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

Yasuyuki Todo[†]
Kentaro Nakajima[‡]
Petr Matous[§]

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Abstract

This paper examines how supply chain networks affected the resilience of firms to the Great East Japan earthquake, particularly the time that passed before firms resumed operations after the earthquake and sales growth from the pre- to post-earthquake period. The results indicate that the expansion of supply chain networks has two opposing effects on resilience of firms to disasters. On the one hand, when firms are connected with additional firms through supply chain networks, they are more likely to experience disruption of supplies and demands, which delays recovery. On the other hand, firms can benefit from diversified networks with suppliers and clients because they can substitute surviving firms in the network for damaged partners and receive support from surviving partners. Our results indicate that networks with firms outside the impacted area contributed to the earlier resumption of production after the earthquake, whereas networks within the region contributed to sales recovery in the medium term, implying that the positive effects of supply chains on recovery typically exceed the negative effects. We conclude that diversified supply chain networks contribute to the resilience of firms to natural disasters.

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[†] Corresponding author. Department of International Studies, the University of Tokyo and Research Institute of Economy, Trade and Industry. 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8563, Japan. Email: yastodo@k.u-tokyo.ac.jp. Tel.: +81-4-7136-4863.

[‡] Graduate School of Economics, Tohoku University. 27-1 Kawauchi, Aoba-ku, Sendai, 980-8576, Japan. E-mail: nakajima.kentaro@gmail.com.

[§] Department of Civil Engineering, the University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan. Email: pmatous@gmail.com.

1. Introduction

Economic resilience to natural disasters, including dynamic economic resilience, defined as speedy recovery through the repair and reconstruction of capital stock (Rose, 2007), has attracted attention in the wake of recent disasters, such as Hurricane Katrina and the Great East Japan earthquake, which had destructive impacts on economic activities. One important factor that affects economic resilience is the structure of supply chain networks, according to Henriet, Hallegatte, and Tabourier (2011). Their simulation analysis using a model based on input–output (IO) tables illustrates 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 are those in Japan, where suppliers and clients are heavily connected across regions (Fujiwara and Aoyama, 2010). Henriet, Hallegatte, and Tabourier (2011) suggest that the Japanese economy has limited resilience to exogenous shocks. In fact, the Great East Japan earthquake (hereinafter, the earthquake) on March 11, 2011, the fourth largest earthquake recorded in world history, had a tremendous effect on economic activities within the impacted areas. The direct regional shock was propagated to the rest of Japan and even to other countries due to the disruption of supply chain networks. According to a survey conducted by the Ministry of Economy, Trade, and Industry one month after the earthquake (METI, 2011), fewer than 10% of surveyed firms, mostly large firms with many plants, including some in the impacted areas, were able to procure sufficient amounts of material, parts, and components to operate normally. General Motors, Ford, Toyota, and Honda had to reduce their production in the United States because the supply of parts and components from Japan was disrupted (Nikkei Newspaper, May 3, 2011). Tokui et al. (2012) estimated that 90% of the output loss in Japan due to the earthquake resulted from indirect effects through the disruption of supply chains, rather than direct effects of damage caused by the disaster.

However, supply chain networks are not always harmful to recovery from disasters. Henriet, Hallegatte, and Tabourier (2011) note that output losses from disasters are smaller when networks are less concentrated. That is, when firms have more redundant ties with suppliers and clients, they can easily compensate for the loss of some of their partners. Indeed, the substitution of damaged partners by new partners was frequently 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 illustrated by anecdotal evidence from after the earthquake.[1] Therefore, the overall effect of supply chain networks on resilience to natural disasters is still unclear.

This paper examines this issue empirically using firm-level data for firms in the impacted areas of the Great East Japan earthquake. Our data consist of two datasets, one from a survey of firms in the impacted areas conducted after the earthquake and the other from another survey conducted a few years before the earthquake to collect detailed information on the suppliers and clients of each firm. We estimated the impact of the number of suppliers and clients inside and outside the impacted areas of each firm on the recovery time after the earthquake, i.e., the length of time before resuming operation, and sales growth from the pre- to post-earthquake period. We find that having more suppliers and clients outside the impacted areas shortened the recovery time but had only weak effects on sales growth in the medium term. In contrast, having more suppliers and clients in the impacted areas did not affect the recovery time but did improve sales growth. In addition, we identify a negative effect of supply chains on recovery through the disruption of supplies and demands and two positive effects through support and substitution. Our findings suggest that the positive effects of supply chain networks typically outweigh the negative effect, leading to an overall positive effect, although supply chains within and outside the region are more helpful in medium- and short-term recovery, respectively. Thus, our analysis suggests that supply chain networks, particularly diversified networks, contribute to the resilience of firms to natural disasters.

To date, only a few studies have examined what determines 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

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[1] See Section 3.1 for more details.

data from the Northridge earthquake in 1994, found that business recovery was affected by firm characteristics, such as financial conditions and the degree of damage suffered. However, unlike this study, those studies only used qualitative measures of recovery. Moreover, they 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 after the Great East Japan earthquake using the same data as in this study, but they did not explicitly analyze the effect of the structure of supply chains. Altay and Ramirez (2010) used 100,000 firm-year observations for more than 15 years to analyze the impact of more than 3,500 disasters in the world. Although they argued that they incorporated supply chains into their analysis, they simply classified firms in the manufacturing sector as upstream firms (i.e., suppliers) and those in the retail sector as downstream firms (clients). 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 are the focus of this study. In addition to economic networks, social networks in local communities were also found to promote recovery from natural disasters in Nakagawa and Shaw (2004) and Aldrich (2011). Although their conclusions are similar to ours for supply chain networks among firms, these studies were based on qualitative case studies, as opposed to our quantitative study. Therefore, the analysis conducted in the present study is a new contribution to the literature on the impact of social and economic networks on recovery from natural disasters.

Furthermore, the results of this study can also contribute to other strands of research on recovery from natural disasters. Many studies have examined whether natural disasters have long-term impacts on economies and have yielded mixed findings. Davis and Weinstein (2002) and Skidmore and Toya (2002) found no negative effect of natural disasters on long-term growth, whereas Cavallo et al. (2013), duPont IV and Noy (2012), and Noy and Nualsri (2007) found a persistent negative effect. Xiao (2011) found a negligible effect of the 1993 Midwest flood on income in the long term but a long-lasting negative effect on agriculture. These mixed results suggest that the effects of natural disasters on economic activities vary depending on the conditions and characteristics of the economy. Our results demonstrate that the structure of the supply chain networks is one of these conditions.

The results of this study may also be useful to research that measures output losses due to natural disasters using simulation of theoretical models, such as IO and computable general equilibrium (CGE) models (Hallegatte and Przyluski, 2010, Rose et al., 1997, Rose and Liao, 2005). Hallegatte (2012) found that output losses are amplified by supply chain relations, particularly when substitution between inputs is more difficult. Hallegatte (2012) also found that because simulation results can vary substantially depending on the degree of substitution and the structure of supply chain networks, further research on the actual nature of network structures and production substitution is needed. This study provides some evidence to enrich theoretical models and simulation analysis in this field.

Finally, this study contributes to the literature on economic geography in identifying the benefits and costs of economic agglomeration. Since Marshall (1890), agglomeration of firms and workers has been considered to improve firm productivity and reduce production costs through input sharing, knowledge spillovers, and labor pooling (Duranton and Puga, 2004). In addition to the above channels, our results suggest that networks of firms within a region can promote medium-term recovery from external shocks. This potential benefit might be considered another raison d'être of agglomerations. However, this study also points to a new source of costs of agglomeration, as it finds that the physical proximity of transaction partners has a negative effect on short-term recovery from region-specific shocks through the disruption of local supply chain networks.

2. Data

2.1 Description of the Data Sources

The dataset used in this study is based on two data sources. The first data source is data from a plant-level survey conducted by the Research Institute of Economy, Trade and Industry (hereinafter, the RIETI survey) in January and February in 2012, 10 months after the earthquake and subsequent tsunami, of plants in areas impacted by the earthquake. The implementation of the survey was subcontracted to

Teikoku Databank, one of the largest corporate research companies in Japan, which already had information on most of the firms in the impacted areas prior to the earthquake. The areas impacted by 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 6,033 firms (with some exceptions, as explained below) that were in the manufacturing sector, were located in the impacted areas, and had at least five employees before the earthquake, according to the prior information possessed by Teikoku Databank. Two categories of firms whose recovery was impeded largely by government regulations were excluded from the survey because one of the primary objectives of the survey was to determine how firm characteristics affected recovery from the earthquake. The first category of excluded firms were 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' plants after the disaster was prevented by regulation, even if their recovery would otherwise have been possible. In fact, according to the Small and Medium Enterprise Agency of Japan (2012), only 50% of the firms in the seafood processing industry in the impacted areas had re-started production by January 2012, whereas 67% of firms in other industries had done so by then. The other category of excluded firms were those located within a 20-km radius of the Fukushima Daiichi Nuclear Plant because they were required by the government to evacuate the area due to possible releases of radioactivity from the plant at the time of the survey.

A questionnaire on the level of damage suffered as a result of 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 responses by February 2012. A total of 2,117 effective responses were received, i.e., the response rate was 35%, which is high for this type of firm-level survey. Firms that were located in the impacted areas before the earthquake but relocated or closed their business after the earthquake were also of interest in the survey, as long as the Teikoku Databank could capture their current contact address.

Among the 2,117 firms, 15 firms had relocated or were going to relocate their plants, six had closed or were going to close their business, and three had merged with other firms. The inclusion of relocated and closed firms in the sample is unique and valuable for a survey intended to examine whether and how well firms recover from disasters.

The other data source is data from Tokyo Shoko Research (the TSR data), another large corporate research company in Japan. The TSR data consist of two datasets. One contains corporate information, such as a firm’s location, sales, and 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 to establish the characteristics of each supplier and client. Although the upper limit of the number of suppliers and clients, 24, is clearly too small for many large firms, it still allows most of the supply chain networks to be captured by looking at the supplier–client relations from both directions. RIETI purchased the entire dataset, which includes corporate information for 803,705 firms and transaction information for 3,904,380 supplier–client pairs, from TSR in 2006. The corporate information was collected in 2005 for 67% of the firms in the TSR data, in 2004 for 28% of the firms, and in 2002, 2003, or 2006 for the other 5%. The maximum number of suppliers for one firm was 7,474, and the maximum number of clients was 7,139.

We merged the RIETI and TSR data using the names and addresses of the firms. In the merging process, we had to exclude firms whose information was in the RIETI data but not in the TSR data. One reason for 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 for this mismatch is that the TSR data were collected before 2006, whereas the RIETI data were collected in 2012. Therefore, firms that started or closed their business or were renamed between 2006 and 2012 were excluded. In addition, we excluded firms whose headquarters were not in the impacted areas because the TSR data are at the firm level, whereas the RIETI data are at the plant level. In other words, the suppliers and clients of firms whose headquarters are outside the impacted areas and that have plants in the impacted areas do not necessarily reflect suppliers and clients of the plants in the impacted areas. After excluding firms with obvious errors in their data, we had a total of 902 firms in the sample used for our analysis.

2.2 Descriptive Statistics

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

According to the Small and Medium Enterprise Agency of Japan (2011), 26% 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, whereas 7% were “half-damaged.” The proportion of completely damaged firms in our sample is lower than the corresponding proportion in the SME Agency (2011) information, most likely for the following two reasons. First, the RIETI survey targeted Ibaraki and Tochigi Prefectures, where the damage caused by the disaster was relatively small (although still large in absolute terms), in addition to Aomori, Iwate, Miyagi, and Fukushima Prefectures, where the damage was greater. Second, we excluded firms in the seafood processing industry and those near the Fukushima Daiichi Nuclear Plant, where damage was substantial, as explained above.

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

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

The rate of change of the number of workers from September 2010 to September 2011, defined as the difference in the number of workers between the two periods divided by the initial number, was -1% on average, and its median was zero. The minimum rate of change was -100% for firms that closed down. The average and median rates of change of sales from before to after the earthquake were 1.19% and -0.57%, respectively. The average and median numbers of days before resuming production after the earthquake were 14.9 and five, respectively. The recovery time was zero for approximately 30% of firms, meaning that those firms did not shut down their production. The maximum number of days was 330, the approximate number of days between the earthquake (March 2011) and survey (February 2012), meaning that those firms had not resumed production at the time of the survey. The average and median of the number of days when any supply of materials, parts, or components was disrupted were 21 and seven, respectively. Approximately 45% of firms did not experience any problems in supply. Thus, many firms in our sample recovered relatively quickly from the damage caused by the earthquake, although many others had difficulty recovering.

The lower rows of Table 3 indicate characteristics of the supply chain networks of the sample firms. Using the entire sample of the TSR data (i.e., including firms in the impacted areas as well as those outside the impacted areas), we computed the number of suppliers and clients inside and outside the impacted areas for each firm. The average number of suppliers in the impacted areas was 3.14,[3] and the maximum was 104. The average number of suppliers outside the impacted areas was 2.61, and the

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

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

maximum was 24. The number of clients was similar to the number of suppliers. These figures illustrate that the sample firms had a relatively small number of suppliers and clients.

In addition, we computed the number of suppliers of the direct suppliers. We were interested in the possible effects of indirect suppliers on recovery from the earthquake because 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 illustrates that the average and median numbers of suppliers of direct suppliers were 620 and 86.5, respectively, and that the maximum was 12,909. The number of clients of direct clients was similarly large. These findings imply that firms in the impacted areas were indirectly connected to a substantial number of firms in Japan through supply chains, as reported by 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 depend on processed materials, parts, or components from suppliers affected by a disaster, these downstream firms may have to shut down their operations even when they themselves are unaffected by the disaster. This situation may also occur when clients of firms’ products are affected by the disaster. Therefore, we hypothesize that a firm’s recovery from a disaster becomes more difficult with an increasing number of connections with suppliers and clients within impacted areas. Firms may also have to stop or reduce production when they are not directly connected to affected suppliers but are indirectly connected to affected upstream suppliers or downstream clients through supply chains. Therefore, focusing particularly on suppliers of suppliers and clients of clients, we presumed that when the number of indirect suppliers and clients increases, the likelihood that firms are indirectly affected also increases, thus leading firms to require more time to resume production.

However, supply chain networks are not always harmful to recovery from disasters. There is considerable anecdotal evidence demonstrating 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 44% share of 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 caused a halt of production lines of automobiles outside the impacted areas. To support the recovery of Renesas, its clients, including major automobile manufacturers, provided 80,000 man-days of labor to Renesas. As a result, Renesas re-started part of its production on June 10, one month earlier than first predicted immediately after the earthquake (Renesas, 2011). This example clearly illustrates that connections to clients, particularly those outside impacted areas, may be helpful in obtaining support for recovery.

Connections to clients in impacted areas may also be helpful. The SME Agency (2011) documented the experience of Horio Seisakusho K.K. in Miyagi Prefecture, a small- to medium-sized enterprise with 52 employees that produced optical pickup components and had a 30% share of the world market. Because Horio Seisakusho was located at a high elevation, it suffered only limited damage as a result of the tsunami. However, one of its suppliers, Ogatsu Musen Co., Ltd., was located near the sea, and all of its equipment was washed away by the tsunami. 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 as a result, Horio Seisakusho was also able to re-start its production quickly, utilizing supplies from Ogatsu Musen. This example demonstrates how supply chain networks within impacted areas can be beneficial to the 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% of firms whose suppliers were damaged actually changed their suppliers. In some cases, damaged suppliers themselves asked their competitors to replace 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 affected by the earthquake and forced to stop its operations temporarily. Iwaki Die-cast decided to provide its dies to one of its competitors so that the competing 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, took the same action (Bloomberg, March, 13, 2012).

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

3.2 Estimation Methods

To examine the questions raised in the previous sub-section, we estimated parameter values for the following equation:

$$\log(RESUME_i + 1) = \beta_0 + \beta_1 NET_i + \beta_2 X_i + \varepsilon_i \, . \qquad (0)$$

$RESUME_i$ is the number of days that passed before firm i resumed 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 included 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 took the log of the number of suppliers or clients plus one, assuming a quasi-log-linear relation. Because the minimum of the dependent variable is zero and the maximum is log 331, where 330 is the maximum number of days after the earthquake (Section 2.1), we employed a Tobit estimation.

We further examined whether the effect of supply chain networks varied depending on the level of damage suffered by a firm. For this purpose, we included in NET interaction terms between one of the network variables and dummy variables for the level of damage: completely destroyed, half destroyed, partially damaged, and not damaged. Because the inclusion of many interaction terms can cause multicollinearity, we focused on one particular type of network and excluded 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 included the number of workers and sales per worker in 2010, both in log form.

Growth in sales and employment prior to the earthquake from 2005 to 2010 were also included because these variables may capture firms' potential capability for recovery. In addition, we incorporated dummy variables representing the level of damage, i.e., dummies for completely destroyed, half destroyed, partially destroyed, and not destroyed by the tsunami. Finally, industry and city dummies were included.

A potential problem in estimating the effect of networks is endogeneity of network variables. In this study, there should be no reverse causality, i.e., causality from recovery to networks, because our network variables were collected six years before the earthquake and damage was exogenously caused by the earthquake. Another source of endogeneity is unobservable factors that affect both the recovery and supply chain networks of each firm. However, growth in sales and employment prior to the earthquake can largely control for firms' potential recovery capabilities, whereas industry and city dummies can control for industry- and location-specific characteristics that most likely affect network characteristics. Therefore, biases due to endogeneity were not expected to be large in this study, although we still tested for endogeneity using Smith and Blundell's (1998) method, as discussed later.

4. Results

4.1 Effects on the Time Not in Operation after the Earthquake

The benchmark effects of the number of suppliers on the number of days not in operation after the earthquake, or the recovery time, are shown in column 1 of Table 4, whereas the effects of the number of clients are shown in column 2. In both cases, the effects of the dummies for the level of damage were highly significant, whereas the effects of other controls, such as the number of workers and sales, were insignificant.

The effect of supply chain networks varied depending on their characteristics. Networks within the impacted areas, measured by the number of suppliers or clients in these areas, had no significant effect on recovery. This lack of significance is most likely 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 increased possibilities of substitution of supplies and demands within supply chain networks, cancel each other out.

In contrast, networks with firms outside the impacted areas, as measured by the number of suppliers or clients outside the areas, significantly decreased the time required for recovery. This significant result is clearly because impacted firms were less likely to face shortages 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, the number of suppliers of direct suppliers and clients of direct clients had positive and significant effects 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 a shortage of supply or demand. The positive effect of indirect networks on recovery time was more evident than the effect of direct networks because support from indirect suppliers cannot be expected, unlike support from direct suppliers.

4.2 Testing for Endogeneity

We further examined the effect of supply chain networks using each of the network variables separately, in addition to the same controls, in one regression. This experiment was conducted so that we could highlight the effect of each type of network on recovery without the potential for multicollinearity and so that we could test the endogeneity of each of the network variables. As we discussed in Section 3.2, although our analysis was not contaminated by endogeneity from reverse causality, it might still have been biased due to endogeneity stemming from unobservable factors affecting both supply chain networks and resilience. However, it was difficult to find good instruments, as is often the case. One possibility was sales in the year before data on the supply chain networks were collected (2004 for most firms). This variable was highly correlated with any network variable but was 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 could not test for endogeneity of the supply chain variables when there was more than one possible endogenous network variable. By limiting the number of endogenous variables to one in each regression, we were able to test for endogeneity for 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 of the network variables from the separate regressions, shown in Table 5, are mostly consistent with the results shown 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 provides the *p* value of the Smith–Blundell statistic. We could not reject the null hypothesis that the network variable was exogenous for any regression.

4.3 Heterogeneity across Levels of Damage

Up to this point, we had assumed that each type of network had 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 damage. To highlight this possible variation, we used interaction terms between each of the network variables and the dummies for the level of damage, i.e., completely destroyed, half or partially destroyed, and not damaged.

The result in column 1 of Table 5 indicate that the number of suppliers in the impacted areas had no significant effect on recovery. The results in column 1 of Table 6 indicate that this lack of significance was the case regardless of the degree of damage. The results in column 2 of Table 5 indicate that the number of suppliers outside the impacted areas had a negative and significant effect. The results in column 2 of Table 6 indicate that this negative effect was mostly due to the negative effect for half-destroyed or partially destroyed firms. In other words, networks with suppliers outside the impacted areas did not help completely destroyed or undamaged firms. These findings imply that support from suppliers is not helpful to recovery once a firm is completely destroyed and that 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 had a negative and significant effect for firms without any damage (column 5), whereas the effect was insignificant for suppliers (column 2). The effect of indirect suppliers and clients was mostly insignificant (columns 3 and 6), as shown in Table 5, except for the negative effect of indirect suppliers on the recovery time of completely destroyed firms.

4.4 Effects on Changes in Sales

Another logical measure of recovery from disasters is changes in sales. Therefore, we examined the effect of supply chain networks on the rate of change in sales from the second and third quarters of 2010 (i.e., before the earthquake) to the corresponding quarters in 2011 (after the earthquake) using ordinary least squares (OLS) estimations. We employed the same network variables and control variables. The results shown in Table 7 indicate that both the number of suppliers and the number of clients in the impacted areas significantly increased sales. We also found 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 had no significant effect.

Table 8 presents the results of the examination of the possible heterogeneous effects of networks on sales growth depending on the level of damage. We found that networks with suppliers and clients in the impacted areas were particularly helpful to firms that were half or partially damaged but were not helpful to either completely destroyed or undamaged firms.

The results shown in Tables 4–8 imply that whereas supply chain networks with firms outside the impacted areas contributed to earlier resumption of production for 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 results are not necessarily contradictory because the time spans of the two measures of recovery were different. The median recovery time was five days (Table 3), and the recovery time was zero days for 30% of the firms and less than 30 days for approximately 90% of the firms. However, sales growth is measured as the growth rate from the second and 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 affected region contributed to medium-term recovery, whereas networks beyond the affected region contributed to short-term 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. First, recovery from the earthquake was often impeded by the disruption of supply chains. Even when firms were ready for production because they were not severely affected by the earthquake or because they repaired damaged production facilities or replaced them with new ones, many could not actually resume production because of a lack of supply of parts, components, or materials. Because we had information on how long the supply of materials and intermediates was affected, we were able to test directly whether supply chain networks affected the disruption of supply chains. Specifically, we regressed the number of days (in log form) for which supply of parts, components, or materials was affected by the earthquake on the network variables and controls, using Tobit estimations. The results presented in Table 9 indicate that when each network variable was used in a separate regression, the effect of any network variable was found to be positive and statistically significant. This finding suggests that firms with more extensive supply chain networks experienced a longer time period of disruption of supply after the earthquake.

Another channel of the effect of supply chains on recovery was support from firms to damaged partners in supply chain networks. Using a probit estimation, we examined the effect of the number of suppliers or clients on whether the firm received human, physical, or financial support from other firms. The results presented in Table 10 indicate that although most types of supply chain networks had no significant effect on the receipt of support, having more clients outside the impacted areas was associated with a greater likelihood of having received support from firms. This statistical evidence is consistent with the anecdotal evidence of the sort illustrated by the Renesas Electronics example described in Section 3.1.

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

5. Discussion and Conclusions

In this paper, we examined how supply chain networks affected the 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 before to after the earthquake. The results shown in Tables 4–8 indicate that supply chain networks with firms outside the impacted areas contributed to quicker resumption of production of moderately damaged firms after the earthquake but had a weak effect on sales growth. In contrast, networks within the impacted areas increased the sales growth of damaged firms in the medium term, although they were not helpful to firms in resuming production more quickly.

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

Combining these results, we can conclude that 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 many other firms through large supply chain networks, they are more likely to experience shortages of supplies, which delay recovery. On the other hand, firms can receive support and find substitutes for damaged partners through supply chain networks, which accelerates recovery. Depending on the characteristics of the supply chain networks, the two opposing effects may balance each other out or one may outweigh the other. For example, suppose that a firm is connected with many firms in a region. When a disaster hits that region, the partner firms may be damaged by disasters, and thus, it is more likely that the firm will experience a shortage of supplies and demands from its damaged partners and less likely that the firm will receive support from its partners (although it is possible, as demonstrated by the example of Ogatsu Musen in Section 3.1). As a result, the negative effect of networks within the impacted areas on resumption of production through disruption of supply chains cancels out their positive effect through support and substitution, and the net effect is zero. However, in the medium term, the disruption of supply chains can be resolved for most firms, as was the case for the Great East Japan earthquake (Section 2.2). Therefore, the positive effect of networks within the impacted areas was more prominent than the negative effect, and thus, the sales growth in the medium term increased for firms that were more connected with other firms in the impacted areas through supply chains.

For networks with firms outside the impacted areas, the positive effect on recovery outweighs the negative effect due to disruption of supply chains because firms outside the impacted areas were less likely to be directly damaged by the earthquake. Accordingly, networks with firms outside the impacted areas may be able to recover more quickly and increase sales after a disaster.[4]

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[4] Our results also indicate that the number of suppliers outside the impacted areas did not have any significant effect on sales growth. One interpretation is that when firms are connected with more suppliers outside area impacted by a disaster, they can resume production more quickly because of support from suppliers, but their sales do not grow considerably because of limited demand in the impacted areas. One example that is consistent with the interpretation is that of Renesas Electronics Co., Ltd., mentioned in Section 3.1. Although Renesas resumed production rather early due to massive support from clients, its sales and profits were stagnant even after the resumption. One possible reason for this stagnation, suggested by Nikkei Newspaper (December 11, 2012), is that the prices of Renesas' products were too low because of the strong bargaining power of its clients. Thus, the strong ties between suppliers and clients did not increase sales for Renesas. In fact, after suffering large losses for a few

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

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

One caveat of this study is that although we found benefits from diversifying supply chain networks, the extent to which firms should diversify their supply chain networks remains unclear because we did not conduct any cost–benefit analysis. Clearly, diversifying suppliers and clients across regions is expensive, which is most likely the main reason why many firms have a limited number of suppliers and clients (Section 2.2). It is expected that future research will investigate the costs of finding suppliers and clients explicitly. This type of investigation would make it possible to find the optimal level of diversification to maximize the net benefit, i.e., the long-term benefits from strengthened economic resilience less short-term costs.

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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: Damage Caused by the Great East Japan earthquake

(A) Raw data from impacted areas

	Number of firms	Share of 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 of 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 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 as 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 the 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 (September 2010)	902	53.12	28.50	84.23	4	1120
Number of workers (September 2011)	899	53.14	29.00	85.64	0	1086
Rate of change of the number of workers (%, September 2010– 2011)	902	-1.06	0.00	14.05	-100	118
Rate of change of the number of full-time workers (%, 2005–2010, annual)	902	1.52	1.23	10.60	-66	61
Sales (April–September, 2010, billions of yen)	902	1.17	0.14	20.01	0	600
Sales (April–September, 2011, billions of yen)	883	1.22	0.14	21.90	0	650
Rate of change of sales (%, April–September 2010 to April–September 2011)	883	1.19	-0.57	39.34	-100	284
Rate of change 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 log form	902	1.10	1.10	0.75	0	4.65
Outside impacted areas	902	3.61	3	2.85	1	25
-- in log form	902	1.02	1.10	0.73	0	3.22
Suppliers of direct suppliers	902	619.69	86.5	1,499.49	1	12,909
-- in log form	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 log form	902	1.06	1.10	0.88	0	4.51
Outside impacted areas	902	3.79	3	3.16	1	29
-- in log form	902	1.05	1.10	0.75	0	3.37
Clients of direct clients	902	932.67	147	1,664.09	1	11,515
-- in log form	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)
Completely destroyed	2.159***	2.114***
	(0.508)	(0.516)
Half destroyed	1.951***	1.912***
	(0.319)	(0.305)
Partially damaged	1.098***	1.092***
	(0.247)	(0.235)
Completely 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 were obtained from Tobit estimations. Robust standard errors clustered within cities are in parentheses. Industry and city dummies were included as independent variables. *, **, and *** indicate significance at the 10, 5, and 1% levels, 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 were obtained from Tobit estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. Other control variables were the dummies for firms being completely damaged, half damaged, partially damaged, and completely 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) * completely 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 or partially 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 were obtained from Tobit estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. Other control variables were the dummies for firms being completely damaged, half damaged, partially damaged, and completely damaged by the tsunami, the log of sales per worker in 2010 (one year before the earthquake), the 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 were obtained from OLS estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. Other control variables were the dummies for firms being completely damaged, half damaged, partially damaged, and completely damaged by the tsunami, the log of sales per worker in 2010 (one year before the earthquake), the 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) * completely 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/partially 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 were obtained from OLS estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. Other control variables are the dummies for firms being completely damaged, half damaged, partially damaged, and completely damaged by the tsunami, the log of sales per worker in 2010 (one year before the earthquake), the 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	-1,417	-1,415	-1,418	-1,420	-1,418	-1,417	-1,419	-1,417
Pseudo R squared	0.0304	0.0319	0.0296	0.0284	0.0294	0.0305	0.0288	0.0302

Notes: The results were obtained from Tobit estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. Other control variables were the dummies for firms being completely damaged, half damaged, partially damaged, and completely damaged by the tsunami, the log of sales per worker in 2010 (one year before the earthquake), the 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 the marginal effects at means obtained from probit estimations. Robust standard errors clustered within cities are in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. Other control variables were the dummies for firms being completely damaged, half damaged, partially damaged, and completely damaged by the tsunami, the log of sales per worker in 2010 (one year before the earthquake), the 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.

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