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Abstract

This paper quantifies the spillover effect of exogenous shocks, such as earthquakes, on other firms through the supply chain network. Combining micro data on inter-firm transaction networks and geographic information systems, we examine firms' sales growth and transaction relationships outside the tsunami-hit areas before and after the Great East Japan Earthquake. We find that sales growth shows a negative but insignificant effect for firms with suppliers in the affected areas and a negative and significant effect for firms with customers in the affected areas. When we focus on exiting firms in the affected areas as the firms from where the spillovers originated, the sales growth of linked firms outside the affected areas exhibits negative and significant effects for both upstream and downstream firms. Furthermore, significantly negative effects on downstream firms are shown for not only directly linked firms but also indirectly linked firms, with two and three degrees of separation. Finally, we find that firms tend to establish new transactions when they have transaction partners in the affected areas.

Keywords: Transaction network, Natural disaster, Spillover
JEL codes: E23, E32, L14

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"Enei Casting Corporation (Minami-souma city, Fukushima) stopped operations after the earthquake, as the factory was located within the off-limits area of the reactor failure. It restarted operations in July 2012, but lost 40% of its customers completely."

[Nikkei, March 8, 2013]

"Supply chain disruptions in Japan have forced at least one global automaker to delay the launch of two new models and are forcing other industries to shutter plants (. . .) The automaker is just one of dozens, if not hundreds, of Japanese manufacturers facing disruptions to their supply chains as a result of the quake, the subsequent tsunami and a still-unresolved nuclear threat."

[Reuters, 2011]

1. Introduction

The backbone of a modern economy is an intricately linked web of specialized production units, each relying on the flow of inputs from their suppliers to produce their own output, which, in turn, is routed towards other downstream units. Emerging literature on production networks suggests that the origins of aggregate fluctuations can be traced back to idiosyncratic disturbances—occurring at particular production units along the supply chain—which then cascade down via input-supply linkages, thereby inducing co-movement of fluctuations across different firms and affecting aggregate behavior. If this is the case, understanding if, and how, shocks propagate across supply chains can therefore better inform both academics on the origins of aggregate fluctuations and policy-makers on how to prepare for and recover from adverse shocks that disrupt these production chains.

While the potential importance of this mechanism is now becoming clearer, identifying plausible exogenous micro shocks in firm-level data and quantifying their actual impact along the supply chain remains a challenge. This paper addresses this challenge by combining a novel large-scale dataset on Japanese firm-level production networks, with information on firm-level exposure to a large, but localized, natural-disaster: the Great East Japan earthquake, which occurred in March 2011. Starting from information on firm location, we exploit the heterogeneous exposure of firms to the earthquake in order to obtain measures of firm-level idiosyncratic shocks. We then combine the latter with extensive micro-data on inter-firm transactions to trace out and quantify the impact of these shocks along the supply chain.

We find that sales growth has a negative but not significant effect for firms who have suppliers in affected areas and a negative and significant effect for firms with customers in affected areas. When we focus on exiting firms in affected areas as the firms from where the spillovers originated, sales growth of linked firms outside the area exhibit negative and significant effects for both upstream and downstream firms. Furthermore, the significantly negative effects on downstream firms are shown for not only directly linked firms but also indirectly linked firms along the supply chain. That is, we find evidence consistent with the cascading effects of disruptions along the supply chain.

Our paper is most closely related to recent work emphasizing the role of production networks in propagating otherwise independent shocks via input-supply linkages, and thereby inducing correlation across interlinked production units (Carvalho, 2010; Acemoglu, Carvalho, Ozdaglar, and Tahbaz-Salehi, 2012; Carvalho and Gabaix, 2012). However, credibly identifying idiosyncratic shocks and quantifying their actual impact along the supply chain networks remains a largely unexplored area. In particular, though recent contributions by Foerster, Sarte, and Watson (2011), Carvalho and Gabaix (2012), Holly and Petrella (2012), and di Giovanni, Levchenko, and Mejean (2012) all find the contribution of idiosyncratic shocks to aggregate volatility to be substantial, they invariably rely on strong identifying assumptions when backing out idiosyncratic shocks from sectoral data. Our contribution to this literature is to exploit the Great East Japan earthquake as a plausible source of exogenous micro-level idiosyncratic variation and to offer a test of whether these micro-level shocks propagate through input chains, as the theory predicts.

Our paper is related to literature documenting the economic impact of natural disasters (Noy, 2009; Raddatz, 2009; Strobl, 2011). Like these papers, we document a negative and significant effect of large natural shocks on ongoing domestic production. We contribute to this literature by exploiting detailed firm-level data around a natural disaster and establishing that supply-chain linkages constitute a powerful transmission mechanism of otherwise localized shocks.

Furhermore, our paper is related to a small literature analysing the network structure and geographical features of the Japanese firm-level production network. Using a large scale dataset of Japanese customer-supplier relations, this network structure is examined by Saito, Watanabe, and Iwamura (2007) and Ohnishi, Takayasu, and Takayasu (2011). The geographical features of this network is also examined in Nakajima, Uesugi, and Saito (2012) and Saito (2012, 2013). Nakajima et al. (2012) examined the localization of transactions, while Saito (2012, 2013) clarifies the role of hub firms in the geographical spread of the supply chain and in shortening network distances among otherwise (geographically) distant firms. Finally, Bernard, Moxnes, and Saito (2014) detail the role of geography and firm characteristics in the formation of these production networks. Complementing our own results in this paper, Bernard et al. (2014) also show that downstream firms' productivity and sales are influenced by the performance of upstream firms.The rest of the paper is organized as follows. Section 2 describes the Great East Japan earthquake and presents the firm-level network data. Section 3 contains our main empirical results. Section 4 concludes.

2. The Earthquake and the Data

2-1. The earthquake

The magnitude 9.0 earthquake on March 11, 2011, brought a three-fold impact on the residents of northeast Japan: the quake that demolished 126 thousand buildings completely, the tsunami that flooded 561 square kilometers of the northeast coastline, and the failure of the Fukushima Daiichi nuclear power plant that led to the evacuation of 99 thousand residents in Fukushima and the electricity shortage crisis. The Disaster Relief Act was applied to many municipalities in the seven prefectures of Iwate, Miyagi, Fukushima, Aomori, Ibaragi, Tochigi, and Chiba for the relief of hazards to life. According to the census of industry and commerce, these municipalities in the seven prefectures are a host to 7% of the business establishments, 9.6% of employees, and 8.9% of shipments in Japan. The index of industrial production (IIP) in this area fell to 67% in March and 68% in April from the February level, and recovered to 91% level by June. IIP in other areas fell to 85% in March and recovered to 95% by June.[1]

Among the affected municipalities, those along the Pacific Ocean coast were the most severely damaged from the tsunami. 75% of the establishments in the flooded area, which is identified using geographic information system data, belong to the chemistry, steel, ceramic, textile, pulp and paper, and electronics devices industries. The production of chemistry, steel, and pulp and paper in this area was halted almost until July, and recovered to only 50%, 80%, and 30%, respectively, of the February level a year later.[2] However, the share of the flooded area in national economic activities is quite limited. The establishments in the coastal municipalities (which is broader than the flooded area) accounts for 2.5% of the total shipment and 2.3% of the GDP of Japan.[3]

Despite the small share of the economic activities in the affected area, many firms outside the affected area were surprised by the ripple effects that the production halt caused through their supply chain. Among many episodes, the most discussed was Renesas Electronics Corporation’s Naka plant located in the Ibaragi prefecture. Renesas held 40% of the world's share of microcontrollers used for automobiles. When Renesas’s main factory for the device, the Naka plant, failed, its impact on automobile production was felt beyond Japanese automakers. A variety of other products suffered due to the breakdown of supply from functional chemicals such as rubber for tires, paint pigments, condenser electrolytes for silicon semiconductor wafers, and thyroid hormone preparation Thyradin-S. The supply-chain shock led to serious debates and actions by Japanese manufactures as to how best to prepare for such supply chain disruptions (Fujimoto, 2011).

To go beyond anecdotes, several studies have attempted to quantify the economic impacts of supply chain disruptions. Tokui et al. (2012) employed an input-output analysis. When they assumed no substitutability, the direct loss in value added production was estimated at 0.11% of the GDP, while the loss

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1 http://www.meti.go.jp/statistics/toppage/report/bunseki/pdf/h25/b2010_h4a1310eeu.pdf

2 http://www5.cao.go.jp/j-j/wp/wp-je12/h05_hz020102.html

3 http://www.meti.go.jp/english/earthquake/recovery/pdf/20110811_impact.pdf

due to the first-round propagation was 0.26%, and the loss due to total propagation was 1.35%. However, these estimates were reduced to a fifth of their magnitude when they assumed substitutability between Tohoku and other areas.

Others used the micro-level data and estimated the effect of the exposure to the supply chain. Using survey conducted by Tohoku University, Ishise et al. (2013) reported the activities of firms in the affected area. According to the survey, the percentage of firms who indicated that their transactions with suppliers or customers were disrupted amounted to 25%, if the firms themselves incurred some direct damage by the earthquake, and 9-13% even if the firms themselves did not incur damage. To respond to the supply chain disruptions, 17.5% of firms reported reduced or no production, 12% reduced inventory, 27% searched for a new transaction partner, and 30.5% increased transactions with other partners, while 31.8% reported that they did none of above. Wakasugi and Tanaka (2013) investigated the effect of a disrupted supply chain using a survey of 2,117 establishments in the affected area. They regressed the duration of halted operations on the duration of disrupted supply, controlling for the durations of disrupted power supply, water supply, and transportation service, among others. The estimates showed that the duration of halted operations was extended most strongly by the disrupted supply, among other factors, when the sample is restricted to the establishments whose operation halted for a period longer than the average.

Some others went further to identify the actual supply-chain network. Todo, Nakajima, and Matous (2013) studied the effect of the supply-chain network on the speed of recovery and sales growth at the firm level. They found that connections with firms outside the affected area help quicker recovery, while connections within the affected area help sales recovery in the medium term. Hosono et al. (2012) used a similar dataset to ours, and investigated the effect of lending behavior of the banks located in the affected area on the borrowing firms, by using difference-in-difference estimation.

2-2. Data

We augment the literature by estimating the effect of the decreased sales by a firm located in the affected area on the sales of firms connected to the affected firm through supply chain linkages. Thus, to quantify the impact of supply chain disruption, we first estimate the differential sales growth performance of firms who either supplied to or were supplied by the affected firms directly (our treatment group), relative to firms who had no direct supply chain linkages in the affected area (our control group). In the second step of the analysis, we aim to establish whether this disruption cascaded across the supply chain, potentially affecting sales of firms who had no direct linkages to affected firms. To do this, we expand our treatment group sequentially to include firms whose supply-chain network distance is two and/or three degrees away from affected firms, and then compare their sales growth performance to that of firms that were relatively more distant—in a supply chain network sense—from affected firms (i.e., the control group are firms that were four or more degrees away from firms in the affected area).

We use data compiled by Tokyo Shoko Research (TSR). TSR is a Japanese private firm specializing in firms' credit research. The data is not census data, nor a representative survey data. The survey of a firm takes place on request of clients of TSR. The dataset provided to us consists of data for the years 2006, 2011, and 2012. In order to check biases of the TSR data samples, we compare TSR data with the census data of 2006. The total number of firms is about 800 thousand in TSR data, compared to 1.5 million in the census data. TSR data includes more than half of all firms in Japan. Table 1 shows the distribution of the number of employees in TSR and census data. The percentage of firms with less than five employees is 33% in TSR data, while it is 51% in the census data. Thus, TSR data is under-sampled in very small firms.

Table 1. Distribution of number of employees for the year 2006

number of employees	TSR	census
0 ～ 4	33%	53%
5 ～ 9	24%	19%
10 ～ 19	18%	13%
20 ～ 29	7%	5%
30 ～ 49	6%	4%
50 ～ 99	5%	3%
100 ～ 299	4%	2%
300 ～ 999	1%	1%
1,000 ～ 1,999	0%	0%
2,000 ～ 4,999	0%	0%
5,000 ～	1%	0%

The data contains information on firm characteristics and inter-firm relations through transactions. The data provides characteristics such as name, address of headquarters, industry code (Japanese standard industry code), year of establishment, number of employees, sales of two preceding periods, profits, and credit scores. The inter-firm relation data reports the firm's suppliers, customers, and major shareholders. These transaction partners are listed up to 24 firms for each category. In spite of this limitation, we can capture the firm's transaction network much better by augmenting a firm's list of suppliers (customers) by other firms' reports stating that they transact with the firm as customers (suppliers). By using own and other reports of transactions, we can identify firms with more than 24 links per category, and even bigger hub firms who often have more than several thousand partners. Since firms are identified by an identification code, there are no issues in matching the identity of firms. We have approximately 4 million relations in the inter-firm relation data: 2 million for supplier relations, 1.9 million for customer relations, and 162 thousand for major shareholder relations, in the data for 2006.

We focus on data of 2011 and 2012 in order to examine changes before and after the Great East Japan earthquake, which occurred on March 11, 2011. We note that the end month for yearly sales differs among firms in the data due to the different survey timings and fiscal year-ends; some firms' fiscal years ended in March and others' in December. When we considered inter-firm transaction networks before the earthquake, we kept data reported by firms whose latest fiscal year-end is between January 201o and February 2011, and dropped other data from the data for 2011. Table 2 shows the summary of the networks before the earthquake. Here, "indegree" means the number of suppliers, "outdegree" the number of customers, and "degree" the number of transaction partners, i.e., suppliers and customers.

Table 2. Summary of Network before the Earthquake

variable	N	mean	sd	p25	p50	p75
indegree	1007935	3.575092	18.02819	0	2	4
outdegree	1007935	3.836406	24.60163	0	1	4
degree	1007935	7.411498	35.7888	1	3	8

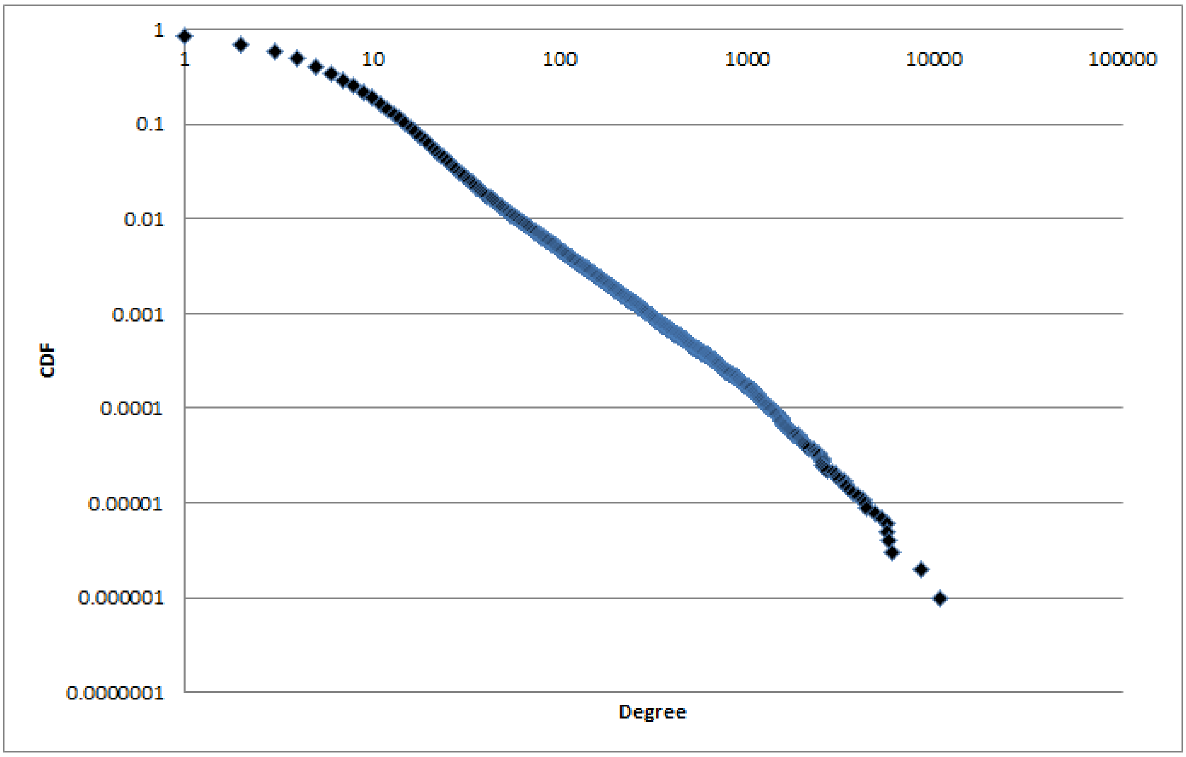

Figure 1. Distribution of Degree

Using the network before the earthquake, we define the firms that have relations with firms in affected areas. First, we define affected areas as those flooded by the tsunami, which occurred as an immediate consequence of the earthquake. The data on the flooded areas are provided by the Center for Spatial Information Science, The University of Tokyo (CSIS). CSIS also provides Geographic Information System (GIS), which enables us to convert a firm's address to a set of longitudes and latitudes. Figure 2 maps the firms in affected areas and other firms in the Tohoku area of Japan. Under this definition, the number of firms in the affected areas is 5344 and the number of exiting firms in the affected areas is 280.

We select firms whose latest fiscal year-end is between January 201o and February 2011 and compare the exit rate and sales growth after the earthquake between firms in the affected areas and those outside the affected areas. We find a higher exit rate and a lower sales growth rate for firms in affected areas after the earthquake. Here, a firm is defined as having exited if the firm could not be contacted by TSR after the earthquake. The exit rate of firms in affected areas is 4.1% while that of firms in other areas is 3.2%. Table 3 shows the summary of log of sales growth after the earthquake, where *deg0* equals 1 if a firm is in an affected area and 0 otherwise. Both the average and median of log of sales growth rates are lower for firms in affected areas. The higher exit rate and lower sales growth rate are statistically significant, as seen in Tables 4 and 5.

We note that the variance of log of sales growth rate is larger for firms in affected areas. Some firms in affected areas even exhibit considerable growth, possibly as a result of emergency and reconstruction assistance. Therefore, we focus on the hardest-hit firms, i.e., those that exited, in order to isolate the spillover effects of a negative impact. A firm's direct or indirect relations with firms in affected areas are denoted by the following variables.

deg1_s: 1 if firm has suppliers in affected areas and 0 otherwise

deg1_c: 1 if firm has customers in affected areas and 0 otherwise

deg1_s_exit: 1 if firm has exiting suppliers in affected areas and 0 otherwise

deg1_c_exit: 1 if firm has exiting customers in affected areas and 0 otherwise

deg(n)_s: 1 if firm has suppliers of *deg(n-1)_s* and is not categorized in lower degree (*deg(k)_s* with *k* less than *n*) and 0 otherwise

deg(n)_c: 1 if firm has customers of *deg(n-1)_c* and is not categorized in lower degree (*deg(k)_c* with *k* less than *n*) and 0 otherwise

deg(n)_s_exit: 1 if firm has suppliers of *deg(n-1)_s_exit* and is not categorized in lower degree (*deg(k)_s_exit* with *k* less than *n*) and 0 otherwise

deg(n)_c_exit: 1 if firm has customers of *deg(n-1)_c_exit* and is not categorized in lower degree (*deg(k)_c_exit* with *k* less than *n*) and 0 otherwise

Higher degrees of firms are defined recursively, where *n* is more than 1. The numbers of *deg1* firms for each relation (s, *c*, *e_exit* or *c_exit*) are 9837, 8686, 347, and 476, respectively. Those of *deg2* firms are 226736, 211478, 37516, and 36641, respectively. Those of *deg3* firms are 445479, 335287, 305291, and 265468, respectively. These figures evidently show the large interconnections of the firms to affected firms through the supply chain.

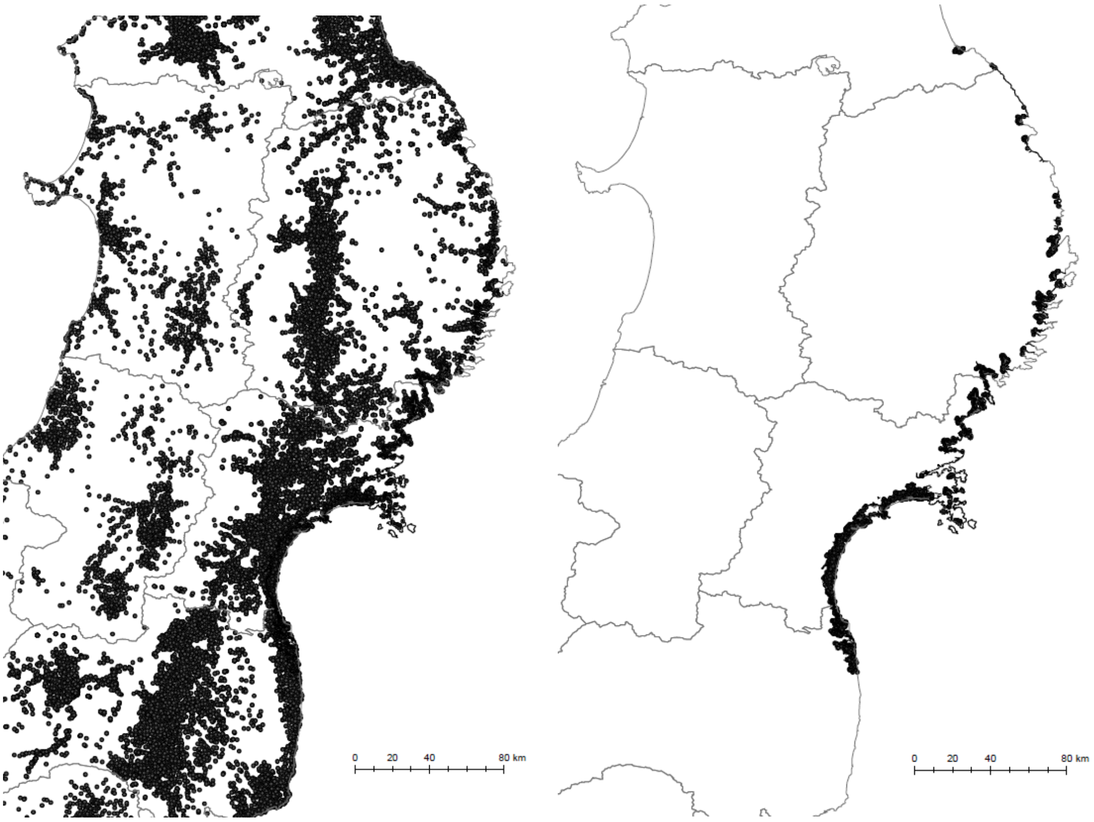

Figure 2. Geographical Distributions of Firms in Tohoku Areas

(All firms (left) and firms in affected area (right))

Table 3. Summary of Log of Sales Growth after the Earthquake

deg0	N	mean	sd	p25	p50	p75
0	814315	-.0138713	.3299251	-.0896122	0	.0645385
1	3531	-.063052	.4852309	-.1890631	-.0266682	.0686773
Total	817846	-.0140836	.3307676	-.0900129	0	.0645385

Table 4. Probit Regression on Firm Exit after the Earthquake

d_exit	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
deg0	.1356059	.0383468	3.54	0.000	.0604477	.2107642
lndegree_before	-.3089498	.0038302	-80.66	0.000	-.3164567	-.3014428
lngrowth_before	-.2160577	.0072392	-29.85	0.000	-.2302463	-.2018692
_cons	-1.385439	.0063804	-217.14	0.000	-1.397944	-1.372933

Table 5. Regression on Firm's Growth after the Earthquake

lngrowth_after	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
deg0	-.0518245	.0055154	-9.40	0.000	-.0626345	-.0410145
lndegree_before	.0151031	.0004222	35.77	0.000	.0142756	.0159307
lngrowth_before	-.0385725	.0010785	-35.77	0.000	-.0406862	-.0364587
_cons	-.045176	.0008498	-53.16	0.000	-.0468416	-.0435105

3. Regression Analysis

3-1. Models

First, we examine how the relations with firms in affected areas affect firm performance. The firms' relations with affected firms are defined in the previous section. Firm's performance is measured by sales growth after the earthquake, i.e., *log(Sales(2011))-log(Sales(2010))* for firms with a fiscal year ending in December. We control the sales growth before the earthquake, i.e., *log(Sales(2010))-log(Sales(2009))*, and "degree," i.e., the number of customers and suppliers for the firm, that are observed before the earthquake. Note that when we compile network variables before the earthquake, we restrict them to firms whose latest fiscal year-end is between January 201o and February 2011. For the sales growth, we use a stricter restriction, by which we keep only firms whose latest fiscal year-end is December 201o in the data for 2011 and December 2011 in the data for 2012. Then, the sample size becomes 113184, about one tenth of that used for the network analysis. We choose December because December has the largest number of firms reporting between March 2010 and February 2011, while few firms report in January and February. Furthermore, we drop firms in four prefectures that were hit by the earthquake, tsunami, and the nuclear plant failure, i.e., Aomori, Iwate, Miyagi, and Fukushima, in order to factor out the direct damage incurred by firms. We also control for the fixed effects of two-digit level industries and of prefectures. The estimated equation has the following form.

$$lngrowth\_after_i = \alpha * relation_i + \beta * lngrowth\_before_i + \gamma * lndegree_i + \delta * controls_i + \varepsilon_i \quad (1)$$

Next, we examine the change of networks after the earthquake. The firms who have transaction partners in affected areas might construct links with new partners in order to mitigate the shock through the supply chain by substitution. We run a regression of a firm's probability of adding new partners in the data after the earthquake, on the firm's relation to the affected firms. The relation and control variables are the same as in the previous regression. If the firm is connected to suppliers (either continuing or exiting) in affected areas, <*d_newlink_after*> denotes the probability of connecting to new suppliers. If the firm is connected to suppliers (customers) in affected areas, the variable denotes the probability of connecting to new suppliers (customers). The estimated equation is as follows.

$$d\_newlink\_after_i = \alpha' * relation_i + \beta' * lngrowth\_before_i + \gamma' * lndegree_i + \delta' * controls_i + \varepsilon'_i \quad (2)$$

3-2. Results on Sales Growth

Table 6 shows regression results of sales growth after the earthquake. We find that the spillover effect is negative but not significant for firms whose suppliers are in affected areas (*deg1_s*), but is significantly negative for firms whose customers are in affected areas (*deg1_c*). This implies that the spillover effect that reduces sales tends to come from customers.

On the other hand, a significant negative spillover effect from both suppliers (*deg1_s_exit*) and customers (*deg1_c_exit*) is found from exiting firms that are likely to have suffered major damages. Moreover, the spillover effect from exiting companies is larger from suppliers than from customers, and a significant spillover effect from suppliers is confirmed to not only impact direct transaction partners (*deg1_s_exit*) but also the partners' partners (*deg2_s_exit*) and subsequently down the supply chain in the third degree (*deg3_s_exit*).

For a robustness check, we run the same regression with differently defined areas of disruption. Since the tsunami affected not only the prefectures in the Tohoku region but also the Pacific coast with the Ibaragi and Chiba prefectures, we add the affected areas in these two prefectures to the affected area under consideration. The estimated coefficient differs for *deg1_c*, for which we lose the significance, but other estimates are largely unchanged.

Table 6. OLS Estimates for the Effects of Relations on Sales Growth

VARIABLES	lngrowth_after	lngrowth_after	lngrowth_after	lngrowth_after	lngrowth_after	lngrowth_after	lngrowth_after	lngrowth_after
deg1_s	-0.0134							
	(-1.054)							
deg1_c		-0.0275***						
		(-2.594)						
deg1_s_exit			-0.201**	-0.204***	-0.210***			
			(-2.560)	(-2.596)	(-2.685)			
deg2_s_exit				-0.0149***	-0.0181***			
				(-3.491)	(-4.049)			
deg3_s_exit					-0.00556***			
					(-2.682)			
deg1_c_exit						-0.0610***	-0.0575***	-0.0417**
						(-2.835)	(-2.683)	(-1.961)
deg2_c_exit							0.0129***	0.0211***
							(2.793)	(4.347)
deg3_c_exit								0.0145***
								(6.089)
lngrowth_before	-0.128***	-0.128***	-0.128***	-0.128***	-0.128***	-0.128***	-0.128***	-0.128***
	(-25.91)	(-25.92)	(-25.91)	(-25.92)	(-25.93)	(-25.91)	(-25.92)	(-25.96)
lndeg_TSR_kes:	0.0221***	0.0224***	0.0221***	0.0227***	0.0238***	0.0221***	0.0215***	0.0187***
	(21.11)	(21.16)	(21.33)	(21.39)	(20.53)	(21.23)	(20.01)	(15.99)
Constant	-0.0283***	-0.0287***	-0.0284***	-0.0291***	-0.0294***	-0.0283***	-0.0276***	-0.0257***
	(-3.686)	(-3.727)	(-3.691)	(-3.784)	(-3.822)	(-3.682)	(-3.584)	(-3.339)
Observations	88,246	88,246	88,246	88,246	88,246	88,246	88,246	88,246
R-squared	0.037	0.037	0.037	0.038	0.038	0.037	0.037	0.038

3-3. Results on New Links

How did firms outside the affected areas cope with the spillover effects from tsunami-hit firms? We focus on the changes in transaction partners. Table 7 shows the marginal effects of probit regression on the dummy variable of building new transaction partners (*d_link_s(c)_new*). First, when a firm outside the affected areas had suppliers (customers) in the affected areas, we find a significant increase in the probability of the firm to form transaction links with new suppliers (customers). The estimated increase in the probability of forming a new link is higher for firms who had customers in the affected area than for those who had suppliers in the affected area. In contrast, when a firm outside the affected areas had transactions with exiting firms in affected areas, we find no significant change in the probability of building new business partners.

These results indicate the varying degree of substitutability upon a supply-chain disruption. Firms whose customers are hit by mild shocks exhibit the largest flexibility in finding new outlets. Firms whose suppliers are hit by mild shocks seem to have less flexibility in finding a substitute partner. It appears that the firms who transacted with exiting firms were unable to establish new transaction partners quickly This is consistent with the lower growth in their sales, as estimated in the previous section. However, we must note that the insignificant estimate in the probability regression here may be caused by the small sample size of these firms. It is important to gauge the degree of substitutability empirically, since smaller substitutability implies that the supply chain disruption can have a substantial macro-level impact. Present estimates suggest that the mild shocks on suppliers and the severe shocks on both suppliers and customers exhibit smaller substitutability than the mild shocks on customers.

Table 7. Estimated Effects of Relations on Constructing New Links

VARIABLES	d_link_s_new	d_link_c_new	d_link_s_new	d_link_s_new	d_link_s_new	d_link_c_new	d_link_c_new	d_link_c_new
deg1_s	0.051**							
	(2.286)							
deg1_c		0.120***						
		(4.623)						
deg1_s_exit			0.0074	0.0124	0.030			
			(0.0765)	(0.128)	-0.292			
deg2_s_exit				0.044***	0.057***			
				(5.719)	(7.027)			
deg3_s_exit					0.018***			
					(5.670)			
deg1_c_exit						0.032	0.042	0.060
						(0.299)	(0.389)	(0.536)
deg2_c_exit							0.048***	0.060***
							(6.896)	(8.100)
deg3_c_exit								0.017***
								(5.071)
lngrowth_before	0.167***	0.105***	0.167***	0.167***	0.168***	0.105***	0.103***	0.102***
	(10.03)	(6.358)	(10.03)	(10.03)	(10.06)	(6.305)	(6.223)	(6.163)
lndeg_TSR_kessan	0.640***	0.623***	0.642***	0.636***	0.618***	0.626***	0.617***	0.602***
	(85.28)	(83.41)	(85.76)	(83.90)	(75.77)	(84.59)	(81.84)	(74.18)
Constant	-2.089***	-2.028***	-2.090***	-2.080***	-2.077***	-2.031***	-2.019***	-2.008***
	(-33.90)	(-33.71)	(-33.91)	(-33.78)	(-33.67)	(-33.77)	(-33.56)	(-33.34)
Observations	88,550	88,477	88,550	88,550	88,550	88,477	88,477	88,477

4. Conclusion

In this paper, we estimated the effect of an idiosyncratic exogenous shock at a firm on the production of another firm transmitted through the supply chain network. We identified the exogenous micro shocks and their impacts by combining a large-scale dataset on Japanese firm-level production networks with information on firm-level exposure to the Great East Japan earthquake. Sales growth showed negative but not significant effects for firms who had suppliers in affected areas and negative and significant effects for firms with customers in affected area. When we focused on exiting firms in affected areas as firms from where the spillovers originated, sales growth of linked firms outside affected areas exhibited negative and significant effects for both upstream and downstream firms. Furthermore, the significantly negative effects on downstream firms were shown for not only directly linked firms but also indirectly linked firms along the supply chain. These estimates provide evidence for the cascading effects of disruptions along the supply chain. While many episodes of supply chain disruption have been reported on this earthquake, and there has been an estimate of the effect of the supply chain disruption by industry-level input-output analysis, this paper augments the literature by presenting an estimate based on the actual firm-level transaction network data and clear identification strategy.

Our identification strategy is characterized by the use of the affected area as the identifier of the firms where the supply-chain shock originated. Using a broader measure, such as municipalities, may contaminate the shocks' origins because firm situations varied greatly within a municipality. Some industries, such as distribution of food and emergency materials or construction, experienced sales growth in the recovery efforts. Identifying the firms that were adversely impacted by the exogenous shock of a natural disaster is the key contribution of our estimate.

Even though our identification is relatively straightforward, we still need to exercise caution in interpreting the estimates. First, we interpret our estimate as a lower bound of the effect of the supply-chain shock, because we did not control for various margins of adjustments that firms could use in responding to the supply chain shock. For example, firms could use inventories (an internal margin of adjustment) and/or form new supply chain linkages by adding new suppliers/customers either domestically or abroad (an external margin of adjustment). The estimate we obtained is best interpreted as the net effect after firms rationally employed these measures. Second, our estimation may well be mis-specified. The "exit" event may also convey information about the firms who transacted with the exiting firms. However, given the relatively large difference in exit rates in the affected areas relative to the rest of the country, we think that exit was likely to be induced by the unforeseeable exogenous shock. Another source of mis-specification is the existence of multiple plants. Even though we could not control for this variable due to the lack of data, future work should control for the possibility that degree 1 (or higher) firms had plants in the affected area.

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