approach incorporates interrelationships among regions, and simulated EMEDA results are affected by both direct impacts, which are inserted as a damage index, and indirect impacts through calculating general equilibrium (Washida et al., 2014).

Simulated EMEDA covers value-added, exports, imports, and consumption, among other variables (Washida et al., 2014). Although the impacts of radioactive substances in the Fukushima forest watershed will be small in foreign countries, some countries have been concerned about any Japanese domestic impacts related to radioactive substances. Therefore, this research focuses not only on Japan but also on East Asia: China, South Korea, and other East Asian countries, including Taiwan, Mongolia, and North Korea. We mainly discuss value-added since value-added is almost equal to GDP in each sector in EMEDA simulation (Washida et al., 2014).

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Figure 1. Cs-134: Bottom Materials in the Abukumagawa-River from 2012 to 2017

Source: Authors’ survey and MOE a.
Note: Values in each scenario are at ⬤.

7) A 1 Bq/kg is equal to a 1 Bq/L.
8) By March 2012, the standards of Cs-134 and Cs-137 for drinking water, and milk and dairy products were 200 Bq/kg, and those for vegetables, grains, and meat, egg, fish, and others were 500 Bq/kg.
9) Rice cultivation data in Fukushima: https://www.pref.fukushima.lg.jp/sec/36035b/inasaku-gaiyou-sakutukeiyoukyou.html.
First, we discuss simulated EMEDA results in Japan. Table 2 shows that the values in Japan are smaller than those in China except for the Transportation and Communication sector and the Other Services sector because most sectors in China are larger in 2012. Figure 2 shows the simulated EMEDA results in Japan in 2012. Since direct damages by the Fukushima disaster in forest watershed are in the paddy field and health and recreation functions, we mainly discuss the simulated EMEDA results in the agriculture, food, and service sectors. In EMEDA, service sectors are the Transportation and Communication, and the Other Services.

Both sectors are over a trillion US dollars in Table 2. Figure 3 shows the simulated EMEDA results in the primary industries, and a unit is US billion dollars. Among them, a sector of the Grains and Crops is the largest. For clarifying the indirect impacts by recovering the Fukushima forest watershed quality, we focus on the differences between the simulated EMEDA results in 2012 and those in 2017. Figure 4 shows the differences between the EMEDA results under “immediately after the Fukushima disaster” and “the present” in Japan, indicating how much the Fukushima forest watershed quality recovery gives benefits to the Japanese economy. Since the differences between the two of 2011 input-output tables in these countries have also changed from 2004. Especially, China, Japan’s major trading partner, has large economic growth in these seven years. Therefore, we use the GTAP9 database here.

### Table 2. Simulated EMEDA results in Japan and East Asia

| Years | Sector                        | Japan   | China     | South Korea | Other East Asia |
|-------|-------------------------------|---------|-----------|-------------|-----------------|
| 2012  | Paddy Rice                   | 0.01157526 | 0.05658095 | 0.00491255 | 0.00082769      |
|       | Wheat                         | 0.00060371 | 0.01730933 | 0.00001151 | 0.00014388      |
|       | Cereal Grains                 | 0.00005938 | 0.03071090 | 0.00002396 | 0.00015316      |
|       | Processed Rice                | 0.00436285 | 0.00340488 | 0.00012234 | 0.00460848      |
|       | Grains & Crops                | 0.03135977 | 0.25015450 | 0.01214241 | 0.00460848      |
|       | Meat & Livestock              | 0.01340005 | 0.10142270 | 0.00405033 | 0.00735289      |
|       | Forestry                      | 0.00421223 | 0.04501926 | 0.00110129 | 0.00199191      |
|       | Fishing                       | 0.00976607 | 0.07103740 | 0.00257673 | 0.00174456      |
|       | Mining & Extraction           | 0.00426821 | 0.26238090 | 0.00225843 | 0.01311338      |
|       | Processed Food                | 0.14347750 | 0.15327000 | 0.00923278 | 0.00994037      |
|       | Textile & Clothing            | 0.01873172 | 0.16035510 | 0.00951185 | 0.01535838      |
|       | Light Manufacturing           | 0.27926240 | 0.52905980 | 0.09892069 | 0.03394325      |
|       | Heavy Manufacturing           | 0.60861629 | 1.33977067 | 0.19068566 | 0.12553858      |
|       | Utilities & Construction      | 0.39490040 | 0.61557190 | 0.07732040 | 0.03890379      |
|       | Transport Communication       | 1.29541300 | 1.07522100 | 0.19877640 | 0.22955710      |
|       | Other Services                | 2.88940400 | 1.88684400 | 0.47520010 | 0.28127640      |

| 2017  | Paddy Rice                   | 0.01160009 | 0.05658078 | 0.00491250 | 0.00082768      |
|       | Wheat                         | 0.00061386 | 0.01730925 | 0.00001151 | 0.00014390      |
|       | Cereal Grains                 | 0.00005969 | 0.03071090 | 0.00002396 | 0.00015316      |
|       | Processed Rice                | 0.00437233 | 0.00340487 | 0.00012234 | 0.00460848      |
|       | Grains & Crops                | 0.03147045 | 0.25015010 | 0.01214169 | 0.00460764      |
|       | Meat & Livestock              | 0.01343664 | 0.20142090 | 0.00405022 | 0.00735246      |
|       | Forestry                      | 0.00422520 | 0.04501843 | 0.00110118 | 0.00199191      |
|       | Fishing                       | 0.00976880 | 0.07103763 | 0.00257675 | 0.00174459      |
|       | Mining & Extraction           | 0.00427123 | 0.26238000 | 0.00225843 | 0.01311346      |
|       | Processed Food                | 0.14353550 | 0.15327000 | 0.00923265 | 0.00994014      |
|       | Textile & Clothing            | 0.01873635 | 0.16035460 | 0.00951193 | 0.01535857      |
|       | Light Manufacturing           | 0.27931720 | 0.52905850 | 0.09892067 | 0.03394312      |
|       | Heavy Manufacturing           | 0.60898277 | 1.33976467 | 0.19068346 | 0.12535990      |
|       | Utilities & Construction      | 0.39493800 | 0.61557660 | 0.07732103 | 0.03907984      |
|       | Transport Communication       | 1.29557900 | 1.07522200 | 0.19877570 | 0.22955740      |
|       | Other Services                | 2.88973200 | 1.88685400 | 0.47520340 | 0.28127740      |

Note: Value-Added (trillions US$).

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1) **Japan**

First, we discuss simulated EMEDA results in Japan. Table 2 shows that the values in Japan are smaller than those in China except the Transportation and Communication sector and the Other Services sector because most sectors in China are larger sizes in 2012. Figure 2 shows the simulated EMEDA results in Japan in 2012. Since direct damages by the Fukushima disaster in forest watershed are in the paddy field and health and recreation functions, we mainly discuss the simulated EMEDA results in the agriculture, food, and service sectors. In EMEDA, service sectors are the Transportation and Communication, and the Other Services.

10) The simulated EMEDA results using GTAP9 database are different from those with GTAP7 database, which we originally used. The GTAP9 database reference year is 2011, while 2004 is the reference year in GTAP7. Since East Asian countries’ economies have grown between 2004 and 2011, the structures
The gain in the Other Services sector is approximately 330 million dollars, and the Transportation and Communication sector receives over 160 million dollar benefits. Since EMEDA simulates economies both with domestic transactions and international trade, we can find these large indirect effects by recovering the Fukushima forest watershed quality. However, the direct recovery in health and recreation functions, i.e., some Shinrin-yoku, camping, or eco-tourism, are still relatively small in Fukushima in 2017.

Comparing to the tertiary industry, the agriculture and food sectors receive relatively smaller gains because the sizes of industries in the primary and tertiary industries are different. The Grains and Crops sector, which includes vegetables and fruits, receives over 110 million dollars of benefits after the recovery. It is over four times more than the Paddy Rice sector gains. Interestingly, there are approximately thirteen million dollars benefits in the Forestry sector, indicating that the recovery of the Fukushima forest watershed quality has relatively small indirect impacts in the sector of forestry in Japan because forestry in Fukushima does not account for a large percentage in Japan’s forestry. Another interest is in the secondary industry. Although the secondary industry has no direct impact on the Fukushima forest watershed quality in this EMEDA simulation, there are relatively large indirect impacts. The Processed Food, Light Manufacturing, and Heavy Manufacturing sectors enjoy approximately 58, 55, and 122 million US dollars of indirect benefits, respectively. This is another feature of CGE analysis since EMEDA calculates the general equilibrium.

2) East Asia

Next, we discuss the simulated EMEDA results in East Asia except for Japan. Results in China, South Korea, and other East Asia are in Table 2. Since the results are in value-added, all sectors in South Korea and other East Asia are smaller than those in Japan, while most sectors in China are larger than the Japanese sectors. Figure 5 shows the differences between the EMEDA results under “immediately after the Fukushima disaster” and “the present” in East Asia, and a unit is US million dollars. Because of relatively smaller magnitudes in these countries, we combined value-added in China, South Korea, and other East Asia as East Asia. Compared with Figure 4, the indirect impacts by recovering the Fukushima forest watershed quality are small but exist through international trade as we expected.

Similar to the case in Japan, East Asia also enjoys some benefits in the tertiary sectors. The largest gain is in the Other Services sector that is eighteen million dollars while less than a million dollars in the Transportation and Communication sector, indicating that the Other Services sector enjoys indirect effects by the recovery. However, there is little benefit in transportation and communications in neighboring countries. Surprisingly, most primary industries except the Fishing sector are negatives in Figure 5. This indicates that there are extra indirect damages in the year 2017 compared with the year 2012. Significantly, the Grains and Crops has a larger negative value-added, which is approximately six
This research assessed the recovery of the Fukushima forest watershed qualities using a CGE simulation model, EMEDA. We compared two scenarios; “immediately after the Fukushima disaster” and “the present” in sixteen regions, with each region broken down into sixteen sectors in the EMEDA simulation.

The primary outcomes of the simulated EMEDA results are as follows. First, the Japanese Other Services sectors receive many benefits through domestic transactions after recovering the water quality in Fukushima forest watersheds. Second, the Grains and Crops sector enjoys approximately four times more than the rice sector that directly receives benefits by water recovery in Japan while it suffers some extra damages in East Asian countries. These findings of indirect impacts are useful knowledge for policymakers, especially for sustainable governance after varieties of disasters. One limitation of our research is that we only consider forest watershed qualities in Fukushima prefecture, although other forest watersheds in the Tohoku and Kanto regions have received radioactive substances by the Fukushima disaster.

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