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RESEARCH ARTICLE

Investigating the impact of the 2011 Great East Japan Earthquake and evaluating the restoration and reconstruction performance

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Three years have passed since the 2011 Great East Japan Earthquake (GEJE) hit the northeastern part of Japan. The earthquake then triggered a devastating tsunami and a nuclear accident, which in turn created a compound disaster that claimed a large number of human casualties and devastated properties. The 2011 GEJE caused the economy growth to decline by 2.2% with the largest decrease experienced by the industrial sector (−7.1%), followed by the agricultural sector (−3.6%) and the services sector (−0.2%). The agriculture and manufacturing sectors underwent large decreases in growth since the economies of most of the affected prefectures have relied on these two sectors. Thus, by investigating the damaging impacts of the 2011 GEJE, we try to evaluate the restoration and reconstruction performance in the agriculture and manufacturing sectors. Our study finds that there has been significant progress made towards restoration and reconstruction on the areas affected by the disaster. Using prefectural data from 2000 to 2012, we apply econometric methods based upon the bias-corrected least-squares dummy variable to estimate the impact of the 2011 GEJE on the agricultural and manufacturing sectors. From this analysis, two major insights emerged. First, the 2011 GEJE had a significant negative impact on agriculture and manufacturing sectors. On average, the impact on the agriculture sector was higher than on the manufacturing sector about twice as large. Second, the most affected prefectures experienced an impact about three times greater than the less affected prefectures in both agriculture and manufacturing sectors.

Keywords: 2011 Great East Japan Earthquake; tsunami; economic growth; damaging impact; restoration; reconstruction; agriculture; manufacturing; bias-corrected least-squares dummy variable

1. Introduction

On 11 March 2011 at 14:46 JST, a powerful earthquake with magnitude 9 Mw hit the northeastern part of Japan. The March 2011 disaster, also known as the 2011 Great East Japan Earthquake (GEJE), caused unprecedented damage in the Tohoku region and resulted in a period of crisis that affected the entire nation (Parwanto and Oyama 2013). The epicentre of the earthquake was approximately 70 km east of the Oshika Peninsula of Tohoku and the hypocentre at an underwater depth of approximately 30 km. This earthquake then triggered a powerful tsunami that devastated cities, towns, and villages along a broad swath of the Pacific coast of the Tohoku Region, causing vast human and material damage. The National Police Agency of Japan, as of 9 May 2014, had confirmed that the number of deaths had reached 15,886, with an additional 2640 missing and 6148 injured (The National Police Agency of Japan 2014). There were also 303,571 displaced people

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living in evacuation centres nearby and 127,382 buildings totally collapsed. The disaster also caused nuclear accidents at the Fukushima Daiichi Nuclear Power Plant complex. The World Bank estimated the economic cost this compound disaster fell between 122 billion US$ and 235 billion US$, or about 2.5–4% of Japan's gross domestic product (GDP) (The World Bank 2011).

When this compound disaster hit Japan, Japan was still recovering from the Financial Crisis of 2007–2008, also known as the Global Financial Crisis (GFC). Before the GFC that began in the US affected the economy of Japan and several other countries in the world, Japan had enjoyed a stable economy during previous decade, namely average growth at about 0.1% annually from 2000 to 2007 (Cabinet Office of Japan (CAO) 2014). The 2008 GFC caused a contraction of the Japanese economy of about 2.5% from 2007 to 2008. The largest decline was experienced by the industrial sector (−4.9%), followed by the agriculture sector (−2.6%) and the services sector (−1.6%). However, it turns out that the effects of the financial crisis worsened in 2009, in which the Japanese economy fell by 5.9% from 2008. The performance of the industry sector declined by 11%, followed by the agriculture sector (−4.6%) and the services sector (−4%). By 2010, the Japanese economy had begun to recover with growth of 2.4%, which far exceeded the average growth over the last decade. The highest growth was experienced by the industrial sector (8.3%), followed by agriculture (4%) and the services sector (0.3%).

Japan's economy, the world's third largest, slid back into recession after the devastation caused by the 2011 GEJE. As argued by Noy (2009), Strobl (2012), and Porfiriev (2012), natural disasters have a statistically adverse impact on the macro-economy in the short run and increase the vulnerability of the global economy (Noy 2009, Strobl 2012, Porfiriev 2012). The 2011 GEJE caused a decrease in Japan's GDP (at the 2005 constant price) of about 2.2%, namely from 4.8 trillion US$ in 2010 to 4.7 trillion US$ in 2011. This decrease was due to a decline in the industrial sector of −7.1%, followed by the agricultural sector (−3.6%) and the services sector (−0.2%). Thus, the first two sectors, industrial and agricultural, are the sectors that most suffered due to the disaster. The high decline in the agricultural sector was presumably due to the damage to and loss of deluged crops, damage to facilities, and radiation released from the Fukushima Daiichi plant. Meanwhile, the industrial sector, including the manufacturing sector, also declined, which was alleged to be as the result of destruction of parts factories in northeastern Japan, which in turn caused severe supply shortages for many manufacturers.

According to the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), the amount of damage and losses to the agriculture, forestry, and fisheries sectors caused by the 2011 disasters was estimated at 238 billion US$ (Ministry of Agriculture, Forestry and Fisheries of Japan 2013). MAFF also estimated about 23,600 ha of farmland were inundated by the tsunami in the Tohoku and Kanto regions, Miyagi Prefectures suffered the worst damage, with 15,002 ha of farmland in five cities flooded by sea water – more than 50% of the total farmland in those cities.

Meanwhile, in the industrial sector, the natural disasters forced auto firms and other manufacturers in Tohoku region to shut down production, and operations have taken a long time to restart (Tohoku Bureau of Economy, Trade and Industry 2012). Toyota and Honda are two examples of giant automotive companies that had to halt their productions due to these natural disasters. As their productions in Tohoku region are mainly affiliated with vehicle body manufacturers, this temporary discontinuation forced other related plants to suspend production, for example, production of hybrid vehicles at the Tsutsumi Plant in Aichi and at Toyota Motor Kyushu in Fukuoka. Globally, the impact of supply shortages of spare parts not only affected production in Japan. In North

America, due to the lack of spare parts, Toyota had to announce the suspension of production of all vehicles, engines, and components at its factories. Due to the same problem, Ford had to idle its automotive plants in Genk, Belgium. Ford also had to stop taking new orders for some car body colours because of the shortage of certain pigments sourced from Japan.

From the descriptions, naturally, the impact of the 2011 GEJE has sharply delineated the critical role played by the agriculture and industrial sectors. The impact has reduced agricultural production and disrupted the supply chains of manufacturing products, namely electronic products and car parts not only domestically but also globally. Therefore, it will be of great interest to study how to get these agricultural producers and internationally competitive parts' and materials' manufacturers back on their feet as part of the recovery process of the Tohoku region as well as an important aspect of maintaining Japan's industrial competitiveness.

Three years have passed, and, as such, it is an appropriate time to reflect on the progress made to date, approaching the reconstruction undertaken after natural disasters as an opportunity for development (Lyons 2009). Reconstruction and revitalization of the economies, communities, and livelihoods impacted by this disaster remains a national priority. This study presents information and lessons on recovery processes following the 2011 GEJE. Its main objectives are to investigate the damaging impact of the 2011 GEJE and the performance of restoration and reconstruction in the agricultural and manufacturing sectors. As the contribution of the manufacturing sector to the industrial sector is, on average, around 70%, so in this study we will focus on the recovery of the manufacturing sector. In addition, the Tohoku region was the most severely damaged region; therefore, in some parts of the discussions, we will focus on this region. In Section 2, we discuss the economic overview before and after the 2011 GEJE. In Sections 3 and 4, the performance of the agriculture sector and manufacturing sector, respectively, before and after the 2011 GEJE will be discussed and analysed using quantitative methods. Finally, in Section 5, we conclude the study with our final comments.

2. Economic overview before and after the 2011 Great East Japan Earthquake

Figure 1 shows share and growth of the GDP by economic activities during the period from 2000 to 2012. We find that the average of the service sector share of the total GDP from 2000 to 2010 was about 70.3% followed by the industry sector (28.4%) and the agriculture sector (1.3%). In the same period, on average, the Japanese economy registered a −0.4%, with the highest growth in 2010 (2.4%), two years after the 2008 GFC hit Japan.

In the period of 2000–2011, the economy of Japan had actually undergone two major disruptions, namely the 2008 GFC (Aragon and Strahan 2012, Dumontaux and Pop 2013) and the 2011 GEJE. The first disruption, which lasted for two years, induced contractions in the Japanese economy 2.5% and 5.9% in 2008 and 2009, respectively, and the highest decrease was experienced by the industrial sector at 11% in 2009. The decline in the growth of the Japanese economy that occurred in 2009 was the largest decline over the last 50 years (Statistics Bureau of Ministry of Internal Affairs and Communications (MIAC) 2014). After suffering from the 2008 GFC for two years, the economy of Japan started to recover in 2010. Unfortunately, when the Japanese economy had just started to recover, another disruption occurred after the 2011 GEJE. The disaster caused Japan's economy to contract by 2.2%. As in 2009, the sector most severely hit by the disaster was the industrial sector, in which growth declined by 7.1%. Based on these two

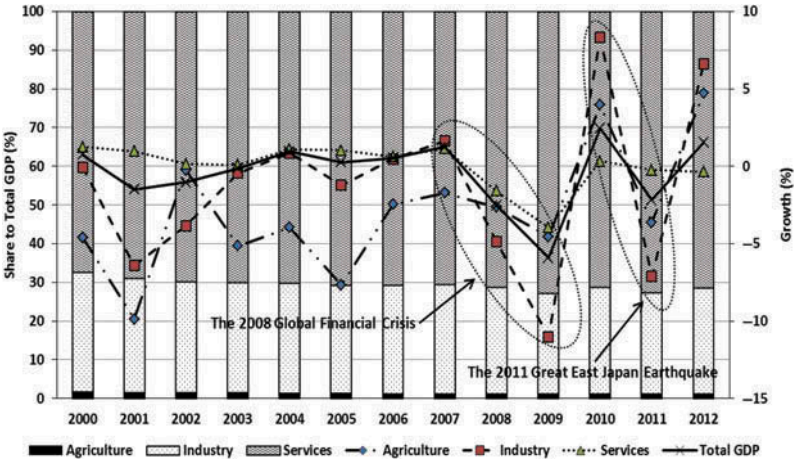

Figure 1. Share and growth of GDP by economic activities, 2000–2012.
Data source: Japan Statistical Yearbook (2000–2012).

experiences, it seems that the industrial sector is relatively prone towards contractions in growth, whereas the agricultural sector and the service sector are less prone. This should be a concern for the Government of Japan (GOJ) in the future, given that workers employed in the industrial sector account for about 28% of the entire workforce.

Japan has 47 prefectures, which are often grouped into eight regions: Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku, and Kyushu (including Okinawa). According to the Disaster Relief Act which is applied to regions (i.e., cities, towns, and villages), there are nine affected prefectures with total of 198 affected regions, including Aomori (2 regions), Iwate (34 regions), Miyagi (39 regions), Fukushima (59 regions), Ibaraki (37 regions), Tochigi (15 regions), Chiba (8 regions), Niigata (3 regions), and Nagano (1 region). Among these affected prefectures, the first four prefectures, namely the Tohoku prefectures, have been the most affected by the 2011 GEJE (Ministry of Economy, Trade and Industry (METI) 2014).

In Hokkaido, agriculture and other primary industries play a large role in the economy as it has nearly one fourth of Japan's total arable land. The Tohoku area is primarily agricultural: 65% of cultivated land is rice paddy fields, accounting for almost a quarter of all the paddy fields throughout the country. The Kanto region, which includes such key cities as Tokyo, Yokohama, Saitama, and Chiba, is the most populous region of Japan and the core of Japan's commerce, services, and industry. The Chubu region has one of the largest rice-producing areas, located along the Sea of Japan. It has three industrial areas: Chukyo, home to the main facility of Toyota Motors; Tokai; and Hokuriku. The Kinki region is Japan's second most important area in terms of industry. The Inland Sea coast in the Chugoku region is an important area of industry and commerce. The Shikoku region has high and steep mountains that serve as a limit to farming and habitation. In the Kyushu region, agriculture, stock farming, hog raising, and fishery all flourish. The Kita Kyushu Industrial Zone contains a concentration of heavy and chemical industries.

Figure 2 shows the value of GDP by region and average growth during the 2000–2012 period. We find that Kanto had the highest regional GDP (RGDP) and average share of Japan's GDP (36.9%), followed by Chubu (17.8%), Kinki (17.2%), Kyushu (9.4%), Tohoku (6.5%), Chugoku (5.7%), Hokkaido (3.8%), and Shikoku (2.7%). In terms of

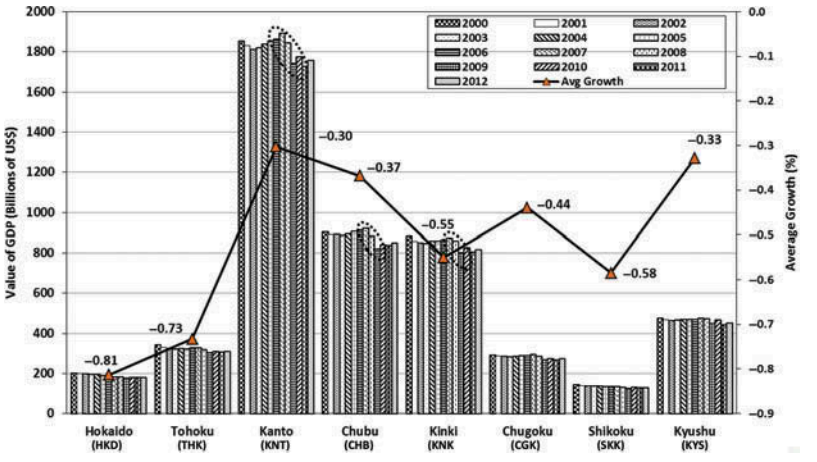

Figure 2. Value of GDP by region and average growth (%), 2000–2012.
Data source: Japan Statistical Yearbook (2000–2012).

the value of GDP growth during this period, it appears that the entire region had an average negative growth, with the Kanto recording the largest growth (−0.3%) and Hokkaido having the smallest at −0.81%. Figure 2 shows the three regions that were most affected by the 2008 GFC, Kanto, Chubu, and Kinki, with the highest share of RGDP.

Figure 3 presents the relationship between the production of rice and gross agricultural products (GAPs) by region from 2000 to 2012. Based on the production of rice and the value of GAP, we can separate the regions into three groups. The first group is regions that have high shares of rice production and GAP (more than 10%), which comprise of the four regions of Tohoku, Chubu, Kanto, and Kyushu. Among these regions, Tohoku has the highest share of rice production but has the lowest share of GAP, whereas Kyushu has

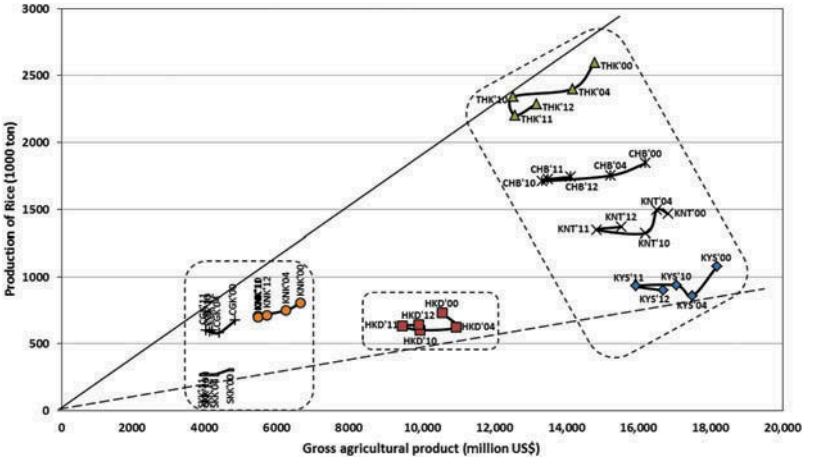

Figure 3. Gross agricultural product and production of rice, 2000–2012.
Data source: Japan Statistical Yearbook (2000–2012).

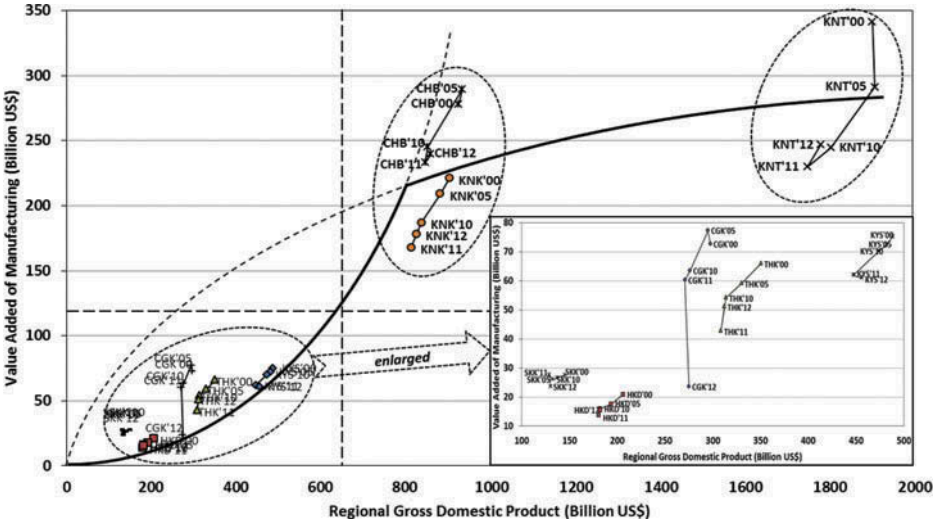

Figure 4. Regional GDP and value-added manufacturing (VAM), 2000–2012.
Data source: Ministry of Economy, Trade, and Industry (2014).

the lowest share of rice production but the highest share of GAP. In the second group, there is only the Hokkaido region, which has GAP in excess 10% but rice production of less than 10%. The third group is regions with low shares (less than 10%) of rice production and GAP; these include Chugoku, Kinki, and Shikoku, with Shikoku having the lowest rice production and GAP.

Figure 4 shows the changes in VAM and the RGDP from 2000 to 2012 by region. VAM is obtained from the Manufacturing Census conducted by the Ministry of Economy, Trade, and Industry (METI 2014). Here, we can classify the regions into three groups, with regions with high RGDP and high VAM as the first group, regions with middle RGDP and high VAM as the second group, and regions with low RGDP and low VAM as the third group. In addition, in Figure 4, we can see the enlarged third group in order to see more details. During 2000–2012, Kanto is in the first group with an average share of 14.73%; Chubu and Kinki are in the second group with average shares of 29.01% and 22.49%, respectively, while the rest of the regions form the third group, with Hokkaido having the smallest share (8.81%). Thus, during 2000–2012, Chubu had the highest share of VAM to RGDP, which implies that although Kanto has the highest VAM, apparently manufacturing is not the leading sector of the economy in Kanto, while with an average share of almost 30%, manufacturing is the leading sector in Chubu.

Furthermore, the relationship model between VAM and RGDP implies that up to a certain value of RGDP, the economy of a region will be dependent on industrial manufacturing. However, after exceeding a particular value (around 800 billion US$) of RGDP, the economy of the region will be less dependent on industrial manufacturing and more dependent on the services and commerce sectors as seen for the Kanto region. Therefore, in the future, the Kinki and Chubu regions will have similar economic structures as that of the Kanto region.

Figure 5 shows a map of the Tohoku region located in the northeastern part of the largest Honshu island in Japan. Tohoku was most affected by the 2011 GEJE, with four of six Tohoku prefectures suffering major damage: Aomori, Iwate, Miyagi, and Fukushima.

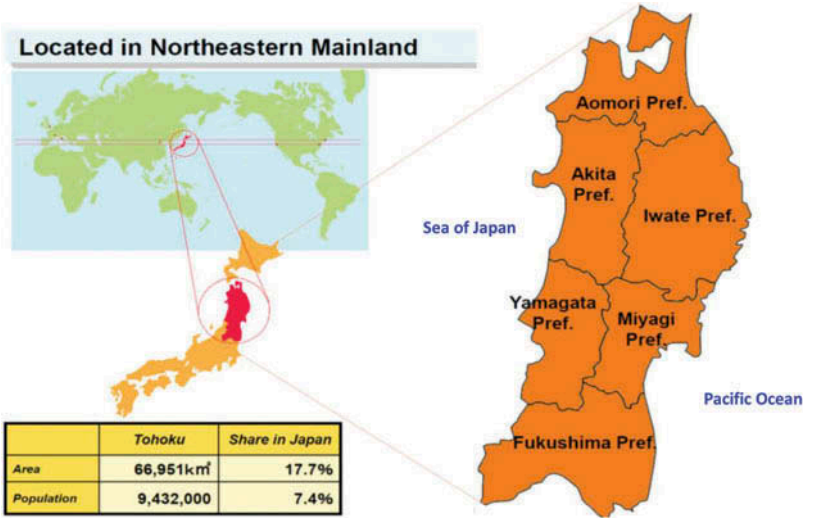

Figure 5. Map of the Tohoku region.

Source: Japanese Ministry of Foreign Affairs (MOFA): Web of Japan.

Tohoku, like most of Japan, is hilly or mountainous; meaning much of the region's population is concentrated in the coastal lowlands. According to the Census of Population in 2010, the area of Tohoku region is about 17.7% of Japan's total area. The population is 7.4% of Japan's total.

In 2010, the Tohoku region contributed about 310.1 billion US$, or 6.3% to the total GDP of Japan, which comes from the primary industries (7.9 billion US$), the secondary industries (68.7 billion US$), and the tertiary industries (232.6 billion US$). The income per capita of Tohoku was about 23,950 US$. With a total planting area of about 17%, the Tohoku region accounts for about 28% of the total production of rice, the staple food of the Japanese people. According to the Census of Manufacturing in 2010, the number of business establishments in Tohoku was 470,282, or 7.8% of the total number of establishments in Japan. The value of manufactured goods shipped from Tohoku is about 163.5 billion US$, or about 5.7% of the total value of Japan's manufactured goods.

In the Tohoku region, during the period 2000–2012, Miyagi had the highest RGDP value with an average value of the total share of Japan's GDP 25.4%; this was followed by Fukushima (23.4%), Iwate (13.8%), Aomori (13.7%), Yamagata (12.2%), and Akita (11.6%). Therefore, we can estimate that the affected prefectures in Tohoku accounted for about 76.3% of the average total RGDP of Tohoku. In terms of RGDP growth during this period, it appears that all the prefectures experienced an average negative growth, with the highest value in Miyagi (−0.72%) and the lowest value in Iwate (−1.37%). In Tohoku, Miyagi and Fukushima were the prefectures most affected by the 2008 GFC.

Figure 6 shows the production of various commodities in the Tohoku region in 2010, among which paddy/rice is a mainstay commodity with contribution of 64.68%, followed by the production of apple and corn, where each commodity has contributed approximately 14.79% of the total agricultural production in Tohoku. However, because of the climate, harsher than in any other parts of Honshu, only one crop can be grown each year. Every prefecture in Tohoku has high rice production of more than 280 kilotons for a total

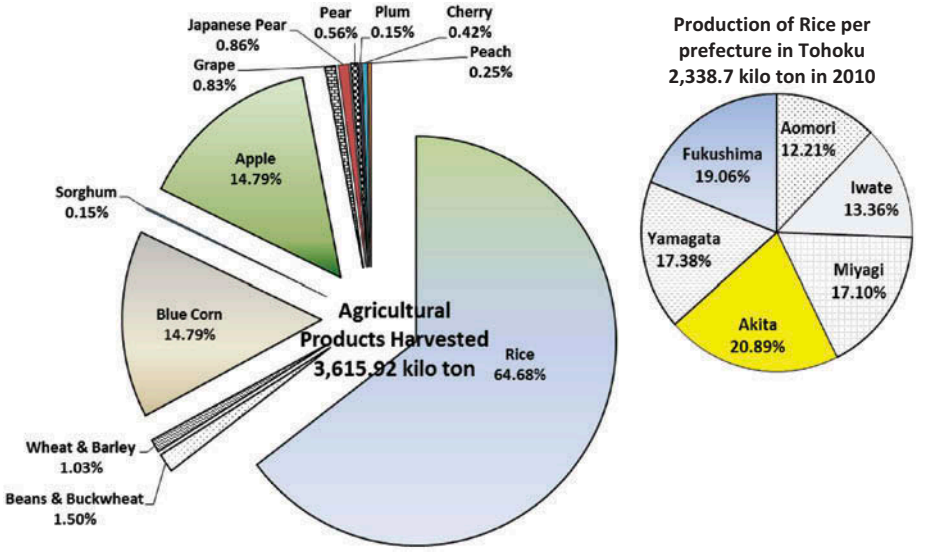

Figure 6. Share of agricultural products harvested by commodity and share of production of rice per prefecture in the Tohoku Region, 2010.

Data source: MAFF, World Census of Agriculture and Forestry (2010).

of about 2,338.7 kilotons in 2010, where Akita Prefecture has the highest rice production, followed by Fukushima Prefecture.

Figure 7 describes shares of manufactured goods shipments by industry and shipments of electronic parts/devices/circuits per prefecture in the Tohoku region. Electrical

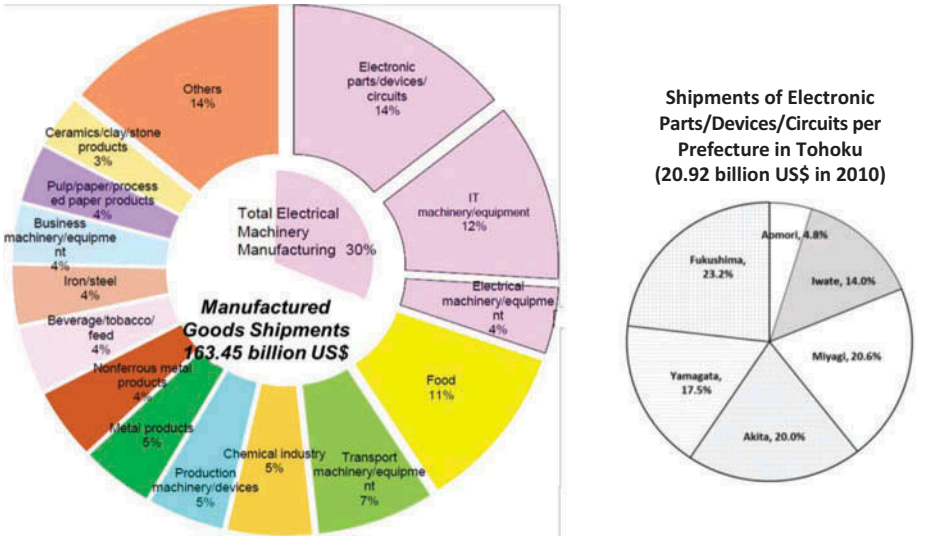

Figure 7. Share of manufactured goods shipments by industry and share of shipments of electronic parts/devices/circuits per prefecture in the Tohoku Region, 2010.

Data source: METI, Census of Manufacturing (2010).

machinery includes electronic parts, devices, and circuits, IT machinery and equipment, electrical machinery and equipment. METI estimated that shipments of electronic parts/devices/circuits from the Tohoku region accounted for about 20.92 billion US$ in 2010, and if we look by prefecture, Fukushima has the largest contribution at 23.2%.

3. The 2011 GEJE: damage, restoration, and reconstruction in agriculture sector

3.1. Damages, restoration, and reconstruction of the 2011 GEJE in agriculture sector

On 11 March 2011, the 2011 GEJE and resultant tsunami hit East Japan, claiming the lives and property of many people. In particular, the agriculture and related industries were severely hit. Most of the agricultural land or farmlands were inundated with sea water, almost all the agricultural facilities in Miyagi, Fukushima, and Iwate Prefectures were badly damaged, and most agricultural crops were washed away as well. Damages related to the agricultural land and facilities and to the agricultural crops were reported to be over 8.8 billion US$ and 9.4 billion US$, respectively. Nevertheless, when losses associated with farmers' inability to work since being hit by the disaster, damage to processing facilities, and loss of processing capacities are combined, such damages are likely to be much larger than these amounts. Table 1 describes the estimated area of farmland washed away, inundated, or damaged by the tsunami. In terms of the estimated area of farmlands damaged, Miyagi Prefecture suffered the most due to the disaster, in which 15,002 ha – about 21.6% of the total planted area – were flooded by sea water. These farmland-damaged areas comprised some 12,685 ha of paddy fields and 2317 ha of upland fields.

Table 2 describes the damage to the agricultural sector in total and particularly in three of the prefectures in Tohoku. Damages related to agriculture were reported to be over 84.7 billion US$, of which about 91.3% were from three prefectures in Tohoku. Again, Miyagi Prefecture had severe losses due to the 2011 GEJE, namely about 55.7% of the total losses.

Immediately after the disaster, the GOJ implemented measures to procure and provide emergency food, beverages, charcoal, and briquette coal to temporarily restore agriculture and other facilities, to prevent secondary disasters, to supply feed, and to secure a stable rice supply in the Tokyo metropolitan area and other regions. The GOJ also issued instructions on restrictions of the distribution of spinach, raw milk, and other products in some regions in line with the fallout radionuclides due to the accident at TEPCO's

Table 1. Estimated area of farmlands washed away, inundated, or damaged by the tsunami.

Prefecture	Planted area (ha)	Area of damaged farmland (ha)			
		Total		Paddy fields area	Upland fields area
Aomori	46,900	79	(0.16)	76	3
Iwate	54,500	1,838	(1.33)	1,172	666
Miyagi	66,400	15,002	(21.60)	12,685	2,317
Fukushima	64,400	5,923	(8.48)	5,588	335
Ibaraki	77,100	531	(0.27)	525	6
Chiba	60,500	227	(1.10)	105	122
Total	369,800	23,600	(5.81)	20,151	3449

Data source: Ministry of Agriculture, Forestry, and Fisheries.
Note: Numbers in parentheses are estimated damaged areas shares of the planted areas.

Table 2. Damage to the agriculture in three affected prefectures in Tohoku region.

Major damage	Total damage & number of places	Damage in Iwate	Damage in Miyagi	Damage in Fukushima
Farmland (BUS$)	40.1	2.3	27.6	9.4
(Places)	(18,186)	(13,321)	(1495)	(1799)
Agriculture purpose (BUS$)	27.5	0.6	12.1	9.3
(Places)	(17,317)	(3657)	(4724)	(3749)
Coastal conservation facilities (BUS$)	10.2	3.3	4.4	2.5
(Places)	(139)	(15)	(103)	(20)
Rural community facilities (BUS$)	6.3	0.1	2.7	2.4
(Places)	(450)	(41)	(107)	(141)
Crops such as damage costs (MUS$)	142	19	82	8
Agriculture, livestock related facility damage cost (MUS$)	492	28	351	13
Grand total (BUS$)	84.7	6.4	47.2	23.7

Data Source: Ministry of Agriculture, Forestry, and Fisheries, as for 5 July 2012.
Notes: BUS$, billion US dollars; MUS$, million US dollars.

Fukushima Daiichi Nuclear Power Station. In addition, on 8 April 2011, the government implemented a policy restricting rice planting in restricted areas, planned-evacuation areas, and areas prepared for evacuation in the case of emergency, as well as in areas where radioactive caesium was detected in paddy field soil.

Agriculture in Japan was an important component of the pre-war Japanese economy. Although Japan had only 16% of its land area under cultivation before the Asia-Pacific War in 1941, over 45% of households made a living from farming. Cultivated land was mostly dedicated to rice. Over the course of Japan's economic growth, its agricultural, forestry, and fishing industries have come to employ fewer workers every year, and their respective shares of GDP have also dropped. The number of workers decreased from 14.39 million in 1960 (32.7% of the total workforce) to 2.38 million in 2010 (4.2% of the total workforce), and the GDP share of the industries fell from 12.8% in 1960 to 1.2% in 2010 (Dumontaux and Pop 2013).

In 2012, the contribution of the agricultural sector to Japan's GDP is only about 1.2%, yet given that the agricultural sector is a very important sector in order to support the availability of food for Japanese people and to maintain Japan's food self-sufficiency ratio, the agricultural sector has become one of the top priorities for restoration and reconstruction. As most of the disaster-damaged areas are rural, it is important for Japan to restore and reconstruct the disaster-damaged areas, including the Tohoku region, as one of Japan's leading food supply bases as soon as possible.

The quick responses and lots of great efforts from the GOJ and the responses from the international community in giving donation and assistance have made significant progress in accomplishing and accelerating towards rebuilding and revitalizing areas affected by the GEJE. According to the Ministry of Foreign Affairs, six months after the disaster, Japan has received assistance from 163 countries and 43 international organizations. In the disaster-hit areas and elsewhere in the country, many people's lives are still greatly inconvenienced because of the damage. Those people include those who are still unable to return to their homes even now because of the nuclear accident. In the agricultural sector, the restoration plan for farming is on schedule, aiming to have approximately 90% of farmland back in operation in 2014, while the fisheries sector is also on its way to a full-scale recovery. There have also been numerous initiatives that support the

Table 3. Gross agricultural products and rice production of major affected prefectures.

	GDP of agriculture (million US$)			Production of rice (1000 ton)		
Prefectures	2010	2011	2012	2010	2011	2012
Total-Japan	82,549	79,545	83,290	8,487	8,405	8,522
Aomori Pref.	2,751	2,478	2,594	286	281	296
Iwate Pref.	2,287	2,330	2,440	313	298	305
Miyagi Pref.	1,679	1,776	1,859	400	363	392
Fukushima Pref.	2,330	2,304	2,412	446	354	369
Ibaraki Pref.	4,306	3,779	3,957	406	397	412
Tochigi Pref.	2,552	2,438	2,553	343	351	345
Chiba Pref.	4,048	3,815	3,995	333	322	334
Total-7 Pref.	19,953	18,920	19,810	2,527	2,366	2,453
Share-7 Pref. (%)	24.17	23.79	23.78	29.77	28,15	28.88

Data source: Ministry of Agriculture, Fishery, and Forestry, 2010–2012.

revitalization of local economies through public–private partnerships, many of which are leveraging advanced technologies such as information and communication technology and clean energy, as well as high-tech agricultural initiatives. The progress of agriculture performance, reflected in the GDP of agriculture and the production of rice, is presented in Table 3.

In the case of the restoration and reconstruction of the agricultural sector in Tohoku, Figure 8 shows the planted area and production by paddy by prefecture in Tohoku before, during, and after the 2011 GEJE. In 2011, all prefectures except Akita experienced a decrease in production by paddy. Fukushima experienced the largest decrease, followed by Miyagi, Iwate, Yamagata, and Aomori. Among the prefectures that experienced a decline in paddy production, Aomori has had the fastest recovery in paddy production with the 2012 paddy production having surpassed the 2010 production; Fukushima, however, has had the slowest recovery in paddy production. One of the reasons is that,

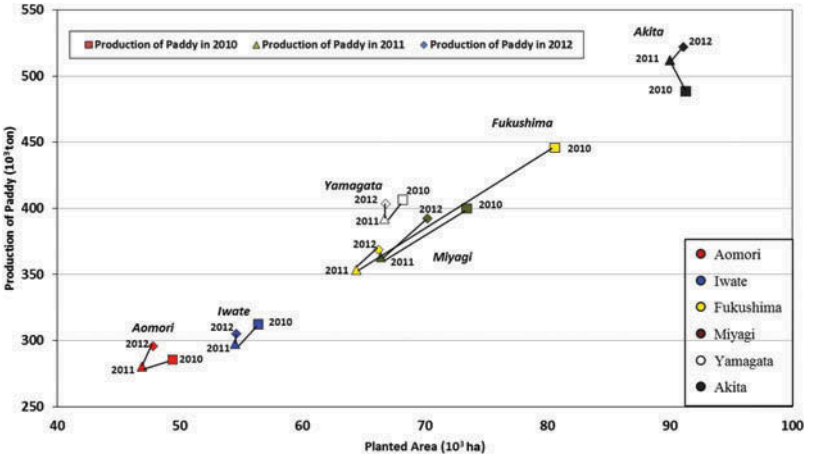

Figure 8. Planted area and production of paddy in Tohoku Region.

Data source: Ministry of Agriculture, Fishery, and Forestry, 2010–2012.

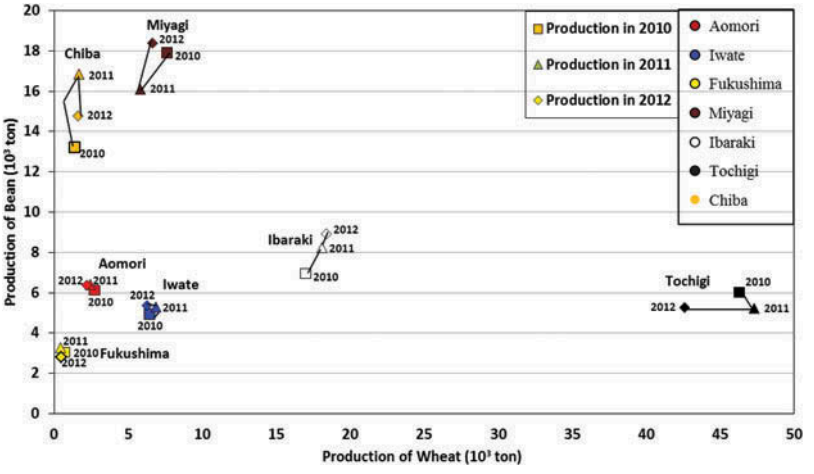

Figure 9. Production of wheat and bean in affected prefectures.
Data source: Ministry of Agriculture, Fishery and Forestry, 2010–2012.

besides the earthquake and tsunami, Fukushima also suffered from the nuclear power plant accident, after which many people had to leave their hometown and, for health safety reasons, the production of paddy was deliberately reduced. In order to maintain the same level of rice production in Japan, the Japanese government redistributed the paddy production from Fukushima to other prefectures.

Figure 9 displays the production of wheat and beans in the affected prefectures, and apparently, some agricultural products such as wheat, beans, and buckwheat were not affected much by the disaster. This implies that the affected prefectures were not the major producer of these crops or the locations of the planting of these crops were far from the disaster area. The contribution of the affected prefectures to the whole country's production of wheat, beans, and buckwheat were 9.29%, 19.17%, and 22.72%, respectively. Also, we can see that Tochigi has the highest production of wheat inasmuch as its production was not affected much by the disaster. Miyagi and Chiba have the largest production of beans, and, clearly, as the prefecture that experienced the most severe impact of the disaster, the production of beans in Miyagi has significantly decreased. Interestingly, in spite of that severe impact on its agricultural sector, the production of beans in Miyagi in 2012 exceeded the production in 2010. This implies that the recovery performance in Miyagi, especially in the production of beans, has been conducted very well. Meanwhile, Fukushima has the lowest production of wheat and beans.

3.2. Methodology

Our balanced panel data encompass 47 prefectures over the period 2000–2012. The data were obtained from various government institutions of Japan, including the Cabinet Office of Japan (CAO), the MAFF, the METI, the MIAC, and from prefectural websites. To investigate the impact of the 2011 GEJE on the agricultural sector, we use the growth of GAP per farm household as the dependent variable. Next, to examine the impact of the disaster on the affected and unaffected prefectures, we run four regression models: one that includes all prefectures (N = 47), a second with less affected prefectures (i.e.,

prefectures in which the Disaster Relief Act was not applied; $N = 38$), a third one using the affected prefectures ($N = 9$), and finally one with the most affected prefectures ($N = 4$).

Major natural disasters are likely to have a large negative impact on economic growth, whether in the short run or in the long run. Given that, the macroeconomic literature generally distinguishes short-run effects and long-run effects, the first recent attempt to empirically describe short-run macroeconomic dynamics of natural disasters was Albala-Bertrand (1993) (Albala-Bertrand 1993). By applying a simple macroeconomics model, he found that GDP increased after the disasters. We try to investigate the impact of uncertain and sudden shocks such as the 2011 GEJE on the output of the agriculture sector.

Following Levine et al. (2000), Bruno (2005a), Noy and Vu (2010), Loayza *et al.* (2012), Strobl (2012), and Bloom and Baker (2013), our model starts with an autoregressive model that includes various policy and institutional variables reflecting the prefecture heterogeneity in efficiency. Moreover, and of importance, it also includes a shock term (i.e., natural disasters):

$$y_{i,t} = \alpha y_{i,t-1} + \beta X_{i,\mathbf{t}} + \gamma \mathrm{GEJE}_{i,t} + \eta_i + \varepsilon_{i,t};\ i = 1, \ldots, N, t = 1, \ldots, T \tag{1}$$

where the subscripts i and t represent prefecture and time period, respectively; α is the parameter for the lagged dependent variable, thus α captures the dynamic process; β represents the parameters for the explanatory variables; γ is the parameter for $\mathrm{GEJE}_{i,t}$, the explanatory variables of interest, in which $\mathrm{GEJE}_{i,t}$ is a binary variable that takes a value of 1 if the prefecture was affected by the 2011 GEJE, and 0 if otherwise; η is an unobserved prefecture-specific effect; and ε is an unobserved white-noise disturbance with constant variance $\sigma^2_{\in}$.

For explanatory control variables as proxy shocks other than the *GEJE*, we use the following five variables. Education is approximated by the ratio of junior high school graduates who proceed to higher education. Infrastructure development is measured by the public work expenditure per capita. Preparedness and rehabilitation from disasters is proxied by the disaster relief expenditure per capita. It should be noted, however, that the spending of this fund is not only for earthquakes but also for all other natural disasters that might occur in Japan (i.e., storms, floods, and landslides) (Parwanto and Oyama 2013). Welfare expenditure per capita is a measure of the responsibility of the government to improve the welfare of society. Inflation rate is a proxy for macroeconomic stabilization, with high inflation being associated with bad macroeconomics policies. Finally, one should also note that in this estimation, we implicitly assume that our GEJE variable as well as the other control variables are exogenous.

We further note that with the inclusion of the lagged dependent variable as one of the regressors, Equation (1) is simply a dynamic panel model. Nevertheless, as pointed by Nickell (1981), this situation introduces a systematic bias in the estimator of the coefficient on the lagged dependent variable (Nickell 1981), which could lead to biases in other coefficients in the model. In addition, according to Judson and Owen (1999), using Monte Carlo simulations has shown that with balanced dynamic panels characterized by $T \leq 20$, and $N \leq 50$, the Kiviet bias-corrected least-squares dummy variable (LSDVC) estimator of α (the parameter on the lagged dependent variable) is better behaved than the Anderson–Hsiao and the Arellano–Bond estimators (Kiviet 1995, Judson and Owen 1999, Alberini and Filippini 2010). Thus, based on this evidence and the fact that our data set has $N = 47$ and $T = 13$ as well as addresses the bias problem, we estimate our dynamic models using the LSDVC estimators. We use the

Stata program *xtlsdvc* for estimating the parameters of the LSDVC models with bias correction as in Equation (1) (StataCorp 2014, Bruno 2005b).

3.3. *Impact analysis on the agriculture sector*

The regression result is presented in Table 4 for the full sample, the less affected prefectures, the affected prefectures, and the most affected prefectures, respectively. From Table 4, all the estimated parameters of our variable of interest – the 2011 GEJE ($\hat{\gamma}$) – are statistically significant and have negative valences. This implies that the disaster has had some negative impact on the growth of GAPs. Furthermore, by looking at the magnitude of the impact of the 2011 GEJE on the agriculture sector by prefectures, we can see that the magnitude for the less affected prefectures is the smallest and for the most affected prefectures is the strongest. This is understandable, for although the total contribution of GAP from the affected prefectures is about 30%, the effect of the disaster as a whole is offset by the less affected prefectures. Comparing the magnitudes in columns [2] and [4], the impact of the disaster on growth of GAP in the most affected prefectures is about three times greater compared to that in the less affected prefectures. This is because the agriculture sector is a leading sector in most prefectures in the Tohoku region.

Looking at the other control variables, the estimated parameter for lagged GAP ($\hat{\alpha}$) is both negative and significant. As pointed out by Pritchett (1997), initial output per capita not only captures the forces of diminishing returns and thus convergence, but also

Table 4. Impact of the 2011 GEJE on growth of the gross agricultural products; estimation method: LSDVC.
Dependent variable: Growth of GAP per farm household

Variable	[1] All prefectures	[2] Less affected prefectures	[3] Affected prefectures	[4] Most affected prefectures
Natural disaster variable				
2011 Great East Japan Earthquake ($\hat{\gamma}$)	−0.0866***	−0.0480***	−0.0882***	−0.1520***
	(0.0248)	(0.0165)	(0.0311)	(0.0504)
Control variables				
Initial growth of gross agriculture products per farm household ($\hat{\alpha}$)	−0.2440***	−0.2670***	−0.2300**	−0.2930**
	(0.0481)	(0.0537)	(0.0929)	(0.1460)
Education (in logs) ($\widehat{\beta_1}$)	−1.2600	−1.0590	0.9390	3.3350
	(1.0500)	(1.0550)	(3.1220)	(6.7330)
Public work expenditure per capita (in logs) ($\widehat{\beta_2}$)	−0.0085	−0.0074	−0.0224	−0.0694
	(0.0241)	(0.0308)	(0.0505)	(0.0841)
Disaster relief expenditure per capita (in logs) ($\widehat{\beta_3}$)	−0.0082*	−0.0069	−0.0140	−0.0045
	(0.0046)	(0.0048)	(0.0120)	(0.0277)
Welfare expenditure per capita (in logs) ($\widehat{\beta_4}$)	0.0704**	0.1100***	0.0356	0.0520
	(0.0292)	(0.0348)	(0.0581)	(0.1030)
Inflation (log (100 + % growth rate of CPI)) ($\widehat{\beta_5}$)	−3.9640***	−3.9820***	−4.2800***	−4.5680***
	(0.4980)	(0.6400)	(0.9970)	(1.5490)
Observations	505	406	99	44
Number of prefectures	47	38	9	4

Notes: Numbers in parentheses are the standard errors.
Parameter estimates with ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

represents institutional and structural conditions that have a positive impact on economic growth, which supports the existence of a dynamic nature of the dependent variable (Pritchett 1997, Baltagi 2000). The estimated parameter for education $(\widehat{\beta_1})$ appears to have different signs, although none of them is statistically significant; the estimated parameter for public work expenditure $(\widehat{\beta_2})$ is also not significant. The estimated parameter for welfare expenditure $(\widehat{\beta_4})$ has positive coefficients, suggesting a beneficial impact on society. On the other hand, the estimated parameters for government expenditures on disaster relief $(\widehat{\beta_3})$ and for price inflation $(\widehat{\beta_5})$ carry negative coefficients, indicating the harmful nature of a large fiscal burden and macroeconomic instability. However, this fact should be interpreted cautiously as most of the major public infrastructure and safety buildings have been already built. Therefore, expenditures on these expenses have been decreasing in recent years, though the situation slightly changed after the disaster.

4. The 2011 GEJE: damage, restoration, and reconstruction of the manufacturing sector

4.1. Damages, restoration, and reconstruction in the manufacturing sector

The 2011 GEJE caused about significant damage in the Tohoku and Kanto areas. Production disruption at affected firms has had extensive negative impacts on production activities in a wide variety of companies through supply chains surrounding the manufacturing industries. Since many firms do not fully understand the supply chains they belong to, negative impacts have spread out further. Figure 10 depicts the impacts of earthquake damage on production activities.

To identify the status of production activities of business establishments in the manufacturing industries, supply and demand trends of produced products, production plans of manufacturers for two months ahead, and production-related facilities and their operational statuses, the Index of Industrial Production (IIP) is often used. IIP is an

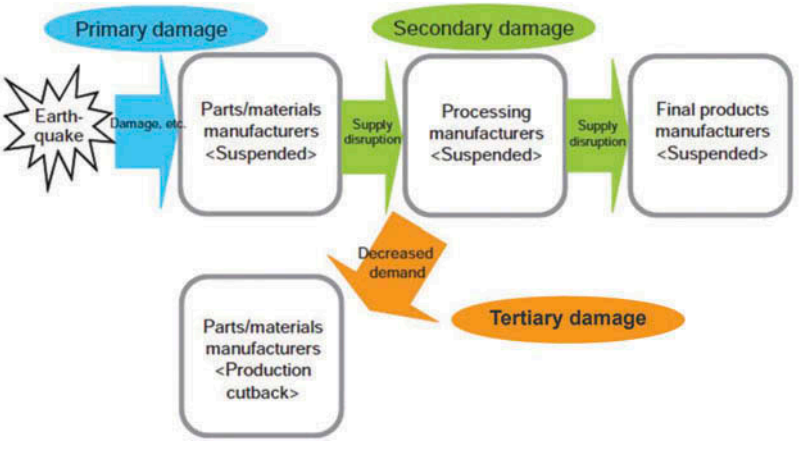

Figure 10. Impacts of earthquake damage on production activities.

Source: Ministry of Economy, Trade, and Industry (2014).

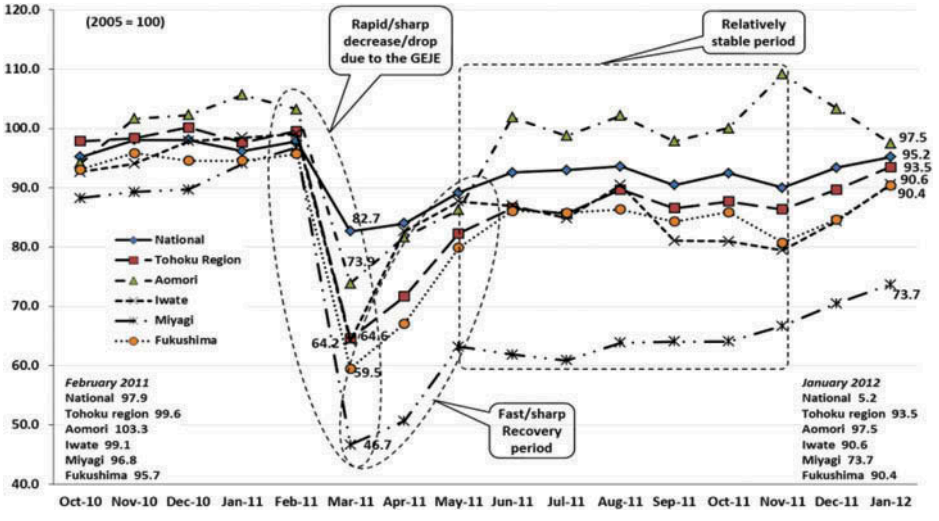

Figure 11. Trends of the Industrial Production Index (seasonally adjusted).
Data source: Ministry of Economy, Trade, and Industry (2014).

abstract number, the magnitude of which represents the status of production in the industrial sector for a given period of time as compared to a reference period of time. Figure 11 portrays the trend of IIP in Japan from October 2010 to January 2012.

In Figure 11, we can see that due to the natural disasters, the IIP for the first quarter of 2011 decreased compared to the previous period. Furthermore, the Tohoku region experienced a greater decrease than the entire country. Among the three worst affected prefectures, Miyagi had the highest decline in IIP, followed by Fukushima and Iwate. One of the possible reasons is because there is a greater amount of auto-related industry agglomeration in Miyagi compared to the other areas.

The Japanese government issued a primary supplementary budget in Fiscal Year 2011 of 5.94 billion US$ in total, of which some 5.1 billion US$ were used for financial support, leaving the remaining budget for restoration of factories and other facilities, energy supply facilities, and infrastructure. The main target of the financial support was small and medium enterprises (SMEs). Many SMEs were so badly damaged directly or indirectly by the 2011 GEJE that through METI the government created a disaster response financial system known as the 'Great East Japan Earthquake Recovery Emergency Guarantee'. The system offered drastically expanded credit lines and reduced interest rates applicable to credit guarantees and public loans to ensure that SMEs, including those indirectly damaged, would be able to cope with the disaster with minimal financial difficulty.

As depicted in Figure 11, the 2011 GEJE led to a decline in the value of the IIP in the first quarter of 2011. However, from the second quarter of 2011 the IIP started to increase. It was a remarkable that from September until November 2011, the IIP of Fukushima surpassed the IIP of Iwate. In January 2012, the IIP of Tohoku had approached the IIP of Japan, and the IIP of Iwate and Fukushima was almost the same, while the IIP of Miyagi remained far behind. Nevertheless, the values of IIP of neither Japan nor Tohoku have reached the levels seen before the 2011 natural disaster.

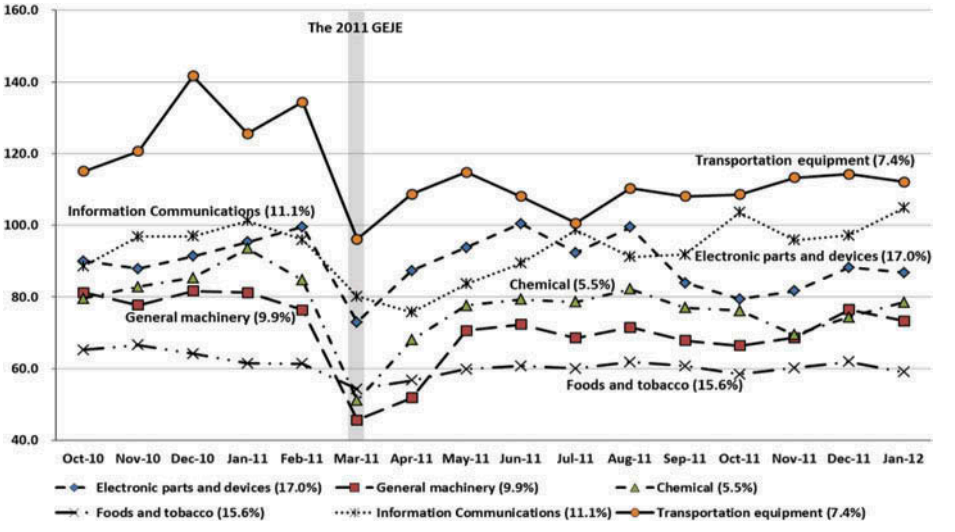

Figure 12. Trends of the Industrial Production Index by industry in Tohoku.
Data source: Tohoku Bureau of Economy, Trade and Industry Statistics.

A breakdown by industry in the Tohoku region shows that the IIP decreased dramatically in the general machinery industry followed by the chemical and the transportation equipment industries. In the recovery period, the IIP increased dramatically in the general machinery and the chemical industries, followed by electronic parts and devices, though they still not yet reached its pre-disaster level. There is considerable variation by industry, with sluggish restoration being reported in the transport equipment industry, the foods and tobacco industry, and the information and communication industry (Figure 12).

Looking at Figures 11 and 12 in more detail, we can distinguish three distinct IIP trends due to the 2011 GEJE, namely the sharp decrease of the IIP from February to March 2011, the sharp recovery from March to May 2011, and the relatively stable period after May 2011. In the first period, the sharpest decline was experienced by Miyagi from 96.8 to 46.7. This sharp decline was caused by a decrease in the IIP values of the pulp, paper, and paper products industry, namely from 103.6 to 35, followed by decreases in the chemical, petroleum, and coal products industry from 99.6 to 34.7 and the general machinery industry from 119.1 to 42.5. Fukushima also experienced a sharp decline in the first period (from 95.7 to 59.5). This decline was due to the decline of the IIP values of the non-ferrous metal industry from 98.0 to 44.9, the chemical industry from 115.9 to 55.1, and the foods and tobacco industry from 71.2 to 33.4. In Iwate, the decline in the IIP value from 99.1 to 64.2 was due to the decline of the steel industry from 140.7 to 52.9; the general machine industry from 129.7 to 63.4; and the pulp, paper, and paper products industry from 95.4 to 44.2. In addition, although it also declined, Aomori was the only one of the affected areas that had IIP values above those of the Tohoku region (from 103.3 to 73.9). The highest decline in Aomori was experienced by the pulp, paper, and paper products industry and the steel industry, from 100 to 37.8 and from 78.2 to 31.7, respectively. Interestingly, while most industries

in Aomori have undergone a decline in IIP value, the chemical industry had positive growth, from 24.4 to 59.4.

In the two months after the disaster, namely in the second period, the manufacturing sector recovered quickly, which can be seen from IIP values. In spite of that recovery, their IIP values have not reached pre-disaster levels. Among the most affected prefectures in the Tohoku region, Iwate experienced the fastest recovery, followed by Miyagi, while Fukushima had the slowest recovery in terms of its production activity status. In Iwate, the IIP was down by around 11.5% compared to pre-earthquake figures; against this background, the highest IIP growth occurred in the general machine industry (177%), followed by the pulp, paper, and paper products industry and the chemical industry at 155.9% and 72.2%, respectively. In the second period, Miyagi still had the highest decline of IIP value compared to pre-disaster levels, which is 34.7%. In Miyagi, the fastest recovery was experienced by the precision machinery industry at 78.8%, followed by the metal product industry (77.1%) and the general machinery industry (72.7%). In Fukushima, the IIP was down by around 16.5% compared to before the disaster. In the recovery period, the ceramic, stone and clay products industry had the highest recovery growth (80.7%), followed by the electronic parts and devices industry and the foods and tobacco industry at 74.2% and 71.6%, respectively. Figures for Fukushima Prefecture have remained at a lower level than those for Iwate and Miyagi Prefectures as the result of the effects of the nuclear accident. The third period shows that almost all manufacturing industries have recovered to about the same level as before the 2011 GEJE.

4.2. Impact analysis on the manufacturing sector

To analyse the impact of the 2011 GEJE on the manufacturing sector, we use the same method and the same explanatory or control variables used to analyse the impact of the 2011 GEJE on the agricultural sector. The differences with the analysis in Section 3.3 are the dependent variable, which is the growth of VAM, and the first explanatory variable, which is the lagged VAM. The estimation results are shown in Table 5.

We can see in Table 5 that, with the exception of column 2 (less affected prefectures), the coefficients of our variable of interest, the 2011 GEJE ($\hat{\gamma}$), are also statistically significant, which implies that the disaster did not really impact the growth of the manufacturing sector in the less affected prefectures. In addition, the impact of the 2011 GEJE on the manufacturing sector in the most affected prefectures is the strongest. Compared to the coefficient values of the 2011 GEJE in Table 4, it appears that the estimated parameter values of GEJE ($\hat{\gamma}$) in Table 4 are higher than those in Table 5. This fact implies that the disaster has had larger negative impacts on the agriculture sector than on the manufacturing sector. Thus we find that the total contribution from the affected prefectures in the agriculture sector (GAP) is larger than in the manufacturing sector (VAM) and that the process of recovery in the manufacturing sector was faster than in the agriculture sector (Figure 11).

Similar to the results in Table 4, the estimated parameter for lagged VAM ($\hat{\alpha}$) is also negative and significant across the different regressions presented in Table 5. Investment in education ($\widehat{\beta_1}$) exhibited positive signs, although, again, none of them is statistically significant. Government expenditure on disaster relief ($\widehat{\beta_3}$) was positive and significant, except in column 4, signifying that the manufacturing sector was

Table 5. Impact of the 2011 GEJE on growth of the VAM; estimation method: LSDVC. Dependent variable: Growth of VAM per establishment

Variable	All prefectures [1]	Less affected prefectures [2]	Affected prefectures [3]	Most affected prefectures [4]
Natural disaster variable				
2011 Great East Japan Earthquake ($\hat{\gamma}$)	−0.0624**	0.0280	−0.0432*	−0.1220*
	(0.0292)	(0.0192)	(0.0412)	(0.0653)
Control variables				
Initial growth of gross agriculture products per farm household ($\hat{\alpha}$)	−0.2740***	−0.2560***	−0.3850***	−0.2380
	(0.0461)	(0.0569)	(0.0994)	(0.1960)
Education (in logs) ($\widehat{\beta_1}$)	1.5410	1.0690	6.4090	8.2910
	(1.2390)	(1.2250)	(4.0880)	(8.7340)
Public work expenditure per capita (in logs) ($\widehat{\beta_2}$)	−0.0632**	−0.0699*	−0.0589	0.0110
	(0.0285)	(0.0362)	(0.0661)	(0.1180)
Disaster relief expenditure per capita (in logs) ($\widehat{\beta_3}$)	0.0147***	0.0129**	0.0358**	0.0262
	(0.0053)	(0.0057)	(0.0157)	(0.0363)
Welfare expenditure per capita (in logs) ($\widehat{\beta_4}$)	−0.0913***	−0.1250***	−0.0349	0.0287
	(0.0345)	(0.0400)	(0.0775)	(0.1350)
Inflation (log (100 + % growth rate of CPI)) ($\widehat{\beta_5}$)	1.7580***	1.6820**	1.6120	0.5980
	(0.5820)	(0.7370)	(1.2850)	(1.9250)
Observations	505	406	99	44
Number of prefectures	47	38	9	4

Notes: Numbers in parentheses are the standard errors.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, indicate significance at the 1%, 5%, and 10% levels, respectively.

benefitting from development of means of protection from disasters. On the other hand, government expenditures on public works ($\widehat{\beta_2}$) and welfare expenditure ($\widehat{\beta_4}$) returned negative values. These negative values justify that the most of the prefectural government expenditures on public works and welfare have decreased in the period of observation. This is a logical result because most of the major public infrastructures in Japan have already been built, and there are only some minor infrastructure projects undertaken. Nevertheless, after the 2011 GEJE, the government expenditure on public works and disaster relief were increased in some prefectures, particularly those affected prefectures.

Different than reported in Section 3.3, the price inflation ($\widehat{\beta_5}$) turned out to have a positive and significant effect on VAM (except in columns 3 and 4). This signifies that the manufacturing sector has benefitted from an increased in price levels, although it is also possible that the rapid growth in the manufacturing sector has induced the rise in prices, which in turn has increased the value added in manufacturing. Of course, this hypothesis needs to be investigated further.

5. Summary and conclusion

The 2011 GEJE that hit Japan on 11 March 2011 was the most powerful quake ever to hit the country. The earthquake then triggered a powerful tsunami and nuclear accident, making it the costliest compound natural disaster in the history of the world. Nine

prefectures were declared affected prefectures and thus received aid under the Disaster Relief Act; of those nine prefectures, the four Tohoku prefectures of Aomori, Iwate, Miyagi, and Fukushima suffered the greatest damage and loss, which made the Tohoku the most severely affected region in Japan. Japan's economy, the world's third largest, slid back into recession due to the disasters. This natural disaster caused a 2.2% decrease in Japan's GDP by sector, the industrial sector including the manufacturing sector experienced the largest decrease (−7.13%), followed by the agriculture sector (−3.64%) and the services sector (−0.85%).

In the agricultural sector, about 5.8% of the farmland was estimated to have been washed away, inundated, or otherwise damaged. The total number of damaged agricultural facilities and the total damage amount came to some 36,092 facilities and 84.7 billion US$, respectively, with Miyagi prefecture suffering the largest damage and losses, followed by Fukushima and Iwate. Agricultural sector, a prominent one for sustaining Japan's food self-sufficiency ratio, became one of the top government priorities for restoration and reconstruction. Looking from the production of paddy as one of the substantial agriculture products in Tohoku, Aomori prefecture has the fastest recovery in paddy production as its production in 2012 has surpassed the production pre-disaster.

In the manufacturing sector, the 2011 GEJE brought about production disruption at affected firms, in which the disruption had extensive negative impacts on production activities in a wide variety of companies through the supply chains. The IIP for the second quarter of 2011 decreased compared to the previous period. At the national level, the IIP decreased by 3.97%, while in the Tohoku region, it decreased by 8.13%. Nonetheless, in the 3rd quarter of 2011, the industrial production at the national level had recovered even though the value of IIP at the national level had not yet reached its pre-disaster level. This implies that the recovery process in the manufacturing sector in the affected areas, including the Tohoku region, in fact has not yet been optimally implemented. One of the possible reasons is because the level of recovery of manufacturing is affected by the level of recovery of other sectors.

We estimate the impact of the 2011 GEJE on the agricultural and manufacturing sectors using the LSDVC, from which two major insights emerge. First, statistically, the 2011 GEJE had a significant negative impact on the agriculture and manufacturing sectors. On average, the impact on the agriculture sector was greater than on the manufacturing sector, about two times higher. Second, as we can see from Tables 4 and 5, the most affected prefectures experienced an impact about three times greater than the less affected prefectures in both agriculture and manufacturing sectors.

Finally, the restoration and reconstruction process in agriculture and manufacturing sectors has been going well as shown in Table 3 and Figure 11, where the performance of these two sectors in the affected areas has been demonstrated although not yet fully recovered. Hopefully, this study can contribute as a record for the government to determine vulnerable sector and to further optimize the process of restoration and reconstruction.

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