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How Do Supply Chain Networks Affect the Resilience of Firms to Natural Disasters? Evidence from the Great East Japan Earthquake*

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Abstract

This paper examines how supply chain networks affected the resilience of firms to the Great East Japan Earthquake, particularly looking at the effects on the time period before resuming operations after the earthquake and sales growth from the pre- to the post-earthquake period. The results indicate that the expansion of supply chain networks has two opposing effects on the resilience of firms to disasters. On the one hand, when firms are connected with more firms through supply chain networks, they are more likely to experience disruptions in supply and demand, which delay recovery. On the other hand, firms can benefit from diversified networks with suppliers and clients because they can substitute the surviving firms in the network for the damaged partners and receive support from them. Our results indicate that the latter positive effect on recovery exceeds the former's negative effect for many types of network, implying that diversified supply chain networks lead to the resilience of firms to natural disasters.

Keywords: Economic resilience, Natural disaster, Supply chain networks
JEL classification: R10, L10, Q54

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1. Introduction

Economic resilience to natural disasters, including dynamic economic resilience defined as speedy recovery through repair and reconstruction of the capital stock (Rose, 2007), has attracted attention, as recent disasters such as Hurricane Katrina and the Great East Japan earthquake had destructive impacts on economic activities. One important factor which affects economic resilience is the structure of supply chains, according to Henriet, Hallegatte and Tabourier (2011). Their simulation analysis using a model based on input-output tables shows that economies are resilient to natural disasters when networks are localized and clustered, i.e., firms in the same area interact with each other, as firms in such networks are isolated from disasters affecting other networks.

An example of less clustered supply chain networks is Japan, where suppliers and clients are heavily connected across regions (Fujiwara and Aoyama, 2010). Therefore, Henriet, Hallegatte and Tabourier (2011) suggest that the Japanese economy has limited resilience to exogenous shocks. In fact, the Great East Japan earthquake (hereafter, the earthquake) in March 11, 2011, the fourth largest earthquake in the world observation history, had not only a tremendous effect on the impacted areas but also forced to reduce outputs in other areas including foreign countries. For example, General Motors, Ford, Toyota, and Honda in the United States and Renault Nissan in South Korea had to reduce their production, since supply of parts and components from damaged firms in Japan was disrupted (Nikkei Newspaper, May 3, 2011). Tokui et al. (2012) estimated that 90 percent of the output loss in Japan due to the earthquake came from indirect effects through disruption of supply chains, rather than direct effects of damages of the disaster.

However, supply chain networks do not always prevent firms from recovery from disasters. Henriet, Hallegatte and Tabourier (2011) point out that output losses from disasters are smaller when networks are less concentrated. That is, when firms have more redundant ties with suppliers and clients, firms can easily compensate the loss of their partners. Indeed, substitution of damaged partners by new ones was often observed after the earthquake. In addition, impacted firms benefited from physical, psychological, and financial support from suppliers and clients in the process of recovery, as anecdotal evidence after the earthquake shows.[1] Therefore, the overall effect of supply chain networks on resilience to natural disasters is still unclear.

This paper empirically examines this issue, using firm-level data for firms in the impacted areas of the Great East Japan earthquake. Our data consist of two sets of data, one from a survey to firms in the impacted areas conducted after the earthquake and the other from another survey conducted a few years before the earthquake for detailed information on suppliers and clients of each firm. We estimated the impact of the number of suppliers and clients in and outside the impacted areas of each firm on the recovery time after the earthquake, i.e., the time length before resuming the operation, and sales growth from the pre- to the post-earthquake period. We find that having more suppliers and clients outside the impacted areas mostly shortens the recovery time and increases sales growth, whereas having more suppliers and clients in the impacted areas does not make the recovery time longer or shorter but increases sales growth. In addition, we find evidence identifying a negative effect of supply chains on recovery through disruption of supplies and demands and two positive effects through support and substitution. Our findings suggest that for many types of supply chain network, the positive effects surpass the negative effect, leading to the positive total effect. Thus, our analysis implies that diversified supply chain networks lead to resilience of firms to natural disasters.

To date, only a few studies have examined what determine firms' recovery and growth after natural disasters, using firm-level data. Dahlhamer and Tierney (1998) using data from the Loma Prieta earthquake in 1989 and Hurricane Andrew in 1992 and Webb, Tierney and Dahlhamer (2002) using data from the Northridge earthquake in 1994 found that firm characteristics such as financial conditions and the degree of damages affected business recovery. However, as opposed to this study, they used only qualitative measures of recovery. Moreover, these two studies did not use any measure of supply chain networks as a potential determinant of business recovery. Wakasugi and Tanaka (2013) examined determinants of the recovery time of firms in the Great East Japan earthquake, using the same data as in

[1] See Section 3.1 for more details.

this study, but they did not analyze the effect of the structure of supply chains explicitly. Altay and Ramirez (2010) used 100,000 firm-year observations for more than 15 years to analyze the impact of over 3,500 disasters in the world. Although they incorporated supply chains into their analysis of the impact on financial variables, they simply classified firms in the manufacturing sector as upstream firms and those in the retail sector as downstream firms. In other words, Altay and Ramirez (2010) ignored supply chains within the manufacturing sector, i.e., networks between suppliers of processed materials, parts, and components and final assemblers, which is the focus of this study.

A positive role of social capital, particularly networks in the local community, in recovery from natural disasters is found in other studies, such as Nakagawa and Shaw (2004) and Aldrich (2011). Although their conclusion is similar to ours for supply chain networks among firms, these works are based on qualitative case studies, as opposed to our quantitative study.

The results in this study can also contribute to other strands of literature on recovery from natural disasters. Many studies have examined whether or not natural disasters have a long-term impact on the economy, finding mixed results: Davis and Weinstein (2002) and Skidmore and Toya (2002) found no negative effect of natural disasters on long-run growth, while Cavallo et al. (2013), duPont IV and Noy (2012), and Noy and Nualsri (2007) find a negative and persistent effect. These mixed results probably suggest that the effect of natural disasters on economic activities varies depending on conditions of the economy. Our results show that the structure of supply chain networks is one of the conditions affecting the impact of disasters.

The results of this study may also be helpful to the literature that measures output losses due to natural disasters, using simulation on theoretical models, such as input-output (IO) and Computable General Equilibrium (CGE) models (Hallegatte and Przyluski, 2010). Hallegatte (2012) find that output losses are amplified by supply-chain relations, particularly when substitution between inputs is more difficult. Hallegatte (2012) further claims that since results from simulation vary substantially, depending on the degree of substitution and the structure of supply chain networks, further research on the actual nature of network structure and production substitution is needed. This study provides some evidence to enrich theoretical models and simulation analysis in this literature.

2. Data

2.1 Description of the Data Sources

The dataset used in this study is based on two data sources. One is data from a plant-level survey conducted by the Research Institute of Economy, Trade and Industry (hereafter, the RIETI survey) in January and February in 2012, ten months after the Great East Japan earthquake and the subsequent tsunami, to plants in areas impacted by the earthquake. The implementation of the survey was subcontracted to Teikoku Databank, one of the biggest corporate research companies in Japan, which already had information on most firms in the impacted areas prior to the earthquake. Impacted areas of the earthquake are formally defined by the Law on Special Great East Japan Earthquake Reconstruction Areas and include cities, towns and villages in the prefectures of Aomori, Iwate, Miyagi, Fukushima, Tochigi, and Ibaraki. The survey targeted all the 6,033 firms, with some exceptions explained below, that were in the manufacturing sector and located in the impacted areas and had at least 5 employees before the earthquake, according to the prior information of Teikoku Databank. The survey excludes from the sample two categories of firm whose recovery was impeded largely by government regulations, because one of the biggest objectives of the survey was to find how firm characteristics affected recovery from the earthquake. One category is those in the seafood processing industry, because in some cases seafood processing firms were not allowed to reconstruct their plants, which are often located near fishery ports, due to regulations by local governments for integrated regional development plans for recovery (Ministry of Agriculture, 2012). Therefore, reconstruction of these firms from the disaster has been prevented by regulation, even if their recovery could otherwise be possible. In fact, according to Small and Medium Enterprise Agency of Japan (2012), only 50 percent of firms in the seafood processing industry in the impacted areas re-started production before January, 2012, while 67 percent of firms in other industries did so. The other category of firm which is excluded from the sample was firms located within the

20-kilometer radius from the Fukushima Daiichi Nuclear Plant, since they were required to evacuate from the area by the government due to possible releases of radioactivity from the plant at the time of the survey.

A questionnaire on the level of damages by the earthquake and business activities before and after the earthquake was sent by mail in January, 2012, and firms were requested to send back their response by February, 2012. 2,117 effective responses were received, i.e., the response rate was 35 percent, which is high for this kind of firm-level survey. It should be emphasized that firms which were located in the impacted areas before the earthquake but were relocated or closed their business after that were also the target of the survey, as long as the Teikoku Databank could capture their current contact address. Among the 2,117 firms, 15 firms have relocated or are going to relocate their plants, 6 have closed or are going to close their business, and 3 were merged with other firms. This inclusion of relocated and closed firms in the sample is unique and valuable for a survey to examine firms' recovery from disasters.

The other data source is data from Tokyo Shoko Research (the TSR data), another big corporate research company in Japan. The TSR data consist of two datasets. One is for corporate information, such as the location, sales, and the number of employees. The other dataset includes information on up to 24 suppliers of intermediates and up to 24 clients of products for each firm. The information on suppliers and clients can be merged with the corporate information data, so that characteristics of each supplier and client can be known. Although the upper limit of the number of suppliers and clients, 24, is obviously too small for many large firms, we can capture most of the supply chain networks by looking at the supplier-client relations from both directions. RIETI purchased the whole dataset from TSR in 2006, which includes corporate information for 803,705 firms and transaction information for 3,904,380 supplier-client pairs. The corporate information was collected in 2005 for 67 percent of firms in the TSR data, 28 percent in 2004, and in 2002, 2003, or 2006 for others. The maximum number of suppliers for one firm is 7,474, whereas the maximum number of clients is 7,139.

We merged the RIETI data and the TSR data, using the names and addresses of firms. In the merging process, we had to drop firms whose information is in the RIETI data but not in the TSR data.

One reason why we have this mismatch between the two data sources is that although both Teikoku Databank and TSR have information on most firms in Japan, their coverage is different particularly for small and micro enterprises. Another reason is that the TSR data were collected before 2006, while the RIETI data were in 2012. Therefore, firms which started or closed their business or are renamed between the two time periods should have been dropped. In addition, we dropped firms whose head quarter was not in the impacted areas, since the TSR data are at the firm level, while the RIETI data are at the plant level. In other words, suppliers and clients of firms which have their headquarters outside the impacted areas and have plants in the impacted areas do not necessarily reflect suppliers and clients of the plant in the impacted areas. After dropping firms with obvious errors in the data, we obtained 902 firms in the sample for our analysis.

2.2 Descriptive Statistics

Most of the firms in the RIETI data are affected by the earthquake and the subsequent tsunami. Among about 2,000 firms in the sample before merging with the TSR data, 114 or 5.7 percent of respondent firms reported that their equipment was completely or almost completely destroyed so that they had to stop operations (panel A of Table 1). Among them, 39 reported that the damage was caused by the earthquake, whereas 79 reported that it was caused by the tsunami. 147, or 7.4 percent, reported that about half of their equipment was destroyed so that they had to stop part of the operations, whereas 1,217, or 61 percent, reported partial damage from the earthquake or the tsunami. 519, or 26 percent, reported no damage from the disaster. After merging with the TSR data, we find a similar distribution of firms in the sample for our analysis in terms of the level of damage (panel B of Table 1).

According to Small and Medium Enterprise Agency of Japan (2011), 26 percent of member firms of the chambers of commerce and industry in the impacted areas (Aomori, Iwate, Miyagi, and Fukushima Prefectures) were completely destroyed by the disaster, while 7 percent were “half-damaged.” The share of totally-damaged firms in our sample is lower than the corresponding share in SME Agency (2011), probably for the following two reasons. First, the RIETI survey targeted Ibaraki and Tochigi Prefectures where damages by the disaster was relatively small (although still large in the absolute term), in addition to Aomori, Iwate, Miyagi, and Fukushima Prefectures where damages were larger. Second, we exclude firms in the seafood processing industry and those near the Fukushima Daiichi Nuclear Plant, where damages were substantial, as we explained above.

The distribution of firms in our sample by prefecture and by industry is shown in Table 2. The number of firms in each prefecture is similar, except for that in Aomori which includes only 26 firms. Industries of firms vary, and 32.5 percent are in the light industry such as the food industry and the lumber and wood products industry, whereas 39.3 percent are in the metal and machinery industries.

Table 3 shows summary statistics of the key variables. The average number and the median of workers in September, 2010, before the earthquake, are 53.1 and 29, respectively. The annual change rate of the number of full-time workers from 2005 to 2010, using the number of full-time workers in or around 2005 in the TSR data, is 1.5 percent on average.[2] The average and the median sales in the half year from April to September, 2010 are respectively 1.17 and 0.14 billion yen. The average of the annual change rate of sales from 2005 to 2010 is -5.4 percent. These figures indicate that the sample firms are mostly small and medium enterprises, and their business was declining on average before the earthquake.

The change rate of the number of workers from September 2010 to September 2011, defined as the difference between the two periods divided by the initial number, is -1 percent on average, and its median is zero. The minimum of change rate is -100 percent, meaning that firms were closed down. The average and median change rate of sales from the pre- to the post-earthquake are 1.19 percent and -0.57 percent, respectively. The average number of days before resuming production after the earthquake is 14.9, whereas its median is 5. The recovery time is zero for about 30 percent of firms, meaning that these firms did not shut down its production. The maximum is 330, the approximate number of days between the earthquake (March, 2011) and the survey (February, 2012), meaning that the firms did not resume production at the time of the survey. The average and the median of the number of days when any supply of materials, parts, or components was disrupted are 21 and 7, respectively. About 45 percent of firms did

[2] We use the number of full-time workers, since the total number of workers is not available in the TSR data.

not experience any problem in supply. Thus, many firms in our sample recovered relatively quickly from the damages by the earthquake, although many others had difficulties in recovery.

The lower rows of Table 3 indicate characteristics of supply chain networks for the sample firms. Using the whole sample of the TSR data (i.e., including firms in the impacted areas as well as those outside the impacted areas), we compute for each firm the number of suppliers and clients in and outside the impacted areas. The average number of suppliers in the impacted areas is 3.14,[3] whereas the maximum is 104. The average number of suppliers outside the impacted areas is 2.61, and the maximum is 24. The number of clients is similar to that of suppliers. These figures show that the sample firms have a relatively small number of suppliers and clients.

In addition, we compute the number of suppliers of the direct suppliers. We are interested in possible effects of indirect suppliers on recovery from the earthquake, since it was reported that the temporary or permanent shut-down of production lines of intermediates affected downstream firms indirectly connected through supply chains. Table 3 shows that the average and the median of the number of suppliers of direct suppliers is 620 and 86.5, respectively, and the maximum is 12,909. The number of clients of direct clients is similarly large. These findings imply that firms in the impacted areas are indirectly connected to a substantial number of firms in Japan through supply chains, as found in Saito (2012).

3. Empirical Procedures

3.1 Conceptual Framework

Supply chain networks may affect resilience to and recovery from disasters, for the following reasons. First, when firms are provided processed materials, parts, or components from suppliers affected by a disaster, these downstream firms may have to shut down the operation even when they themselves are not damaged. This may also be the case, when clients of firms' products are damaged. Therefore, we

[3] In Table 3, the mean is 4.14, since these numbers indicate the number of suppliers plus one.

hypothesize that as firms have more connections with suppliers and clients within impacted areas, recovery from the disaster becomes more difficult. Firms may also have to stop or reduce production, when they are not directly connected with affected suppliers but indirectly connected to affected upstream suppliers or downstream clients through supply chains. Therefore, particularly focusing on suppliers of suppliers and clients of clients, we presume that when the number of indirect suppliers and clients increases, the probability that firms are indirectly affected also increases so that firms need more time to resume production.

However, supply chain networks are not always harmful to recovery from disasters. There is a lot of anecdotal evidence showing that impacted firms received support from clients in the process of recovery. A typical example is Renesas Electronics Co., Ltd., a major producer of microcontrollers for automobiles with a share of 44 percent in the world market. Its main plant in Ibaraki Prefecture was severely damaged by the earthquake, and the resulting complete shut-down of the production of microcontrollers further caused a halt of production lines of automobiles outside the impacted areas. To support the recovery of Renesas, its clients including major automobile manufacturers sent 80,000 man-days of their workers to Renesas. As a result, Renesas re-started part of the production on June 10, one month earlier than the first prediction right after the earthquake (Renesas, 2011). This example clearly shows that connections to clients, particularly those outside the impacted areas, may be helpful to obtain supports for recovery.

Connections to clients in the impacted areas may also be helpful. SME Agency (2011) documents an experience of Horio Seisakusho K.K. in Miyagi Prefecture, a small and medium enterprise with 52 employees producing optical pickup components with a share of 30 percent in the world market. Since Horio Seisakusho was located at a high elevation, its damage from the tsunami was limited. However, one of its suppliers, Ogatsu Musen Co., Ltd. was located near the sea, and thus all of its equipment was washed away by the tsunami. Then, Horio Seisakusho let Ogatsu Musen use Horio’s idle factory space and production machinery for free. Because of this support, Ogatsu Musen recovered quickly, and hence Horio Seisakusho also could re-start its production quickly, utilizing supplies from Ogatsu Musen. This example indicates that supply chain networks within impacted areas can be beneficial to recovery of both suppliers and clients.

In addition, firms can substitute surviving or new partners for damaged partners after disasters. In our data, 8.1 percent of firms whose suppliers were damaged actually changed their suppliers. In some cases, damaged suppliers themselves asked their competitors to substitute them in providing resources to their clients. For example, Iwaki Die-cast Co., Ltd., a supplier of dies and metal parts to Toyota and other firms, was severely hit by the earthquake and forced to stop their operations temporarily. Then, Iwaki Die-cast decided to provide its dies to one of its competitors, and thus the competitor firm could supply metal parts to Iwaki's clients, using the dies (Kahoku Shimpo Newspaper, October, 29, 2012). Uchida, a supplier of metal parts for the automobile industry, also took the same action (Bloomberg, March, 13, 2012).

Therefore, it is not crystal clear whether supply chain networks have a positive or negative effect on recovery from disasters in total. In addition, it is of great interest to examine what type of network, e.g., networks within or outside the impacted areas, or indirect supply-client relations through supply chains, is more effective to recovery than others.

3.2 Estimation Methods

To examine questions raised in the previous sub-section, we estimate the following equation:

$$\log(RESUME_i + 1) = \beta_0 + \beta_1 NET_i + \beta_2 X_i + \varepsilon_i . \quad (1)$$

$RESUME_i$ is the number of days before resuming production after the earthquake, or the recovery time, for firm i. *NET* is a set of variables related to supply chain networks. In the benchmark estimation, *NET* includes the number of suppliers in the impacted areas, the number of suppliers outside the areas, and the number of suppliers of direct suppliers, or the corresponding numbers for clients. In any case, we take the log of the number of suppliers/clients plus one, assuming a quasi-log linear relation. Since the minimum of the dependent variable is 0 and the maximum is log331, where 330 is the maximum days after the earthquake (Section 2.1), by nature, we will employ a Tobit estimation.

We further examine whether the effect of supply chain networks varies depending on the level of damages of the firm. For this purpose, we include in *NET* interaction terms between one of the network variables and dummy variables for the level of damages, totally destroyed, half destroyed, partially damaged, and not damaged. Since the inclusion of many interaction terms can cause multicollinearity, we focus on one particular type of network and exclude other types in each regression of this type.

X is a set of control variables. To control for the effect of firm size and productivity on recovery from disasters, we include the number of workers and sales per worker in 2010, both in logs. Growth in sales and employment prior to the earthquake from 2005 to 2010 is also included, since these variables may be able to capture firms' potential capability for recovery. In addition, we incorporate dummy variables which represent the level of damages, i.e., dummies for totally destroyed, half destroyed, partially destroyed, and totally destroyed by the tsunami. Finally, industry and city dummies are included.

When the effect of networks is estimated, a potential problem is endogeneity of network variables. In the case of this study, there should be no reverse causality, i.e., causality from recovery to networks, since our network variables were collected 6 years before the earthquake and damages were exogenously made by the earthquake. Another source of endogeneity is unobservable factors which affect both recovery and supply chain networks of each firm. However, growth in sales and employment prior to the earthquake can largely control for firms' potential capability, whereas industry and city dummies can control for industry- and location-specific characteristics which most likely affect network characteristics. Therefore, biases due to endogeneity may not be large in this study, although we will still test the presence of endogeneity using Smith and Blundell's (1998) method, as we will show later.

4. Results

4.1 Effects on the time without operation after the earthquake

The benchmark effects of the number of suppliers on the number of days without operation after the earthquake, or the recovery time, are shown in column 1 of Table 4, while those on the effect of the number of clients are in column 2. In both results, effects of the dummies for the level of damages are highly significant, while effects of other controls, such as the number of workers and sales, are insignificant.

The effect of supply chain networks varies depending on their characteristics. Networks within the impacted areas, measured by the number of suppliers or clients in these areas, have no significant effect on recovery. This is probably because a negative effect on the recovery time due to disruption of supplies and demands from damaged firms and a positive effect due to provision of support for recovery from network members and increasing possibilities of substitution of supplies and demands within supply chain networks cancel out each other.

By contrast, networks with firms outside the impacted areas, measured by the number of suppliers or clients outside the areas, significantly decrease the time required for recovery. This is clearly because impacted firms were less likely to face shortage of supplies or demands, when they were connected with more undamaged firms outside the impacted areas. In some cases, impacted firms could substitute suppliers or clients outside the impacted areas for damaged suppliers or clients in the impacted areas, when necessary.

Finally, either the number of suppliers of direct suppliers or clients of direct clients has a positive and significant effect on the recovery time. This finding implies that as indirect supply networks expand, i.e., as impacted firms are connected with more firms indirectly through supply chains, the impacted firms are more likely to be connected with any damaged firm and thus to face shortage of supply or demand. The positive effect of indirect networks on the recovery time is more evident than the effect of direct network, because support from indirect suppliers cannot be expected, unlike support from direct suppliers.

4.2 Testing for Endogeneity

We further examine the effect of supply chain networks, using each of the network variables separately, in addition to the same controls, in one regression. One reason for this experiment is that we can highlight the effect of each type of network on recovery, not worrying about multicollinearity. Another reason is that we can test the endogeneity of each of the network variables. As we discussed in Section 3.2, although our analysis is not contaminated by endogeneity from reverse causality, it may still be biased due to endogeneity stemming from unobservable factors which affect both supply chain networks and resilience. However, it is difficult to find good instruments, as is often the case. One possibility is sales in the year before data on supply chain networks were collected, mostly in 2004. This variable is highly correlated with any network variable, but it is most likely to be uncorrelated with the error term in the equation for recovery from the disaster in 2011 after controlling for sales in 2010 and growth in sales from 2005 and 2010. With only one instrument in hand, we cannot test for endogeneity of the supply chain variables, when there are more than one possible endogenous network variables. By limiting the number of endogenous variables to one in each regression, we will test for endogeneity of each network variable, using the method of Smith and Blundell (1986), which is an application of the Durbin-Wu-Hausman test to Tobit regressions.

The estimated coefficients on the network variables from the separate regressions are shown in Table 5, which are mostly consistent with the results in Table 4. One large difference is that the effect of the number of either indirect suppliers or clients is insignificant, implying that the negative effect of indirect relations through supply chains may not be robust. The bottom row shows the *p* value of the Smith-Blundell statistic. In any regression, we cannot reject the null hypothesis that the network variable is exogenous.

4.3 Heterogeneity across levels of damages

So far, we assumed that each type of network has the same effect, regardless of how much firms were damaged by the disaster. However, the effect of supply chain networks on recovery may be heterogeneous, depending on the level of damages. To highlight the possible variation, we use interaction terms between each of the network variables and the dummies for the level of damages, i.e., totally destroyed, half or partly destroyed, and not damaged.

In column 1 of Table 5, we found that the number of suppliers in the impacted areas has no significant effect on recovery. The results in column 1 of Table 6 show that this is the case regardless of the degree of damages. In column 2 of Table 5, we found a negative and significant effect of the number of suppliers outside the impacted areas. The results in column 2 of Table 6 indicate that this negative effect is mostly coming from the negative effect for half or partly destroyed firms. In other words, networks with suppliers outside the impacted areas do not help totally-destroyed or undamaged firms. These findings imply that the support from suppliers is not helpful for recovery once the firm is totally destroyed, while firms without any damage did not receive any support from suppliers outside the impacted areas. The results using the number of clients shown in columns 4 and 5 of Table 6 are similar to those using the number of suppliers. One difference is that the number of clients outside the impacted areas has a negative and significant effect for firms without any damage (column 5), while the effect is insignificant for suppliers (column 2). The effect of indirect suppliers and clients is mostly insignificant (columns 3 and 6), as found in Table 5, except for the negative effect of indirect suppliers on the recovery time of totally destroyed firms.

4.4 Effects on changes in sales

Another natural measure to look at recovery from disasters is changes in sales. Therefore, we now examine the effect of supply chain networks on the change rate of sales from the second and third quarters in 2010 (i.e., before the earthquake) to the corresponding quarters in 2011 (after the earthquake), using ordinary least squares (OLS) estimations. We employ the same network variables and the same control variables. The results in Table 7 indicate that both the number of suppliers and clients in the impacted areas increased the sales by about 3-4 percentage points. We also find weak evidence of a positive and significant effect of the number of clients outside the impacted areas. The number of suppliers of direct suppliers or clients of direct clients has no significant effect.

In Table 8, we examine possible heterogeneous effects of networks on sales growth depending on the level of damages. It is found that networks with suppliers and clients in the impacted areas are particularly helpful to firms damaged half or partially, but not to totally-destroyed or undamaged firms.

These results in Tables 4-8 imply that while supply chain networks with firms outside the impacted areas contributed to earlier resumption of production of firms whose damage from the earthquake was not devastating, networks within the impacted areas were helpful to sales recovery for the same type of firms. The two sets of result are not necessarily contradictory to each other, because the time span of the two measures of recovery is different. The recovery time was 5 days at the median (Table 3), 0 for 30 percent of firms, and less than 30 days for about 90 percent. However, sales growth is measured by the growth rate from the second and the third quarters in 2010 to the same quarters in 2011, including sales several months after the earthquake. Therefore, we can conclude that networks within the region contributed to medium-run recovery, whereas networks beyond the region contributed to short-run recovery.

4.5 Channels of effects of supply chains on economic resilience

There are several channels of the effect of supply chain networks on recovery from the earthquake, as we discussed in Section 3.1. Fist, recovery from the earthquake was often impeded by disruption of supply chains. Even when firms were ready for production because they were not severely hit by the earthquake or because they repaired damaged production facilities or replaced them with new ones, many of them could not actually resume the production due to lack of supply of parts, components, or materials. Since we have information on how long the supply of materials and intermediates was affected, we can directly test whether supply chain networks affected disruption of supply chains. Specifically, we regress the number of days for which supply of parts, components, or materials was affected by the earthquake in logs on the network variables and the controls, using Tobit estimations. The results shown in Table 9 indicate that when each network variable is used in a separate regression, the effect of any network variable is positive and statistically significant. That is, as any type of supply chain network expands, firms experienced a longer time period of disruption of supply after the earthquake.

Another channel of the effect of supply chains on recovery is support from firms to damaged partners in supply chain networks. Using a probit estimation, we examine the effect of the number of suppliers or clients on whether the firm received human, physical, or financial support from other firms. The results shown in Table 10 indicate that although most types of supply chain network had no significant effect on the receipt of support, having more clients outside the impacted areas lead to a larger probability of receiving support from firms. This statistical evidence is consistent with the anecdotal evidence of Renesas Electronics, described in Section 3.1.

Finally, supply chain networks enable firms to more easily substitute new partners for damaged suppliers or clients. Using the same firm-level data for the impacted areas as used in this study, Nakajima and Todo (2013) find that the quality of new suppliers substituted for damaged suppliers after the earthquake is lower when firms found new one through the Internet or Yellow Pages than through other firms and industry organizations. This evidence suggests that supply chain networks are helpful for firms to find more qualified new suppliers, when they face disruption of supply chains.

5. Discussion and Conclusion

In this paper, we examined how supply chain networks affected resilience of manufacturing firms to the Great East Japan Earthquake, measured by the time period without operation after the earthquake, or the recovery time, and sales growth from the pre- to the post-earthquake period. The results in Tables 4-8 indicate that supply chain networks with firms outside the impacted areas contributed quicker resumption of production of moderately damaged firms after the earthquake, while having a weak effect on sales growth. By contrast, networks within the impacted areas increased sales growth of damaged firms in the medium run, although they were not helpful to resume the production more quickly.

In addition, we looked into possible channels of the effects of supply chain networks on resilience to the earthquake. Then, we found that the time period without supply of parts, components, or materials increased as the firm was connected more with other suppliers and clients, regardless of whether they are in or outside the impacted areas, or they are connected with the firm directly or indirectly. We also found evidence showing that firms connected with more clients outside the impacted areas are more likely to receive support after the earthquake and that firms use supply chain networks to find qualified substitutes for damaged suppliers (Nakajima and Todo, 2013).

Combining these results, we can conclude that expansion of supply chain networks has two opposing effects on resilience of firms to disasters. On the one hand, when firms are connected with many other firms through large supply chain networks, they are more likely to experience shortage of supplies, which delays recovery. On the other hand, firms can receive supports and find substitutes for damaged partners through supply chain networks, speeding up recovery. Depending on the characteristics of supply chain networks, the two opposing effects may balance, or one of the two may surpass the other. For example, suppose that a firm is connected with many firms in the region. Then, when a disaster hits that region, the partner firms may be damaged by disasters, and thus, it is more likely that the firm experiences shortage of supplies and demands from the damaged partners and less likely that the firm can receive support from the partners (though it is possible as the example of Ogatsu Musen in Section 3.1 shows). As a result, the negative effect of networks within the impacted areas on resuming production through disruption of supply chains cancelled out their positive effect through support and substitution, and thus the total effect is zero. However, in the medium run, the disruption of supply chains can be resolved for most firms, as it was the case in the Great East Japan earthquake (Section 2.2). Therefore, the positive effect of networks within the impacted areas is more prominent than the negative effect, and thus the sales growth in the medium run increases as firms are more connected with other firms in the impacted areas through supply chains.

In the case of networks with firms outside the impacted areas, the positive effect on recovery surpasses the negative effect due to disruption of supply chains, since firms outside the impacted areas are less likely to be directly damaged by the earthquake. Accordingly, networks with firms outside the impacted areas can shorten the recovery time and raise sales after the disaster.[4]

[4] Our results also show that the number of suppliers outside the impacted areas do not have any significant effect on sales growth. One interpretation is that when firms are connected with more suppliers outside the impacted areas, they can resume the production more quickly due to support from the suppliers, but their sales do not grow much because of limited demand in the impacted areas. One example which is consistent with the interpretation is Renesas Electronics Co., Ltd., mentioned in Section 3.1. Although Renesas resumed production quite early thanks to massive support from clients, its sales and profits were stagnant even after the resumption. One possible reason

To summarize, our results reveal that supply-chain networks facilitate recovery from natural disasters in many cases, although the effect varies depending on the location of suppliers and clients and on the time span of the recovery measure (the short-run recovery time or medium-run sales growth). We do not find any adverse effect of supply-chain networks on recovery, except for a small positive effect of indirect suppliers and clients on the recovery time which is mostly offset by negative effects of other types of network. Therefore, we conclude that supply-chain networks, in particular, diversified networks with suppliers and clients in different locations, are helpful to resilience of firms to natural disasters.

The positive effect of supply chain networks on economic resilience found here has not been recognized well in the literature. The finding of this research suggests that simulation exercises on output losses from disasters such as Hallegatte (2012) should incorporate this positive effect into theoretical models, which may lower estimated output losses indirectly affected by disasters through supply chain networks.

One caveat of this study is that although we find benefits from diversifying supply chain networks, it is still unclear how much firms should actually diversify them because we do not conduct any cost-benefit analysis. Obviously, diversifying suppliers and clients across regions is costly, and this is probably the largest reason why many firms have a limited number of suppliers and clients (Section 2.2). It is expected that future research will investigate costs of finding suppliers and clients explicitly. Then, it would be possible to find the optimal level of diversification to maximize its net benefit, i.e., long-term benefits from strengthened economic resilience less short-term costs.

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for this stagnation suggested by Nikkei Newspaper (December 11, 2012) is that prices of Renesas's products are too low because of strong bargaining power of clients. Thus, the strong ties between suppliers and clients did not pick up sales growth of Renesas. In fact, after making large losses for a few years, Renesas was finally bailed out by a governmental fund, the Innovation Network Corporation of Japan, and several clients including Toyota in 2013.

Table 1: Damages Caused by the Great Tohoku earthquake

(A) Raw data from impacted areas

	Number of firms	Share in total	Damage by earthquake	Damage by tsunami
No damage	519	26.0%	602	1,874
Partial damage	1,217	60.9%	1,224	21
Half destruction	147	7.36%	132	23
Complete destruction	114	5.71%	39	79
Total	1,997	100%	1,997	1,997

(B) Data after matching with the transaction data from TSR

	Number of firms	Share in total	Damage by earthquake	Damage by tsunami
No damage	227	25.2%	272	847
Partial damage	553	61.3%	554	9
Half destruction	72	7.98%	62	12
Complete destruction	50	5.54%	14	34
Total	902	100%	902	902

Table 2: Sample Firms by Prefecture and by Industry

Prefecture	Number of firms	Percent
Aomori	26	2.9
Iwate	167	18.5
Miyagi	173	19.2
Fukushima	186	20.6
Tochigi	126	14.0
Ibaraki	224	24.8
Total	902	100

Industry	Number of firms	Percent
Food	115	12.8
Beverages, tobacco, and feed	27	3.0
Textile mill products	13	1.4
Lumber and wood products, except furniture	55	6.1
Furniture and fixtures	4	0.4
Pulp, paper and paper products	16	1.8
Printing and allied industries	63	7.0
Chemical and allied products	14	1.6
Petroleum and coal products	2	0.2
Plastic products, except otherwise classified	51	5.7
Rubber products	4	0.4
Leather tanning, leather products and fur skins	1	0.1
Ceramic, stone, and clay products	90	10.0
Iron and steel	14	1.6
Non-ferrous metals and products	18	2.0
Fabricated metal products	114	12.6
General-purpose machinery	6	0.8
Production machinery	52	5.8
Business oriented machinery	22	2.4
Electronic parts, devices and electronic circuits	13	1.4
Electrical machinery, equipment and supplies	68	7.5
Information and communication electronics equipment	10	1.1
Transportation equipment	37	4.1
Miscellaneous manufacturing	76	8.4
Non-manufacturing	17	1.9
Total	902	100

Note: Industry classifications are based on Japan Standard Industrial Classification (Rev. 12).
http://www.stat.go.jp/english/index/seido/sangyo/san07-3a.htm#e

Table 3: Summary Statistics of the Key Variables

	N	Mean	Median	S.D.	Min.	Max.
Number of workers (Sep. 2010)	902	53.12	28.50	84.23	4	1120
Number of workers (Sep. 2011)	899	53.14	29.00	85.64	0	1086
Change rate of the number of workers (%, Sep. 2010 to 2011)	902	-1.06	0.00	14.05	-100	118
Change rate of the number of full-time workers (%, 2005-2010, annual)	902	1.52	1.23	10.60	-66	61
Sales (April-September, 2010, billion yen)	902	1.17	0.14	20.01	0	600
Sales (April-September, 2011, billion yen)	883	1.22	0.14	21.90	0	650
Change rate of sales (%, Apr.-Sep., 2010 to Apr.-Sep., 2011)	883	1.19	-0.57	39.34	-100	284
Change rate of sales (%, 2005-2010, annual)	902	-5.40	-2.52	22.80	-185	174
Number of days before resuming operation	902	14.86	5	41.81	0	330
Number of days when supplies were disrupted	828	21.03	7	46.58	0	330
Number of suppliers + 1						
In impacted areas	902	4.14	3	5.22	1	105
-- in logs	902	1.10	1.10	0.75	0	4.65
Outside impacted areas	902	3.61	3	2.85	1	25
-- in logs	902	1.02	1.10	0.73	0	3.22
Suppliers of direct suppliers	902	619.69	86.5	1499.49	1	12,909
-- in logs	902	4.51	4.47	2.15	0	9.47
Number of clients + 1						
In impacted areas	902	4.63	3	7.33	1	91
-- in logs	902	1.06	1.10	0.88	0	4.51
Outside impacted areas	902	3.79	3	3.16	1	29
-- in logs	902	1.05	1.10	0.75	0	3.37
Clients of direct clients	902	932.67	147	1664.09	1	11,515
-- in logs	902	4.98	5.00	2.38	0	9.35

Table 4: Effects of Supply Chain Networks on Recovery from the Earthquake

Dependent variable: Log (number of days without operation after the disaster + 1)

	(1)	(2)
Totally destroyed	2.159***	2.114***
	(0.508)	(0.516)
Half destroyed	1.951***	1.912***
	(0.319)	(0.305)
Partly damaged	1.098***	1.092***
	(0.247)	(0.235)
Totally destroyed by tsunami	1.080***	1.118***
	(0.342)	(0.349)
Log(sales per worker in 2010)	-0.252	-0.246
	(0.221)	(0.219)
Log(number of workers in 2010)	0.0387	0.0594
	(0.141)	(0.134)
Growth in sales from 2005 to 2010	0.325	0.313
	(0.257)	(0.251)
Growth in the number of full-time workers from 2005 to 2010	0.161	0.230
	(0.374)	(0.390)
Log(number of suppliers in impacted areas + 1)	0.108	
	(0.0790)	
Log(number of suppliers outside impacted areas + 1)	-0.351***	
	(0.126)	
Log(number of suppliers of direct suppliers + 1)	0.0814**	
	(0.0348)	
Log(number of clients in impacted areas + 1)		0.0539
		(0.0631)
Log(number of clients outside impacted areas + 1)		-0.305***
		(0.0926)
Log(number of clients of direct clients + 1)		0.0678**
		(0.0275)
Number of observations	902	902
Pseudo R squared	0.149	0.149
Log likelihood	-1324	-1326

Notes: The results are obtained from Tobit estimations. Robust standard errors clustered within cities are in parentheses. Industry and city dummies are included as independent variables. *, **, and *** indicate the 10, 5, and 1% level of significance, respectively.

Table 5: Endogeneity Test of Variables for Supply Chain Networks

Dependent variable: Log (number of days without operation after the disaster + 1)

	(1)	(2)	(3)	(4)	(5)	(6)
Log(number of suppliers in impacted areas + 1)	0.114					
	(0.0771)					
Log(number of suppliers outside impacted areas + 1)		-0.162**				
		(0.0783)				
Log(number of suppliers of direct suppliers + 1)			0.0247			
			(0.0221)			
Log(number of clients in impacted areas + 1)				0.0646		
				(0.0748)		
Log(number of clients outside impacted areas + 1)					-0.145**	
					(0.0628)	
Log(number of clients of direct clients + 1)						0.0198
						(0.0233)
N	902	902	902	902	902	902
Pseudo R squared	0.146	0.146	0.146	0.145	0.146	0.146
Smith-Blundell statistic (*p* value)	0.695	0.246	0.704	0.597	0.340	0.572

Notes: The results are obtained from Tobit estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate the 10, 5, and 1% level of significance, respectively. Other control variables are the dummies for totally damaged, half damaged, partially damaged, and totally damaged by the tsunami, log of sales per worker in 2010 (one year before the earthquake), log of the number of workers in 2010, the growth rate of sales from 2005 to 2010, the growth rate of full-time workers from 2005 to 2010, and industry and city dummies.

Table 6: Heterogeneous Effects of Supply Chain Networks on Recovery from the Earthquake

Dependent variable: Log (number of days without operation after the disaster + 1)

	(1)	(2)	(3)	(4)	(5)	(6)
X	Number of suppliers in impacted areas	Number of suppliers outside impacted areas	Number of suppliers of direct suppliers	Number of clients in impacted areas	Number of clients outside impacted areas	Number of clients of direct clients
Log(X+1) * totally destroyed	0.170	-0.224	-0.134*	-0.230	-0.0672	0.0198
	(0.215)	(0.174)	(0.0708)	(0.236)	(0.161)	(0.0996)
Log(X+1) * half/partly destroyed	0.0333	-0.202***	0.0108	-0.00221	-0.143**	0.00688
	(0.0876)	(0.0671)	(0.0304)	(0.0423)	(0.0607)	(0.0266)
Log(X+1) * no damage	0.121	-0.128	0.0229	0.125	-0.297**	-0.00683
	(0.181)	(0.197)	(0.0609)	(0.218)	(0.125)	(0.0541)
N	902	902	902	902	902	902
Pseudo R squared	0.145	0.147	0.146	0.146	0.147	0.145

Notes: The results are obtained from Tobit estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate the 10, 5, and 1% level of significance, respectively. Other control variables are the dummies for totally damaged, half damaged, partially damaged, and totally damaged by the tsunami, log of sales per worker in 2010 (one year before the earthquake), log of the number of workers in 2010, the growth rate of sales from 2005 to 2010, the growth rate of full-time workers from 2005 to 2010, and industry and city dummies.

Table 7: Effects of Supply Chain Networks on Changes in Sales

Dependent variable: Growth rate of sales from April-September, 2010 to April-September, 2011

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log(number of suppliers in impacted areas + 1)	3.618*		3.128*					
	(1.739)		(1.784)					
Log(number of suppliers outside impacted areas + 1)	2.610			1.294				
	(2.976)			(1.460)				
Log(number of suppliers of direct suppliers + 1)	-1.043				-0.116			
	(0.997)				(0.578)			
Log(number of clients in impacted areas + 1)		3.074**				3.797***		
		(1.248)				(1.317)		
Log(number of clients outside impacted areas + 1)		2.272					4.034*	
		(2.659)					(2.275)	
Log(number of clients of direct clients + 1)		0.510						1.200
		(0.930)						(0.747)
N	883	883	883	883	883	883	883	883
Pseudo R squared	0.129	0.134	0.128	0.126	0.126	0.131	0.129	0.130
Smith-Blundell statistic (*p* value)			0.568	0.451	0.356	0.634	0.569	0.593

Notes: The results are obtained from OLS estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate the 10, 5, and 1% level of significance, respectively. Other control variables are the dummies for totally damaged, half damaged, partially damaged, and totally damaged by the tsunami, log of sales per worker in 2010 (one year before the earthquake), log of the number of workers in 2010, the growth rate of sales from 2005 to 2010, the growth rate of full-time workers from 2005 to 2010, and industry and city dummies.

Table 8: Heterogeneous Effects of Supply Chain Networks on Changes in Sales

Dependent variable: Growth rate of sales from April-September, 2010 to April-September, 2011

	(1)	(2)	(3)	(4)	(5)	(6)
X:	Number of suppliers in impacted areas	Number of suppliers outside impacted areas	Number of suppliers of direct suppliers	Number of clients in impacted areas	Number of clients outside impacted areas	Number of clients of direct clients
Log(X+1) * totally destroyed	1.475	-8.083	-5.751**	-4.158	1.289	-0.864
	(8.599)	(4.860)	(2.127)	(9.070)	(3.747)	(2.002)
Log(X+1) * half/partly destroyed	4.944**	1.895	0.462	4.282***	4.489	1.840**
	(2.340)	(2.068)	(0.496)	(0.950)	(2.758)	(0.860)
Log(X+1) * no damage	-0.340	1.501	-0.0250	4.947	2.729	0.0538
	(4.015)	(3.092)	(1.131)	(4.260)	(3.745)	(0.917)
N	883	883	883	883	883	883
R squared	0.130	0.127	0.131	0.133	0.130	0.134

Notes: The results are obtained from OLS estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate the 10, 5, and 1% level of significance, respectively. Other control variables are the dummies for totally damaged, half damaged, partially damaged, and totally damaged by the tsunami, log of sales per worker in 2010 (one year before the earthquake), log of the number of workers in 2010, the growth rate of sales from 2005 to 2010, the growth rate of full-time workers from 2005 to 2010, and industry and city dummies.

Table 9: Effects of Supply Chain Networks on Disruption of Supply Chains

Dependent variable: Log (number of days without supply of intermediates after the earthquake + 1)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log(number of suppliers in impacted areas + 1)	0.299		0.380*					
	(0.203)		(0.201)					
Log(number of suppliers outside impacted areas + 1)	-0.0198			0.217*				
	(0.191)			(0.111)				
Log(number of suppliers of direct suppliers + 1)	0.0834*				0.108***			
	(0.0454)				(0.0314)			
Log(number of clients in impacted areas + 1)		0.284**				0.356***		
		(0.127)				(0.117)		
Log(number of clients outside impacted areas + 1)		0.0180					0.268**	
		(0.149)					(0.125)	
Log(number of clients of direct clients + 1)		0.0860						0.117***
		(0.0653)						(0.0441)
Number of observations	840	840	840	840	840	840	840	840
Log likelihood	-1417	-1415	-1418	-1420	-1418	-1417	-1419	-1417
Pseudo R squared	0.0304	0.0319	0.0296	0.0284	0.0294	0.0305	0.0288	0.0302

Notes: The results are obtained from Tobit estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate the 10, 5, and 1% level of significance, respectively. Other control variables are the dummies for totally damaged, half damaged, partially damaged, and totally damaged by the tsunami, log of sales per worker in 2010 (one year before the earthquake), log of the number of workers in 2010, the growth rate of sales from 2005 to 2010, the growth rate of full-time workers from 2005 to 2010, and industry and city dummies.

Table 10: Effects of Supply Chain Networks on Receiving Support after the Earthquake

Dependent variable: Dummy variable for receiving support from firms after the earthquake

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log(number of suppliers in impacted areas + 1)	-0.107		-0.110					
	(0.0758)		(0.0818)					
Log(number of suppliers outside impacted areas + 1)	-0.102			-0.0777				
	(0.114)			(0.129)				
Log(number of suppliers of direct suppliers + 1)	0.0252				-0.00220			
	(0.0369)				(0.0399)			
Log(number of clients in impacted areas + 1)		-0.171*				-0.134		
		(0.0972)				(0.0888)		
Log(number of clients outside impacted areas + 1)		0.183*					0.165**	
		(0.0992)					(0.0721)	
Log(number of clients of direct clients + 1)		0.0101						0.0290
		(0.0445)						(0.0322)
Number of observations	662	662	662	662	662	662	662	662
Log likelihood	-237.3	-234.9	-237.6	-237.9	-238.1	-236.9	-236.8	-237.6
Pseudo R squared	0.243	0.250	0.242	0.241	0.240	0.244	0.244	0.242

Notes: This table shows marginal effects at means obtained from probit estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate the 10, 5, and 1% level of significance, respectively. Other control variables are the dummies for totally damaged, half damaged, partially damaged, and totally damaged by the tsunami, log of sales per worker in 2010 (one year before the earthquake), log of the number of workers in 2010, the growth rate of sales from 2005 to 2010, the growth rate of full-time workers from 2005 to 2010, and industry and city dummies.

References

Renesas (2011), Renesas: Recovery from the disaster, YouTube,
http://www.youtube.com/watch?v=4P784ZXw3iU

Aldrich D. P. (2011). The Externalities of Strong Social Capital: Post-Tsunami Recovery in Southeast India. *Journal of Civil Society.* 7 (1), 81-99.

Altay N. and Ramirez A. (2010). Impact of disasters on firms in different sectors: implications for supply chains. *Journal of Supply Chain Management.* 46 (4), 59-80.

Cavallo E., Galiani S., Noy I. and Pantano J. (2013). Catastrophic natural disasters and economic growth. *Review of Economics and Statistics.*).

Dahlhamer J. M. and Tierney K. J. (1998). Rebounding from disruptive events: Business recovery following the Northridge earthquake. *Sociological Spectrum.* 18 (2), 121-41.

Davis D. R. and Weinstein D. E. (2002). Bones, Bombs, and Break Points: The Geography of Economic Activity. *American Economic Review.* 92 (5), 1269-89.

duPont IV W. and Noy I. (2012). What happened to Kobe? A reassessment of the impact of the 1995 earthquake in Japan. *Working Papers, University of Hawaii at Manoa, Department of Economics*, No. 201204.

Fujiwara Y. and Aoyama H. (2010). Large-scale structure of a nation-wide production network. *The European Physical Journal B-Condensed Matter and Complex Systems.* 77 (4), 565-80.

Hallegatte S. (2012). Modeling the roles of heterogeneity, substitution, and inventories in the assessment of natural disaster economic costs. *World Bank Policy Research Working Paper*, No. 6047.

Hallegatte S. and Przyluski V. (2010). The economics of natural disasters: concepts and methods. *World Bank Policy Research Working Paper Series, Vol*, No. 5057.

Henriet F., Hallegatte S. and Tabourier L. (2011). Firm-network characteristics and economic robustness to natural disasters. *Journal of Economic Dynamics and Control.* 36 (1), 150-67.

Ministry of Agriculture F., and Fisheries of Japan, (2012). *FY2011 Trends in Fishries.*

Nakagawa Y. and Shaw R. (2004). Social capital: A missing link to disaster recovery. *International Journal of Mass Emergencies and Disasters.* 22 (1), 5-34.

Noy I. and Nualsri A. (2007). What do Exogenous Shocks Tell Us about Growth Theories?

Rose A. (2007). Economic resilience to natural and man-made disasters: Multidisciplinary origins and contextual dimensions. *Environmental Hazards.* 7 (4), 383-98.

Saito Y. (2012). Hisaichi Igai no Kigyo niokeru Higashi Nihon Daishinsai no Eikyo: Sapurai Chen nimiru Kigyokan Nettowaku Kozo to Sono Ganni (in Japanese), RIETI Discussion Paper, No. 12-J-020.

Skidmore M. and Toya H. (2002). Do natural disasters promote long‐run growth? *Economic Inquiry.* 40 (4), 664-87.

Small and Medium Enterprise Agency of Japan (2011). *2011 White Paper on Small and Medium*

Enterprises in Japan.

Small and Medium Enterprise Agency of Japan (2012). *2012 White Paper on Small and Medium Enterprises in Japan.*

Smith R. J. and Blundell R. W. (1986). An Exogeneity Test for a Simultaneous Equation Tobit Model with an Application to Labor Supply. *Econometrica.* 54 (4), 679-86.

Tokui J., Arai N., Kawasaki K., Miyagawa T., Fukao K., Arai S., Edamura K., Kodama N. and Noguchi N. (2012). Higashi-Nihon Dai-shinsai no keizaiteki eikyo: Kako no saigai tono hikaku, sapurai chen no sundan koka, denryoku seiyaku no eikyo (in Japanese), RIETI Policy Discussion Paper, No. 12-P-004.

Wakasugi R. and Tanaka A. (2013). Shinsai karano hukkyukikan no kettei yoin: Tohoku seizogyo no jissho bunseki (in Japanese).

Webb G. R., Tierney K. J. and Dahlhamer J. M. (2002). Predicting long-term business recovery from disaster: a comparison of the Loma Prieta earthquake and Hurricane Andrew. *Global Environmental Change Part B: Environmental Hazards.* 4 (2), 45-58.