RIETI Discussion Paper Series 18-E-041

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RIETI Discussion Paper Series 18-E-041
June 2018

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Abstract

This study investigates the indirect effects of shocks by Hurricane Sandy that hit the United States in 2012. Using firm-level data on global supply chains, we examine how sales growth of firms inside and outside the United States changed when their suppliers or clients were damaged by the hurricane. Our results show that the effect of damaged firms on their transaction partners in the United States is negative and statistically significant, while the effect on their partners outside the United States is insignificant. Alternative specifications suggest that internationalized firms' ability to substitute for damaged partners most likely explains the absence of international propagation.

Keywords: Global supply chains, Propagation of shocks, Natural disasters
JEL classification: E23, E32, L14

[1] This study was conducted as part of a project titled "Research on Global Inter-firm Networks and Related Policies," which was undertaken at the Research Institute of Economy, Trade, and Industry (RIETI). Financial support from JSPS KAKENHI Grant Number JP25101003 is gratefully acknowledged. The authors would like to thank Sunghoon Chung, Stephane Hallegatte, Hidehiko Ichimura, Tomohiko Inui, Keiko Ito, Yukiko Saito, Yohei Sugita, Russel Thomson, Zhihong Yu, and seminar participants at the European Trade Studies Group Annual Conference, Japanese International Economics Association, Hitotsubashi University, Osaka University, the University of Sydney, Waseda University, and World Bank for comments and Fu Jiangtao and Yohei Kobashi for data extractions. The opinions expressed and arguments employed in this paper are the sole responsibility of the authors and do not necessarily reflect those of RIETI, Waseda University, the University of Sydney, or any institution with which the authors are affiliated.

1. Introduction

Negative economic shocks may propagate through input–output linkages to both upstream and downstream firms, leading to substantial damage to the entire economy (Acemoglu et al. 2012, Baqaee 2016, Di Giovanni and Levchenko 2010, Caliendo et al. 2014, Bigio and La'O 2016). While the literature mostly relies on input–output tables aggregated at the sector level, recent studies have started to utilize newly available firm-level data with information on supply chain links to investigate this issue (Carvalho, Nirei, and Saito 2014, Lu et al. 2017, Barrot and Sauvagnat 2016). These studies have confirmed that negative shocks by natural disasters affect the production and financial performance of firms that are located outside the disaster region through supply chains.

However, both strands of literature have focused only on domestic shock propagation within a country mostly owing to data limitations. In reality, however, supply chains are becoming increasingly globalized (Baldwin 2016) and negative shocks might propagate internationally (Sarathy 2006). Therefore, it is important to understand the impact of disasters on global supply chains (Altay and Ramirez 2010), but the literature has not examined this issue. One exception is a study by Boehm, Flaaen, and Pandalai-Nayar (2015). The authors examine propagation from parent firms damaged by a disaster to their overseas affiliates. However, propagation between unaffiliated firms is not explored in their study.

To fill the gap, this study utilizes firm-level data for global supply chains to investigate how negative shocks by natural disasters propagate both within and across countries through supply chains. Specifically, we take Hurricane Sandy as a source of negative shocks and examine how sales of firms change if their direct or indirect customers or suppliers are located in areas affected by the hurricane.

Hurricane Sandy hit the east coast of the United States (US) in 2012 and caused an economic loss of 50 billion US dollars, which is the second largest economic loss by a natural disaster after 2010 in the world (Center for Research on the Epidemiology of Disasters 2017). The hurricane also affected international trade and sharply decreased exports from seaports in the New York region for several months (Figure 1), a common observation in the literature on disasters and trade (Gassebner, Keck, and Teh 2010, Felbermayr and Gröschl 2013, Oh and Reuveny 2010).

We analyze the effect of the hurricane on the global economy, using a unique firm-level dataset that covers 110,000 major firms in the world, including 17,656 in the US, and contains detailed information on supply-chain ties among them. We merge the dataset with another firm-level dataset that contains information on networks of capital shareholding and patent co-application to examine how multilayer interfirm networks amplify or dampen propagation of negative shocks.

We find that the patterns of domestic and international propagation of shocks are different. After the disaster, the sales growth of domestic partners of firms directly damaged by the disaster was significantly lower than that of other firms, implying that there is a substantial propagation of disaster shocks. However, no negative impact is observed for directly damaged firms' transaction partners outside the US. This finding suggests that disaster shocks are less likely to propagate beyond national borders. Our additional analysis reveals the mechanism of no international propagation as follows: because non-US firms connected to damaged US firms tend to be highly internationalized and have more access to the international market, they have larger options to substitute their damaged partners when needed. This result is consistent with Barrot and Sauvagnat (2016), who find the importance of input specificity in propagation of disaster shocks. In addition, we find that density of supply chains and the combination of supply-chain and shareholding ties affect propagation.

This study contributes to the literature in the following three aspects. First, although several studies have focused on either supply chains within a country or between parent firms and their overseas affiliates, as mentioned earlier, the present study incorporates most major interfirm transaction relations in the world, including international and arm's-length relations. Our finding that economic shocks propagate within a country but not across countries is quite surprising in the literature and deserves attention. Second, we find there is no international propagation because internationalized firms can easily substitute inputs from damaged firms for those from others in the global supply chains. This finding confirms the role of input specificity in international trade in the recent literature (Rauch 1999). Finally, we investigate the effect of measures of the network structure, such as network density, the share of international links, and the combination of multiple links, rather than focusing on the effect of direct links with damaged firms. The use of these measures enables us to examine the mechanism of propagation across global supply chains.

2. Empirical Strategy

2.1 Conceptual Framework

Natural disasters, such as hurricanes or earthquakes, may disrupt industrial production by damaging machinery and buildings or interrupting the supply of water, gas, and electricity. When directly damaged firms become unable to supply parts and components to their clients, the disaster may indirectly affect firms beyond the disaster region. Propagation in the opposite direction, that is, upstream propagation from customers to suppliers, can also occur owing to lack of demand from damaged customers. Carvalho, Nirei, and Saito (2014), Barrot and Sauvagnat (2016), and Lu et al. (2017) empirically or theoretically observe such propagation effects. Therefore, our first hypothesis is as follows.

Hypothesis 1: The sales growth of customers and suppliers of firms damaged directly by a natural disaster is lower than otherwise as a result of supply chain disruptions.

Furthermore, because supply chains are multi-tiered from final assemblers to the most upstream suppliers, the customers of directly damaged firms may be suppliers of some other firms. If this is the case, the negative shock due to the disaster may propagate to more downstream customers through several steps in the supply chains. Shock propagation beyond direct customers is observed by Carvalho, Nirei, and Saito (2014). However, because at each step, suppliers and customers of directly or indirectly damaged firms can potentially substitute for their damaged partners, the overall effect of damaged firms on suppliers of their direct suppliers (hereafter, "two-step suppliers") and customers of their direct customers ("two-step customers") may be smaller than the effect on their direct suppliers and customers. This conjecture leads to the following hypothesis.

Hypothesis 2: The sales growth of two-step customers and two-step suppliers of firms damaged directly by a natural disaster is lower than otherwise by supply chain disruptions.

Hypothesis 3: The sales growth of two-step customers and two-step suppliers of firms damaged directly by a natural disaster is higher than that of direct customers and suppliers of the damaged firms.

In addition, because we use global data, we can distinguish between effects on customers (suppliers) in the US, that is, downstream (upstream) propagation within the country, and effects on customers (suppliers) outside the US, that is, downstream (upstream) propagation beyond the country. It is not clear which propagation effects should be stronger. On one hand, firms outside the US linked through trade with US firms are more likely to have more developed operations than are domestic firms and a diversity of potential partners from which to choose. Such firms may have more opportunities to substitute for damaged US partners. On the other hand, parts and components supplied by US firms may be more specific to technologies and knowledge in the US so that suppliers outside the US may not be substitutes for US suppliers. The importance of input specificity as a determinant of the propagation of negative shocks is argued by Barrot and Sauvagnat (2016). This leads us to the last hypothesis.

Hypothesis 4: The negative effect of damaged suppliers (customers) in the US on customers (suppliers) in the US may be larger or smaller than the effect on customers (suppliers) outside the US, depending on the substitutability of transaction partners.

2.2 Estimation Equation

To test these hypotheses, we consider the following estimation equation:

$$\Delta \ln Sales_{i(2011-t)} = \beta_0 + \beta_1 Shock_{i2011} + \beta_2 X_{i2011} + \varepsilon_{it} \tag{1}$$

The dependent variable, $\Delta \ln Sales_{i(2011\text{-}t)}$, is the growth rate of sales of firm *i* from 2011 to year *t* where *t* is either 2012 or 2013. We experiment with the two growth rates to examine both short- and long-term effects. Because Hurricane Sandy hit the US in October 2012, immediate propagation within a few months is captured by sales growth from 2011 to 2012, whereas growth from 2011 to 2013 captures longer-run propagation.

Shock is the vector of key independent variables that represent ties with suppliers and customers directly hit by Hurricane Sandy. When we examine downstream propagation, that is, propagation from suppliers to customers, we measure ties with directly damaged suppliers by the log of the number of damaged suppliers plus one. In addition to firm *i*'s direct suppliers hit by the hurricane, *Shock* includes measures of suppliers of firm *i*'s suppliers, or firm *i*'s indirect suppliers in two steps, which were directly hit by the hurricane. In order to distinguish between propagation within the US and beyond the US, we classify *Shock* variables by the location of firm *i*, either in the US or outside the US. Similarly, when we examine upstream propagation, we rely on the number of damaged customers or damaged two-step customers. The vector of the control variables *X* includes firm attributes and network related variables, as described in Subsection II.B.

2.3 Estimation Method

To estimate equation (1), we use ordinary least squares (OLS) regression, following Carvalho, Nirei, and Saito (2014). This simple method is appropriate in the present case because Hurricane Sandy is an exogenous shock and therefore, whether a firm is linked to damaged firms should be exogenously determined, after controlling for the total number of links of the firm in focus. We check the exogeneity of the shock by testing the correlation between the shock and predisaster sales growth, as we show in Subsection III.A.

3. Data

3.1 Data Sources

This study uses three datasets, LiveData of FactSet Revere and Osiris and Orbis of Bureau van Dijk. LiveData includes information on supply chain relations collected from public sources, such as financial reports and websites. LiveData is derived from information disclosed by each firm and its partners as well as news articles. In this way, FactSet Revere maximizes the coverage of the network links. Furthermore, their trained analysts manually verify information collected automatically from the Internet. Although LiveData focused on US firms in earlier periods, it has recently expanded its coverage to other regions, including Europe and Asia. We utilize LiveData for 2011, 1 year before Hurricane Sandy, to identify predisaster global supply chains, which include 110,313 firms and 66,553 supply chain ties. Among the 110,313 firms, 17,656 are located in the US, 3,908 in Japan, 2,499 in the United Kingdom (UK), 1,378 in Germany, and 2,947 in China.

The other two datasets, Osiris and Orbis, include firm-level data from a number of countries. Orbis covers 200 million firms around the world, including nonlisted small and medium enterprises. Osiris, which mostly covers publicly listed firms, is a subset of Orbis. Because Osiris contains detailed and globally comparable financial information, we extract from Osiris each firm's information about sales, the value of total assets, the number of employees, firm age, industry code, and account closing date. Orbis also contains information about shareholding and patent co-application relations between firms. Thus, we can identify global interfirm shareholding and patent co-application networks. Taking advantage of the fact that patents are mostly registered jointly by several co-inventors, we construct a patent co-application network as a proxy for the global interfirm research collaboration network.

In Orbis, the number of shareholding ties in 2011 is 6,179,501, whereas the number of firms with any shareholding tie is 6,964,796. Among them, 1,994,713 are located in the US, 378,671 in Japan, 524,926 in Germany, 361,150 in the UK, and 34,405 in China. Orbis data on patents are based on patents approved by any patent office in the world. Because it takes time for applied patents to be approved, we focus on patent applications before the day Hurricane Sandy hit the US among patents approved from 2005 (the oldest available year in Orbis) to 2014 (the last available year). The total number of such patent co-application ties is 834,706 for 641,862 patents. The number of firms that have any patent application tie with other firms is 63,442, of which 15,167 are located in the US, 6,121 in Japan, and 621 in China.

We merge LiveData, Osiris, and Orbis using the International Securities Identification Number (ISIN). Thus, we have to omit 67,814 firms without ISIN, which are mostly nonlisted firms in LiveData. We also restrict our sample for regressions to firms that are not directly hit by Hurricane Sandy. We exclude 1,709 firms in areas damaged at least moderately, as defined by Federal Emergency Management Agency (2014), to examine propagation from damaged firms only to firms that were not directly damaged by the hurricane. The excluded area is depicted in Figure 2 by yellow border lines. In addition, we exclude firms in the financial and real estate industries, and governments, assuming that those are less likely to be affected by supply chain disruptions caused by natural disasters. Finally, we have to exclude firms without sufficient information. The final number of observations for our benchmark regression is 8,906, among which 1,660 are in the US, 1855 in Japan, 1,559 in China, 541 in the UK, and 397 in France (Table 1).

3.2 Variable Construction

Our key independent variables are the number of each firm's suppliers and customers that were directly damaged by Hurricane Sandy. To create these variables, we first identify the global supply chains in 2011, 1 year before the Hurricane Sandy, using all firms in LiveData, including observations omitted from our estimation sample. Next, we define firms directly damaged by Hurricane Sandy as those in "very highly damaged areas" according to the Federal Emergency Management Agency (2014). In these highly affected regions (areas colored red in Figure 2), more than 10,000 people in each county were exposed to storm surge, many buildings were flooded more than 1 meter in depth, and their exterior walls collapsed (Federal Emergency Management Agency 2014, 2013). It is most likely that the production activities of firms subjected to such conditions were heavily disturbed. We count the number of each firm's suppliers and customers located in these heavily affected counties, as well as its two-step suppliers (suppliers of suppliers) and two-step customers that were in the disaster region.

To control for the size of the production network of each firm, we include the total number of suppliers and customers in the set of independent variables. We also incorporate another measure, PageRank, developed by Page et al. (1999), to represent each firm's centrality in the global supply chains. Although the number of supply chain partners, or the degree, is also a measure of network centrality, it captures only direct links and ignores indirect links. PageRank, originally developed to evaluate the centrality of websites on the Internet, takes into account all links within the global network, not only the number of those directly connected to a website, or a firm in focus.

The dependent variable is sales growth from 2011 to 2012 and from 2011 to 2013. Sales growth is calculated as $\Delta \ln Sales_{i(2011-t)} = (netsales_t / netsales_{2011})^{1/(t-2011)} - 1$. The dependent variable and control variables (sales growth from 2006 to 2011, sales per worker in 2011, the number of workers in 2011, the value of total assets in 2011, industry dummies, country dummies, and firm age) are constructed based on Osiris data. We use industry dummies based on the firms' four-digit industry group code of the Global Industry Classification Standard (GICS). Each firm in Osiris also reports account closing date. Since each firm's financial information is not updated simultaneously because of the difference in the fiscal year-end even within the same countries, we include account closing month dummy and the interaction term with *Shock* variables, for which we set December as a base category.

3.3 Descriptive Statistics

The upper rows of Table 2 show summary statistics for the variables related to supply chains. The mean and median of the number of suppliers is 1.897 and 0, respectively. This is because the coverage of our supply chain data is mostly limited to links between major firms and their transaction partners, as we can infer from the data-collection method of FactSet Revere. On average, the number of domestic suppliers is 0.930, indicating that the number of domestic suppliers and that of foreign suppliers do not differ substantially. This is because firms included in our sample are mostly publicly listed firms that are more likely to operate internationally. The average number of damaged suppliers is 0.090. Looking at the mean of the dummy variable for damaged suppliers, we find 4.7 percent of all firms in the global data are directly connected to suppliers directly damaged by the hurricane. When we disaggregate the dummy for any links with damaged suppliers into a dummy for US firms and non-US firms, 3.2 percent of US firms are directly linked to suppliers in the damaged area. The average, median, and maximum number of links with damaged suppliers is 0.071, 0, and 25, respectively. By contrast, non-US firms have 0.019 links with damaged suppliers on average and the maximum number of such links is seven. These figures indicate that US firms seem to be linked with more suppliers in the damaged area. This is plausible, since the damaged area is within the US.

By contrast, the mean of the number of customers is 2.535. The mean of the number of domestic customers is 0.974. Again, this small ratio of domestic customers is probably because firms in our sample are mostly publicly listed firms. Including indirect links, the firms in the sample have on average 30 two-step customers. Furthermore, regarding links with firms in the damaged area, US firms have 0.066 such links on average, and 11 links at the maximum, while non-US firms have 0.021 links with damaged firms on average and 6 links at the maximum.

The bottom rows of Table 2 indicate summary statistics of network measures and other control variables. The median predisaster sales growth is 7.8 percent, whereas the median number of workers and firm age are 1,162 and 23 years, respectively. These figures confirm that the sample firms are mostly established, large, and growing firms.

Table 3 reports the ratio of each industry. Here, industry is defined by the four-digit code of the GICS, as mentioned in Subsection II.B. As major industries in our sample, we have capital goods, materials, and technology hardware and equipment industries.

4. Results

4.1 Balancing Tests

We first verify the exogeneity of direct damage of the hurricane because our OLS estimations rely on this assumption. For this purpose, we run OLS estimations to test whether a firm's supply chain links to damaged suppliers (customers) predict sales growth before the disaster, including only country and industry dummies as control variables. Tables 4 and 5 show that neither the log of the number of suppliers (customers) plus one nor that of two-step suppliers (customers) has a significant correlation with sales growth before the hurricane. The results indicate that direct and indirect supply-chain links with damaged firms are randomly allocated to firms in our sample and hence, that our key variables of interest, the number of links with damaged firms, are uncorrelated with the error term in equation (1). Therefore, our use of OLS estimations can be justified.

4.2 Benchmark Results

The benchmark results of downstream propagation of disaster shocks are presented in Table 6. In columns (1) and (2), the dependent variable is sales growth of undamaged firms from 2011 to 2012 to examine immediate propagation effects, and sales growth from 2011 to 2013 in columns (3) and (4) to examine longer-term effects.

The negative and significant effects of links with damaged suppliers on US customers in columns (1) and (2) of Table 6 indicate that US customers directly dependent on supplies from the heavily affected areas experienced lower sales growth after the hurricane. According to the size of the coefficient, US firms linked with a supplier damaged by Hurricane Sandy experienced sales growth 12 percentage points lower than those not linked with damaged suppliers. This result is in line with Hypothesis 1. The effect of the number of damaged suppliers on longer-run sales growth of US firms in columns (3) and (4) is also negative and significant, while it is smaller in size and less significant than the immediate effects shown in (1) and (2). This finding suggests that the negative propagation effect through supply chains diminished in a year, probably because of either recovery of or substitution for damaged partners.

Furthermore, in columns (1) and (2) of Table 6, we observe that the coefficients of the links with damaged suppliers for non-US customers are insignificantly positive, indicating no immediate effect on non-US customers. This evidence implies that the negative shock by the hurricane did not propagate beyond the US. Similarly, in columns (3) and (4), there is no significant effect of the number of links with damaged suppliers on the sales growth of non-US customers. Regardless of their national affiliation, customers do not seem to be significantly affected by negative shocks from their damaged suppliers in the long run.

In addition, the coefficients of indirect two-step links with damaged suppliers in columns (2) and (4) of Table 6 show insignificance for both US and non-US customers, both in the short and the longer run. This implies there is no propagation of disaster shocks beyond direct customers, a finding in line with Hypothesis 3 but against Hypothesis 2. Our interpretation of the results is that the negative shocks are absorbed quickly in supply chains through substitution. Barrot and Sauvagnat (2016) also find no downstream propagation beyond direct customers based on the US firm-level panel analysis, while Carvalho, Nirei, and Saito (2014) observe downstream propagation beyond direct customers after the Great East Japan Earthquake.

Table 7, the benchmark results for the effect on sales growth of suppliers of damaged firms, shows that upstream propagation from damaged customers to their suppliers is similar to downstream propagation examined in Table 6. Columns (1) and (2) of Table 7 show negative and significant effects of links with damaged customers on short-run sales growth of US suppliers, which is consistent with Hypothesis 1. Columns (3) and (4) of Table 7 indicate either a smaller effect or no significant effect in the longer run. The magnitude of the negative significant effect is large in the short run: an 11-percentage point decline for the increase in the number of links with damaged suppliers from zero to one and a 6.4-percentage point decline when the number of links with damaged suppliers increases from one to two. This finding suggests that domestic suppliers of affected companies suffer from demand shocks immediately after the earthquake, but they recover in the following year by either the recovery or replacement of their customers.

By contrast, we do not find any significant effect of links with damaged customers on non-US suppliers, as in the case of the effect of links with damaged suppliers. As this finding—no international propagation of economic shocks through global supply chains—is surprising, we examine the mechanism of this further in Section III. E.

Lastly, two-step links with damaged customers have an insignificant effect on US suppliers in the short run but a significant negative effect in the long run. However, this negative impact is quite small in size, as it implies that a firm's sales growth declines by 1 percentage point when one of its customers' customers is directly damaged by the hurricane. For non-US suppliers, we find a substantial positive effect from two-step customers in the long run. An increase from zero to one indirect link with a damaged two-step customer increases sales growth by 10 percentage points within a few months.

4.3 Robustness Check

Dummies Instead of the Number of Links

In order to incorporate the possibility that the negative effect of the number of damaged suppliers might not monotonically increase, we repeat our estimation using a dummy variable, which takes a value of one if the number of damaged suppliers is one or more and zero otherwise. This is the case when the lack of only one part or a component leads to a complete halt of production lines, particularly if input substitution is quite difficult. We conduct this alternative estimation using dummy variables only for the downstream propagation, because propagation of negative shocks to upstream firms is caused by reductions in demand. In other words, a loss of a single customer should not lead to a complete halt of production activities and should be conceptually different in size from the loss of two or more customers.

Table 8 presents the result. Columns (1) and (2) suggest that if a firm has links with any damaged supplier, the sales growth of US firms in the short run is 13.4 percentage points lower at the 1 percent significance level, while no significant impact is observed for non-US firms. This is consistent with the baseline results and the magnitude of the effects is similar. The results in columns (3) and (4) indicate that the sales growth from 2011 to 2013 is not significantly lower for US and non-US customers of damaged firms, which is consistent with the baseline results.

By contrast, the coefficient of the dummy for any two-step link with damaged suppliers for US firms is negative and statistically and economically significant in the short and long runs, implying that negative shocks may propagate beyond direct customers within the US. However, we still find no propagation beyond the US. In summary, Table 8 suggests that our main findings are stable, that is, there is large propagation within the US but no propagation beyond the US, although we do not obtain a robust result for propagation to two-step customers.

Using Lost Links

Another possible source of noise is the diverse levels of damage experienced by firms in the damaged counties. To identify links with heavily damaged firms, we focus on links with damaged firms that were lost in the next year after the hurricane in our dataset, assuming that firms dropped these links because their partners were heavily damaged and could not recover soon. Then, we conduct OLS estimations using the number of lost links with damaged firms and report the results in Table 9. We find negative effects for both downstream and upstream propagation to the US firms. However, we still do not observe any significant effect of damaged firms on firms outside the US, confirming negligible propagation of shocks internationally.

Placebo Tests

Although we confirm the exogeneity of *Shock* by testing the predisaster balance in Tables 4 and 5, we further test whether the negative effect for US firms linked to the damaged firms is driven by any particular characteristics of the damaged firms. We estimate effects of links with (1) US firms outside the damaged area with similar characteristics to the damaged firms, and (2) firms located in neighboring states of the disaster-states, rather than links with directly damaged firms as in the baseline estimations, as placebo tests.

We use propensity score matching to identify US firms with similar characteristics to the affected ones. Specifically, we conduct one-to-one matching based on a logit model with replacement. We use industry dummies, number of employees, and amount of total assets as covariates in the procedure.

Using the matched firms outside the damaged area, we create placebo *Shock* variables and run OLS models as in the baseline estimations. The results are reported in Table 10. No results show negatively significant effects, indicating that our results are not driven by the features of firms in the damaged area.

In addition, we estimate placebo effects by replacing damaged firms with firms in seven neighboring states of the damaged states, including Vermont, New Hampshire, Maryland, District of Colombia, Ohio, Virginia, and West Virginia. As reported in Table 11, we observe no negative significant effect. Our placebo tests imply that the results were not driven by location-specific factors of the damaged firms.

4.4 Heterogeneous Effects

Next, we examine heterogeneous effects to explore whether there are certain conditions under which the propagation of negative shocks is alleviated or amplified. The factors we examine are motivated by the differences between US firms linked to the damaged firms and non-US ones inferred from descriptive accounts, visualization of networks, and existing studies on supply chain networks.

Geographic Distance

Next, we examine whether long geographic distance from damaged US firms alleviates propagation of shocks to non-US firms by estimating the following nonlinear estimation following Keller (2002):

$$\Delta \ln Sales_{i(2011-t)} = \alpha + \beta_{US} Shock_{i,US,2011} + \beta_{nonUS} e^{-\delta distance} Shock_{i,nonUS,2011} + \theta X_{i2011} + \varepsilon_{it} , \qquad (2)$$

where *distance* is the distance from New York in kilometers. Distance is calculated using longitude and latitude. We use the location for capital of the country if a more detailed address is not available. Furthermore, when the country a firm locates is unknown, we give the average distance of our sample for such observations and include a dummy variable coded one if neither address nor country information of the firms is available.

As shown in Table 12, δ for non-US firms appears statistically insignificant in the short- and long-run estimations. This result implies that national borders differentiate the level of propagation rather than the distance.

Network Density

Second, we incorporate in the model an interaction term between the number of links with damaged suppliers (customers) and network density. Doing so addresses the hypothesis that dense networks amplify the level of propagation by the circulation of shocks through various routes within the network of firms linked to the focal firm.

In order to measure the density, we utilize the local clustering coefficient, defined as the ratio of existing links to the maximum possible number of links between all pairs of nodes in the ego network. A large clustering coefficient implies that the node's partners are also highly linked, creating a high-density cluster of nodes in a network. This measure is not defined for nodes without any link or nodes that have only one link. For those cases, we replace the local clustering coefficient with zero by including no link dummy and one link dummy coded one if there is no link or only one link, respectively, so that we do not lose those observations from our sample.

Table 13 shows the estimation results of the effect of dense ego networks, using the interaction term between local clustering coefficient and *Shock* variables. The negative significant effect of the interaction term between the number of links with damaged suppliers for US firms and local clustering coefficients in column (1) of Table 13 suggests that dense networks amplify the downstream propagation within the US. This finding implies that a negative effect of directly or indirectly damaged suppliers or customers tends to propagate through various paths in the sub-network and thereby is intensified. However, beyond the US, we observe a significant positive effect, as shown in columns (1) and (3) of Table 13. Durlauf and Fafchamps (2005) and Centola (2010) find positive effects of density of ego networks on the normal performance of firms and individuals. Thus, we interpret the positive effect of dense networks for non-US firms as a reflection of normal operations outside the US.

In addition, the results for upstream propagation are shown in Table 13. Column (2) suggests that firms that have denser sub-networks suffer more from supply chain disruptions. Taken together, the results indicate that it is most likely that dense networks amplify the level of propagation once negative shocks propagate.

Multilayer Networks

Third, we test whether the uncovered negative effect is alleviated or amplified by other types of networks. Our analysis distinguishes the number of supply chain links with damaged suppliers (customers) that include a shareholding or research collaboration link. We can estimate the effect of multilayer networks only for US firms, because only a few non-US firms have other than supply chain links with the damaged firms. As Todo and Kashiwagi (2017) observe, unlike production networks, interfirm research collaboration and shareholding networks tend to be clustered domestically.

When suppliers are major shareholders of their customers or vice versa, damaged suppliers might be expected to preferentially provide limited supplies to partners within their group after disasters. Similarly, when demand is reduced by operational disruptions, producers would be expected to purchase inputs preferentially from their shareholding partners. Thus, the negative effect of damaged suppliers (customers) on their affiliated customers (suppliers) through shareholding ties may be smaller than on unaffiliated customers (suppliers). By contrast, when suppliers and customers are engaged in research collaboration, parts and components transacted between them are likely to be specific to the firm pairs. Therefore, substituting for parts and components developed from research collaboration between suppliers and customers or selling them to other firms may be problematic. Thus, the negative effect of damaged suppliers (customers) on their customers (suppliers) that engage in research collaboration with the damaged suppliers (customers) may be larger than on other customers (suppliers) without research collaboration.

The results reported in Table 14 indicate that shareholding links are likely to alleviate negative effects of damaged customers. This result corresponds to the prediction that customers with reduced operations prioritize their affiliated partner for input procurement. Since disaster-damaged firms might only reduce their operations instead of stopping completely, the priority of transaction can differentiate the level of disaster shock propagation.

By contrast, research collaboration links tend to amplify the negative propagation effects. This finding corresponds with the expectation that research collaboration between suppliers and customers is conducted to develop parts and components specific to customers' products and thus, it may not be possible to substitute the clients. This result is consistent with the finding of Barrot and Sauvagnat (2016), which demonstrates that a failure of one specific goods supplier can significantly affect its clients.

International Links

Lastly, we examine how the share of international links affects shock propagation by adding the interaction term between the *Shock* variable for US firms and the share of links with non-US suppliers (customers). Previous research suggests that countries directly hit by disasters smooth negative output shocks owing to natural disasters by international trade. The degree to which this can be achieved depends on the countries' access to international markets (Yang 2008, Felbermayr and Gröschl 2013). Extending this idea, we hypothesize that a higher share of international links can alleviate shock propagation, because internationalized firms have more global opportunities to find alternative transaction partners. In our sample, the average share of international links for US firms linked with damaged suppliers (customers) is 19 percent (26 percent), while the average share of international links for non-US firms linked to damaged suppliers (customers) is 78 percent (69 percent This result suggests that non-US firms linked to firms in the damaged area are highly internationalized[1]. To examine the effect of international links, we create an interaction term between *Shock* and density for US firms, which displays more variation in the level of internationalization.

Tables 15 and 16 report the estimation results. Columns (1) and (3) of Table 15 show positive significant effects of the share of links with foreign suppliers, which is shown as the coefficient of the interaction term with the *Shock* variable, implying that the globalization of firms alleviates propagation of negative shocks. This is probably because of predisaster knowledge of and access to multiple markets, which enable globalized firms to find alternative partners. By contrast, we do not observe a significant effect of international links for upstream propagation (Table 16). This may be the result of a mixture of positive effects of more access to international markets and negative effects of more exposure to amplified shocks in dense network cliques by linking to diverse network cliques. In order to distinguish the effects of international links from the effects of dense network cliques, we add a network measure called Burt's constraint[2], which is a reverse diversity measure on the networks, and the interaction terms with *Shock* variables.

In columns (2) and (4) in Tables 15 and 16, the coefficient of the interaction term between the number of links with damaged suppliers and the share of international links shows a substantial positive significant effect. Similarly, the positive coefficient of the interaction term between the number of links with damaged customers and the share of international links is economically and statistically significant. These results imply that international links alleviate the propagation of negative shocks.

4.5 Discussions and Mechanisms

Why is there no propagation beyond the US?

There are several potential explanations for the difference in the size of disaster-shock propagation within the US and beyond the US: differences in density of supply chain networks, differences in distance from the damaged area, differences in the ability to substitute quickly,

[1] This is the most striking difference we find. Predisaster sales growth, number of employees, and total assets are balanced between US firms with links with damaged suppliers (customers) and their non-US counterparts.
[2] See the appendix for a detailed definition of this indicator. We place zero in the index if no link exists.

and existence of institutions on a national border. Unfortunately, our data do not allow us to examine directly how firms substitute their partners. However, the results imply that the ability to substitute quickly is most likely to explain the lack of shock propagation beyond the US.

Since we find no evidence of negative effects of distance on the level of negative shock propagation, we conclude that not the geographical distance but the national border is the determinant of the level of propagation. Furthermore, although we find that dense network amplifies propagation, differences in density might not be the main reason for the lack of shock propagation beyond the US, because we observe no such amplification effects on non-US customers. By contrast, the explanation for the difference in the level of the internationalization of firms is supported by descriptive accounts and estimation results. Between US-firms linked with damaged firms and non-US counterparts, the share of international links tends to be much larger for non-US firms, as observed in Section III.D. Moreover, a large decrease in exports at US ports was reported after Hurricane Sandy[3]. Nevertheless, looking at sales growth of non-US firms, we do not find any negative impact from damaged suppliers and customers, and the results are robust to several alternative specifications. We conclude that the high level of internationalization of non-US firms in the sample enables them to substitute undamaged firms for the damaged suppliers and customers quickly and thus, non-US firms are not affected much by the supply chain disruptions.

External Validity

The difference in the average internationalization level between firms in the same country as the damaged firms and foreign firms linked to the damaged firms is not the characteristics of this particular US example, but is a common tendency. Thus, we expect our findings—that the propagation of disaster shocks beyond the national border is smaller than the propagation within the national border—to apply to other disaster events. In addition, our study is applicable to other negative shocks, such as bankruptcy or accidents, which force firms to terminate transaction relationships with their partners.

5. Conclusions

In this study, we take Hurricane Sandy that struck the east coast of the US in 2012 as a

[3] The value of US exports of "parts and components" is $262,260,048,007 in 2010, which is greater than that of Japanese exports of parts and components (Research Institute of Economy 2016). Thus, the US also exports parts and components to a certain degree.

source of negative shocks and examine its indirect effects on the global economy through supply chains. Specifically, using firm-level data on global supply chains, we analyze how sales growth of firms in and outside the US changed when their direct and indirect suppliers (customers) were damaged by the hurricane.

Our results show that direct links with damaged suppliers or customers decreased the sales growth of firms within the US. However, we do not observe any negative effects on non-US firms, and conclude that negative shocks due to natural disasters are less likely to propagate outside the disaster-hit country. The difference probably comes from the difference in the level of internationalization of firms linked to firms in the damaged area and the consequent possibility of transaction partner substitution.

We further find that the negative effect is heterogeneous in size across firms depending on the characteristics of their networks. For example, the negative effect is smaller when a supply chain link is associated with a shareholding link, whereas it is larger when a supply chain link is associated with a research collaboration link. In addition, the negative effect on a firm's sales growth is larger when the network structure of their suppliers' sub-network is denser. Taken together, our findings imply that diversity and flexibility of links are important for the resilience of global supply chains.

Although our study is unique in that we investigate the difference between propagation within a country and beyond, which has not been studied owing to the lack of global supply chain data, there are some limitations. First, our data tends to cover relatively large firms and the major relationships. This limitation might affect the lack of robust results for propagation of shocks beyond the direct partners. Second, because the coverage of Asian supply chains is not high, this might also make us underestimate the level of propagation beyond the direct partners. Third, because our data is not plant-level data, our data can misspecify the damaged firms. However, since we find the propagation of disaster shocks within the US, we believe these issues do not affect our estimation of the difference between propagation within a damaged country and beyond. Finally, although we find the benefits of internationalization and network diversification in times of supply chain disruptions, we do not conduct any cost-benefit analysis. Thus, the investigation of the best balance between the diversification and the dense relationships is remained for future study.

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Appendix

Burt (1992, 2004) argues that nodes that link different groups in a network (or, in Burt's terminology, nodes that bridge "structural holes") have advantageous access to information and diverse opportunities. The reverse of high access to diverse cliques of otherwise disconnected nodes is quantified by Burt's constraint, which is defined as

$$\sum_j c_{ij} = \sum_j (p_{ij} + \sum_q p_{iq} p_{qj})^2, \; i \neq q \neq j$$

where p_{ij} is 1/(the number of links of node i), assuming that all links have the same weight. This constraint measure is larger when a node is linked with nodes that are linked with one another and the constraint is low for nodes linked with a variety of nodes that are not linked to each other. Although both Burt's constraint and local clustering are high when the density of links around the node in focus is higher, the difference between the two measures emerges in the case in which a firm has many partners that are connected to another dominant firm. In this case, such network composition can be characterized by low clustering (because such a structure can be achieved by a relatively small number of interconnecting links relative to the number of all possible links between the partners) but high constraint (because one firm dominates the whole network of the firm). Burt (2004) argues that when the ego network, or the network of a particular node, is highly clustered, knowledge of the node and its neighbors is largely overlapped so that they cannot learn much from each other. This is related to the argument of Granovetter (1973) about the "strength of weak ties," whereby weak ties with outsiders are more helpful to obtain information.

Figure 1: Drop in Exports at the Damaged Area of the Port in 2012

Data Source: United States Census Bureau (2017)

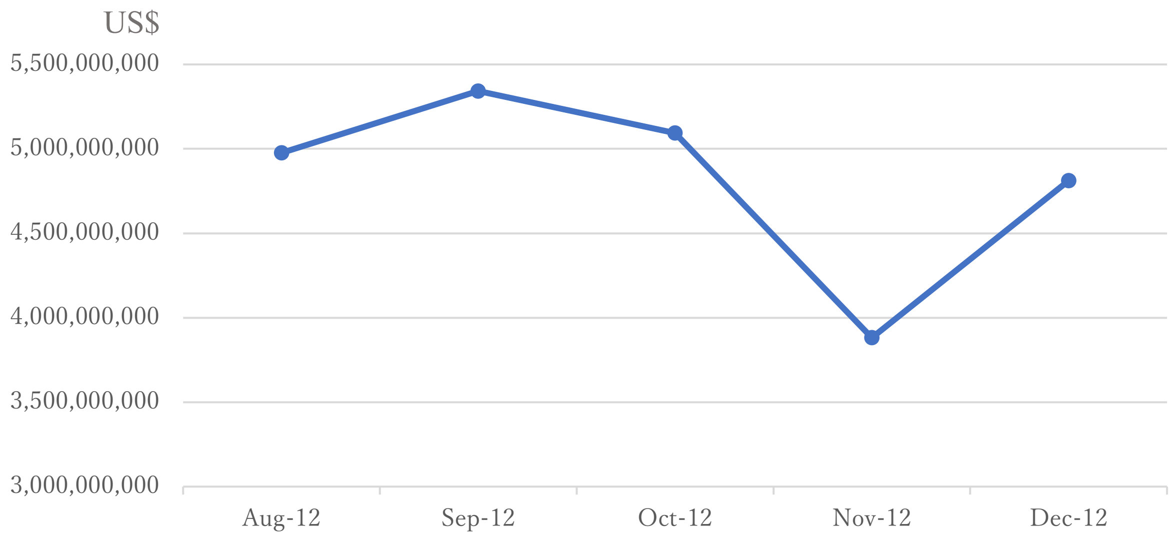
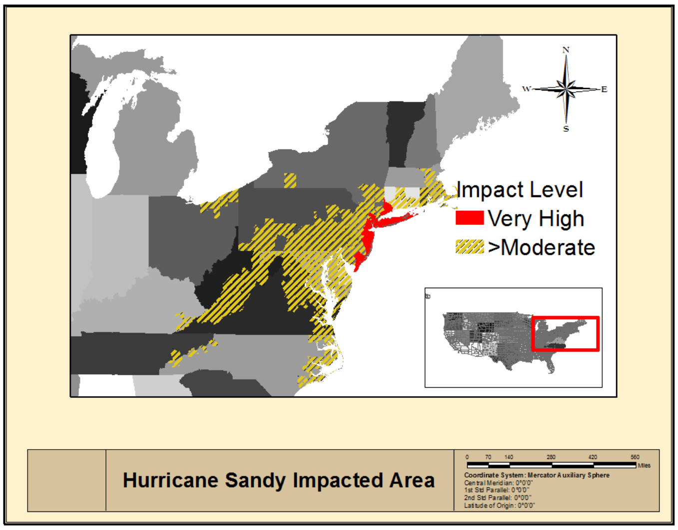


Figure 2: Area Damaged by Hurricane Sandy



Data Source: FEMA Hurricane Sandy Impact Analysis FINAL from Federal Emergency Management Agency (2014).
Notes: This map is drawn by the author using ArcGIS Desktop. Red-colored counties are areas coded as very high in the original data and our defined damaged area, while the yellow-bordered area indicates the locations of firms dropped from the sample.

Table 1: Number of firms by country of location (top 5 countries in shares)

Country	number of firms	percent in total
Japan	1,855	20.83
United States	1,660	18.64
China	1,559	17.51
United Kingdom	541	6.07
France	397	4.46

Table 2: Summary statistics

Variable	Mean	S.D.	Min.	Median	Max
Links with suppliers in 2011					
# of suppliers	1.897	8.068	0	0	233
-- in logs	0.432	0.825	0	0	5.455
# of domestic suppliers	0.930	5.255	0	0	189
-- in logs	0.240	0.614	0	0	5.247
# of suppliers in 2 steps	22.921	91.05	0	0	1341
-- in logs	0.783	1.631	0	0	7.202
Links with damaged suppliers in 2011					
# of links with damaged suppliers	0.090	0.631	0	0	25
Dummy	0.047	0.212	0	0	1
# of links with damaged suppliers for US firms	0.071	0.604	0	0	25
-- in logs	0.033	0.198	0	0	3.258
Dummy	0.032	0.177	0	0	1
# of links with damaged suppliers for non-US firms	0.019	0.188	0	0	7
-- in logs	0.012	0.100	0	0	2.079
Dummy	0.014	0.119	0	0	1
# of 2-step links with damaged suppliers for US firms	0.791	4.458	0	0	78
-- in logs	0.150	0.584	0	0	4.369
Dummy	0.076	0.265	0	0	1
# of 2-step links with damaged suppliers for non-US firms	0.353	2.523	0	0	71
-- in logs	0.083	0.410	0	0	4.277
Dummy	0.052	0.222	0	0	1
Links with customers in 2011					
# of customers	2.535	7.822	0	0	196
-- in logs	0.507	0.953	0	0	5.283
# of domestic customers	0.974	3.715	0	0	108
-- in logs	0.277	0.659	0	0	4.691
# of customers in 2 steps	30.153	114.986	0	0	2297
-- in logs	0.919	1.780	0	0	7.740
Links with damaged customers in 2011					
# of links with damaged customers for US firms	0.066	0.432	0	0	11
-- in logs	0.034	0.192	0	0	2.485
# of links with damaged customers for non-US firms	0.021	0.195	0	0	6
-- in logs	0.013	0.106	0	0	1.946
# of 2-step links with damaged customers for US firms	0.887	4.261	0	0	88
-- in logs	0.180	0.629	0	0	4.489
# of 2-step links with damaged customers for non-US firms	0.359	2.408	0	0	60
-- in logs	0.090	0.419	0	0	4.111
Other networks measure in 2011					
PageRank	0.000057	0.0001	0.000017	0.000026	0.003018
Firm pre-disaster attributes					
Sales growth from 2006 to 2011	0.122	0.288	-0.925	0.078	10.111
Sales growth from 2011 to 2012	0.192	3.496	-1.000	0.014	180.563
Sales growth from 2011 to 2013	0.056	0.532	-1.000	0.014	19.456
Sales per worker in 2011	688	8268	0	237	496205
-- in logs	5.479	1.152	-6.302	5.466	13.115
# of workers in 2011	5416	30039	1	1162	2200000
-- in logs	6.978	1.853	0	7.058	14.604
Value of total assets in 2011	1837887	7910619	4	341532	270441984
-- in logs	12.695	1.886	1.495	12.741	19.416
Firm age	35.392	31.677	6	23	493

Table 3: Number of firms by industry

Industry Group	Freq.	Percent
Capital Goods	1476	17%
Materials	1049	12%
Technology Hardware & Equipment	831	9%
Software & Services	660	7%
Consumer Durables & Apparel	558	6%
Food, Beverage & Tobacco	476	5%
Retailing	417	5%
Energy	371	4%
Consumer Services	365	4%
Commercial & Professional Services	363	4%
Pharmaceuticals, Biotechnology & Life Sciences	360	4%
Transportation	323	4%
Health Care Equipment & Services	308	3%
Media	281	3%
Semiconductors & Semiconductor Equipment	264	3%
Automobiles & Components	254	3%
Utilities	250	3%
Food & Staples Retailing	132	1%
Telecommunication Services	85	1%
Household & Personal Products	83	1%

Table 4: Balancing tests (1)

	(1)	(2)	(3)	(4)
	Dependent variable: Sales growth from 2006 to 2011			
# of links with damaged suppliers for US firms (log)	-0.011			
	(0.016)			
# of links with damaged suppliers for non-US firms (log)		-0.015		
		(0.030)		
# of 2-step links with damaged suppliers for US firms (log)			-0.009	
			(0.006)	
# of 2-step links with damaged suppliers for non-US firms (log)				0.009
				(0.008)
Observations	8,906	8,906	8,906	8,906
R-squared	0.089	0.089	0.089	0.089

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. Country and industry dummies are included.

Table 5: Balancing tests (2)

	(1)	(2)	(3)	(4)
	Dependent variable: Sales growth from 2006 to 2011			
# of links with damaged customers for US firms (log)	-0.010 (0.017)			
# of links with damaged customers for non-US firms (log)		0.002 (0.028)		
# of 2-step links with damaged customers for US firms (log)			-0.006 (0.006)	
# of 2-step links with damaged customers for non-US firms (log)				-0.0003 (0.0076)
Observations	8,906	8,906	8,906	8,906
R-squared	0.089	0.089	0.089	0.089

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. Country and industry dummies are included.

Table 6: Effects of the number of damaged suppliers

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
# of links with damaged suppliers for US firms (log)	-0.175***	-0.177***	-0.0291***	-0.00746*
	(0.0339)	(0.0229)	(0.00855)	(0.00434)
# of links with damaged suppliers for non-US firms (log)	0.103	0.0475	0.00231	-0.0122
	(0.138)	(0.216)	(0.0251)	(0.0354)
# of 2-step links with damaged suppliers for US firms (log)		0.0139		-0.0227
		(0.0608)		(0.0145)
# of 2-step links with damaged suppliers for non-US firms (log)		0.0655		0.00242
		(0.113)		(0.0204)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.076	0.077

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics, but the results are not reported for the brevity of presentation.

Table 7: Effects of the number of damaged customers

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
# of links with damaged customers for US firms (log)	-0.163***	-0.158**	-0.0322**	-0.00577
	(0.0580)	(0.0724)	(0.0145)	(0.00914)
# of links with damaged customers for non-US firms (log)	0.154	0.0357	0.0202	-0.0171
	(0.150)	(0.133)	(0.0318)	(0.0329)
# of 2-step links with damaged customers for US firms (log)		0.0563		-0.0160**
		(0.0511)		(0.00772)
# of 2-step links with damaged customers for non-US firms (log)		0.150**		0.0237**
		(0.0665)		(0.0113)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.076	0.077

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics, but the results are not reported for the brevity of presentation.

Table 8: Effects of the dummy variable for the link with damaged suppliers

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
Dummy for any link with damaged suppliers for US firms	-0.163***	-0.134***	-0.00997	0.0109***
	(0.0289)	(0.0202)	(0.00799)	(0.00305)
Dummy for any link with damaged suppliers for non-US firms	0.0894	0.0579	0.00494	-0.00311
	(0.120)	(0.156)	(0.0210)	(0.0250)
Dummy for any 2-step link with damaged suppliers for US firms		-0.191***		-0.0716***
		(0.0307)		(0.0214)
Dummy for any 2-step link with damaged suppliers for non-US firms		-0.0227		-0.0206
		(0.0898)		(0.0279)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.076	0.077

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics, but the results are not reported for the brevity of presentation.

Table 9: OLS using alternative shock measures

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
# of lost links with damaged suppliers for US firms (log)	-0.216***		-0.0174	
	(0.0306)		(0.0141)	
# of lost links with damaged suppliers for non-US firms (log)	0.103		0.0370	
	(0.185)		(0.0405)	
# of lost links with damaged customers for US firms (log)		-0.159**		-0.0513**
		(0.0682)		(0.0228)
# of lost links with damaged customers for non-US firms (log)		-0.0244		-0.0201
		(0.250)		(0.0637)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.076	0.076

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics, but the results are not reported for the brevity of presentation.

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Table 10: Placebo test using firms with similar characteristics as treatment group

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
Downstream propagation				
# of links with treatment group for US firms (log)	0.444***		0.0153**	
	(0.0663)		(0.00706)	
# of links with treatment group for non-US firms (log)	0.118		0.0550*	
	(0.257)		(0.0302)	
# of 2-step links with treatment group for US firms (log)	-0.0911		-0.0179	
	(0.0771)		(0.0215)	
# of 2-step links with treatment group for non-US firms (log)	0.0843		-0.00320	
	(0.103)		(0.0211)	
Upstream propagation				
# of links with treatment group for US firms (log)		0.0461		0.0210**
		(0.0580)		(0.0100)
# of links with treatment group for non-US firms (log)		0.0378		0.0250
		(0.117)		(0.0360)
# of 2-step links with treatment group for US firms (log)		-0.00703		-0.0154
		(0.0292)		(0.0113)
# of 2-step links with treatment group for non-US firms (log)		0.169***		0.0296*
		(0.0615)		(0.0170)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.077	0.077

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics, but the results are not reported for the brevity of presentation.

Table 11: Placebo test using firms in neighboring state of damaged states as treatment group

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
Downstream propagation				
# of links with treatment group for US firms (log)	0.0588		0.0411***	
	(0.0372)		(0.00615)	
# of links with treatment group for non-US firms (log)	0.0300		0.0268	
	(0.167)		(0.0901)	
# of 2-step links with treatment group for US firms (log)	-0.134*		-0.0197	
	(0.0759)		(0.0189)	
# of 2-step links with treatment group for non-US firms (log)	0.0883		0.00615	
	(0.131)		(0.0261)	
Upstream propagation				
# of links with treatment group for US firms (log)		0.180		0.0335**
		(0.113)		(0.0142)
# of links with treatment group for non-US firms (log)		0.0575		0.0636
		(0.171)		(0.0455)
# of 2-step links with treatment group for US firms (log)		0.0941		-0.00570
		(0.0566)		(0.00971)
# of 2-step links with treatment group for non-US firms (log)		0.305***		0.0541***
		(0.0786)		(0.0142)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.076	0.077

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics, but the results are not reported for the brevity of presentation.

Table 12: Nonlinear estimation result

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
Downstream propagation				
β for US firms	-0.177***		-0.031***	
	(0.036)		(0.005)	
β for non-US firms	0.055		-0.002	
	(0.285)		(0.011)	
δ for non-US firms	4.13E-5		-1.40E-4	
	(5.34E-4)		(2.46E-4)	
Upstream propagation				
β for US firms		-0.229***		-0.036**
		(0.050)		(0.018)
β for non-US firms		0.794		0.010
		(0.671)		(0.022)
δ for non-US firms		2.64E-4		-9.77E-5
		(1.91E-4)		(9.33E-5)
Observations	8,906	8,906	8,593	8,593
R-squared	0.032	0.032	0.072	0.072

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include country fixed effects. We also control for firm level characteristics and no geo location information dummy, but the results are not reported for the brevity of presentation.

Table 13: Effect of Density

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
Downstream propagation				
# of links with damaged suppliers for US firms	-0.125***		-0.00909	
	(0.0255)		(0.00864)	
# of links with damaged suppliers for non-US firms	-0.0262		-0.0283	
	(0.222)		(0.0344)	
# of links with damaged suppliers for US firms * local clustering coefficient	-0.724**		0.0285	
	(0.278)		(0.0895)	
# of links with damaged suppliers for non-US firms * local clustering coefficient	1.676**		0.381***	
	(0.771)		(0.117)	
Upstream propagation				
# of links with damaged customers for US firms		-0.0846		-0.000808
		(0.0822)		(0.00970)
# of links with damaged customers for non-US firms		0.0594		0.0137
		(0.116)		(0.0254)
# of links with damaged customers for US firms * local clustering coefficient		-1.475***		-0.0909
		(0.203)		(0.0647)
# of links with damaged customers for non- US firms * local clustering coefficient		-0.458		-0.553**
		(1.190)		(0.260)
Local Clustering Coefficient	-0.281	-0.221	-0.109***	-0.0788**
	(0.176)	(0.187)	(0.0318)	(0.0362)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.077	0.078

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics and number of two-step links with damaged suppliers (customers), and include one link dummy and two link dummy, but the results are not reported for the brevity of presentation.

Table 14: Effect of other networks

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
Downstream propagation				
# of links with damaged suppliers for US firms (log)	-0.178***		-0.00766*	
	(0.0235)		(0.00441)	
# of links with damaged suppliers for non-US firms (log)	0.0497		-0.0118	
	(0.215)		(0.0353)	
# of links with damaged suppliers associated with shareholding links for US firms (log)	0.348		0.0496	
	(0.627)		(0.0519)	
Upstream propagation				
# of links with damaged customers (log) for US firms		-0.159**		-0.00130
		(0.0713)		(0.00952)
# of links with damaged customers (log) for non-US firms		0.0367		-0.0172
		(0.133)		(0.0327)
# of links with damaged customers associated with shareholding links for US firms		0.589**		0.116***
		(0.245)		(0.0409)
# of links with damaged customers associated with collaboration links for US firms		-0.513***		-0.426***
		(0.178)		(0.0432)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.077	0.077

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics and number of two-step links with damaged suppliers (customers), but the results are not reported for the brevity of presentation.

Table 15: Effect of international links (downstream propagation)

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
# of links with damaged suppliers for US firms	-0.286***	-0.326***	-0.0298***	-0.0413**
	(0.0594)	(0.0856)	(0.00800)	(0.0160)
# of links with damaged suppliers for non-US firms	0.215	0.148	-0.00875	0.00103
	(0.495)	(0.228)	(0.0972)	(0.0482)
# of links with damaged suppliers for US firms* share of links with foreign suppliers	0.483**	0.495**	0.0951***	0.153***
	(0.232)	(0.190)	(0.0342)	(0.0507)
# of links with damaged suppliers for US firms* Burt's constraint		0.444		0.0369
		(0.346)		(0.0707)
# of links with damaged suppliers for non-US firms * Burt's constraint		-0.620**		-0.0768
		(0.293)		(0.100)
Burt's constraint		-0.111		-0.0358
		(0.174)		(0.0353)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.077	0.078

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics and number of two-step links with damaged suppliers, and include one link dummy (columns (2) and (4)). But the results are not reported for the brevity of presentation.

Table 16: Effect of international links (upstream propagation)

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth from 2011 to 2012		Sales growth from 2011 to 2013	
# of links with damaged customers for US firms	-0.116**	-0.119**	-0.0176**	-0.0368***
	(0.0483)	(0.0543)	(0.00747)	(0.0122)
# of links with damaged customers for non-US firms	0.160	0.105	0.0242	0.0143
	(0.252)	(0.103)	(0.0418)	(0.0259)
# of links with damaged customers for US firms * share of links with foreign suppliers	-0.250*	-0.277	0.0447	0.0860**
	(0.143)	(0.265)	(0.0349)	(0.0372)
# of links with damaged customers for US firms * Burt's constraint		0.123		0.195***
		(0.638)		(0.0707)
# of links with damaged customers for non-US firms * Burt's constraint		-0.612		-0.336
		(0.653)		(0.297)
Burt's constraint		-0.0564		-0.0224
		(0.201)		(0.0342)
Observations	8,906	8,906	8,593	8,593
R-squared	0.035	0.035	0.077	0.078

Notes: Robust standard errors clustered at the country level are in parentheses. * **, and *** signify statistical significance at the 10, 5, and 1% level. All regressions include industry and country fixed effects. We also control for firm-level characteristics and number of two-step links with damaged customers, and include one link dummy (columns (2) and (4)). But the results are not reported for the brevity of presentation.