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International propagation of economic shocks through global supply chains

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Abstract

This study examines whether and how economic shocks by natural disasters propagate through global supply chains to regions not directly hit by disasters. Although such propagation within a country has been studied, this study contributes to the literature by incorporating international propagation. Using firm-level data for more than 100,000 major firms in the world that include information on supply-chain ties among them, we find evidence of intra-national propagation as found in the literature but no international propagation. We further investigate possible mechanisms, finding that internationalized firms' ability to substitute for damaged partners most likely explains the absence of international propagation.

Keywords: Global supply chains, Propagation of shocks, Spillover, Natural disasters

JEL classification: E32, F14, L14, Q54

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1. Introduction

Negative economic shocks have been found to propagate through input-output linkages to both upstream and downstream firms, leading to a substantial effect on the entire economy (Acemoglu et al. 2012; Bigio and La'O 2016; Caliendo et al. 2014; Di Giovanni and Levchenko 2010). Suppliers of a firm directly affected by a negative shock are also indirectly affected because of lack of demand, whereas its customers are affected because of a lack of material, parts, and components. While the literature mostly relies on input-output tables aggregated at the sector level, recent studies have begun utilizing newly available firm-level data with information on supply-chain links to investigate this issue (Barrot and Sauvagnat 2016; Carvalho et al. 2016; Lu et al. 2017). Many of these studies take natural disasters as a source of exogenous economic shocks because their direct effect is exogenous and extensive (Cavallo, Powell, and Becerra 2010), confirming that, through supply chains, economic shocks degrade the performance of firms that are located outside the directly affected region.

However, the literature has mostly focused on propagation of shocks within a country owing to data limitations. In practice, however, supply chains are becoming increasingly globalized (Baldwin 2016), and thus negative economic shocks might propagate internationally. Although international propagation of shocks through financial networks has been analyzed (Elliott, Golub, and Jackson 2014), whether and how much negative shocks propagate through global supply chains across countries have rarely been examined. One exception is a study by Boehm, Flaaen, and Pandalai-Nayar (2015), who examine propagation from parent firms damaged by a disaster affecting their overseas affiliates. However, propagation between unaffiliated firms or the difference between intra-national and international propagation are not explored in their study.

To fill this gap, this study utilizes a unique firm-level dataset that covers 110,000 major firms from around the world, including 17,656 in the United States (US), and contains information on supply-chain ties among them to investigate how negative shocks from natural disasters propagate both within and across countries through supply chains. We take Hurricane Sandy (henceforth, the hurricane) that hit the east coast of the US in October, 2012 as a source of negative shocks. The hurricane is reported to have caused an economic loss of 50 billion US dollars, the second largest economic loss from a natural disaster worldwide since 2010 (Center for Research on the Epidemiology of Disasters 2017). Figure 1 shows that the hurricane also sharply decreased exports from seaports in New York and New Jersey for several months (United States Census Bureau 2017), as is often the case after large natural disasters (Felbermayr and Gröschl 2013; Gassebner, Keck, and Teh 2010; Oh and Reuveny 2010).

More specifically, we estimate how much the sales of firms outside the hurricane's disaster area changed after the hurricane if their direct or indirect customers or suppliers were located in the disaster area, using ordinary least squares (OLS) estimation, which is appropriate because of the

exogenous nature of the hurricane. Our major finding is the stark contrast between intra-national and international propagation. After the hurricane, the sales growth of US suppliers and customers of firms directly damaged by the hurricane was significantly lower than that of other firms. This finding confirms the upstream and downstream propagation within the country at the firm level found in Barrot and Sauvagnat (2016) and Carvalho et al. (2016). However, we do not find any negative impact of damaged firms on their suppliers or customers outside the US, concluding that international propagation of economic shocks is less likely than intra-national propagation.

Furthermore, while suppliers and customers in the US connected directly to damaged firms generally saw a decline in sales growth, the negative effect on those additionally connected to foreign partners and those with a large number of workers was smaller. Combined with the finding of no significant international propagation, these results indicate that firms were less affected by propagation of shocks if they were internationalized, regardless of their location or size. We interpret the results as showing that in the presence of costs to search for transaction partners, internationalized or large firms can use substitutes for their suppliers and customers affected by negative economic shocks and thus mitigate the propagation of shocks more easily because of their lower search costs relative to sales. The importance of search costs in firm transactions is in line with theoretical and empirical findings in terms of selection of markets (Allen 2014) and partner firms (Antras, Fort, and Tintelnot 2017; Bernard, Moxnes, and Saito 2018). Moreover, it is consistent with Barrot and Sauvagnat (2016), who find that input specificity, which makes substitution of partners more difficult, amplifies propagation.

We also examine how the structure of supply chains as a network affects propagation. Links through international trade can be viewed as a network (Rauch 1999), and recent literature finds that the network structure substantially affects how economic shocks propagate through firm networks (Acemoglu, Ozdaglar, and Tahbaz-Salehi 2015; Elliott, Golub, and Jackson 2014). Our analysis reveals that when a firm's partners are densely connected with each other through supply chains, propagation of negative effects is augmented as the shock can circulate in the dense network.

This study contributes in various aspects to the growing literature on propagation of economic shocks through firm networks. First, it is the first work to compare intra-national and international propagation of economic shocks through supply chains. Our result that shocks propagate within a country but are less likely to propagate across countries is a new finding and deserves attention. Second, we find that there is no propagation to internationalized firms, possibly because these firms can easily find substitutes for damaged suppliers and customers. This finding confirms the role of input specificity in international trade (Rauch 1999) and propagation of shocks (Barrot and Sauvagnat 2016) in the recent literature because input specificity implies difficulty obtaining substitutes for partners. Third, we investigate how the network structure, network density in particular, affects propagation, rather than simply focusing on direct links with damaged firms. The use of measures of network structure is new in the empirical literature on propagation of shocks through supply chains,

although a similar issue has been examined in the context of financial networks (Acemoglu, Ozdaglar, and Tahbaz-Salehi 2015; Elliott, Golub, and Jackson 2014).

In addition, we contribute more broadly to the literature on international trade. First, our study is closely related to the abundant literature on extensive margins of trade (Bernard et al. 2009; Eaton, Kortum, and Kramarz 2004). Our results imply that expanding export destinations can lead to resilience of firms to economic shocks. The relationship between export diversification and economic development has been discussed in, for example, Cadot, Carrère, and Strauss-Kahn (2011), whereas the relationship between financial diversification and economic resilience has also been argued (Acemoglu, Ozdaglar, and Tahbaz-Salehi 2015; Allen and Gale 2000; Elliott, Golub, and Jackson 2014; Freixas, Parigi, and Rochet 2000). However, the relationship between export diversification and economic resilience has not been considered much in the trade literature, except in the context of trade collapse during the global financial crisis (Behrens, Corcos, and Mion 2013; Bricongne et al. 2012). Second, our findings suggest that an economic shock influences domestic firms in the same country substantially more than firms located in foreign countries. Thus, we provide firm-level evidence to supplement the literature that finds larger co-movements among gross regional product within a country than co-movements among country-level gross domestic product (GDP) (Clark and Van Wincoop 2001; Martincus and Molinari 2007; Panteladis and Tsiapa 2014; Wynne and Koo 2000).

Finally, our findings suggest a policy implication that diversifying supply-chain partners in terms of both geography and network structure can mitigate propagation of shocks through supply chains and thus lead to economic resilience. Although some studies argue the policy implications of the role of supply chains in recovery from disasters (De Mel, McKenzie, and Woodruff 2012; Todo, Nakajima, and Matous 2015), better supply-chain structure to mitigate propagation of disaster shocks has not been proposed in the literature.

2. Empirical Strategy

2.1. Conceptual Framework

Our conceptual framework is built upon general equilibrium models of production networks developed by and extended by Acemoglu et al. (2012), Barrot and Sauvagnat (2016), and Carvalho et al. (2016). We particularly rely on Barrot and Sauvagnat (2016) and Carvalho et al. (2016) who examine propagation of shocks from natural disasters, generating several theoretical predictions as follows.

First, in the model of Barrot and Sauvagnat (2016), firms monopolistically produce a variety of goods that can be consumed or used as inputs for other products. A firm's production function is characterized by constant elasticity of substitution (CES) among labor and a variety of intermediate inputs and constant returns to scale. Simulation analysis by Barrot and Sauvagnat (2016) shows that

destruction of a firm's production capacity by a disaster negatively affects the output of its direct customers through input-output linkages. Using a similar theoretical model, Carvalho et al. (2016) reach the same conclusion. In their model, when a firm's productivity is negatively affected by a shock, the price of the firm's product becomes higher. As a result, its customers utilize a smaller amount of its product as an intermediate good, producing a smaller amount of their products. Indirect customers of the firm directly damaged by a shock, such as customers of their direct customers, or two-step customers, are also negatively affected, although the effect on indirect customers is smaller than the effect on direct customers. These findings suggest the following testable hypotheses regarding downstream propagation of a shock generated by a natural disaster through supply chains from suppliers to customers.

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

Hypothesis 2: The sales growth of two-step customers of firms directly damaged by a natural disaster is lower than that of two-step customers of undamaged firms, whereas the effect on their two-step customers is smaller than the effect on their direct customers.

Second, Carvalho et al. (2016) further show that a negative productivity shock on a firm decreases the output of upstream suppliers of the firm when labor and intermediates are substitutes. This effect is due to an increase in the demand for labor relative to intermediates because of a negative productivity shock on the intermediate-goods sector. As in the case of downstream propagation, negative shocks propagate further to more upstream suppliers beyond direct suppliers, although the propagation effect diminishes along supply chains. These findings lead to the following hypotheses regarding upstream propagation.

Hypothesis 3: The sales growth of suppliers of firms directly damaged by a natural disaster is lower than that of suppliers of undamaged firms as a result of supply chain disruptions.

Hypothesis 4: The sales growth of two-step suppliers, i.e., suppliers of suppliers, of firms damaged directly by a natural disaster is lower than that of two-step suppliers of undamaged firms, whereas the effect on their two-step suppliers is smaller than the effect on direct suppliers.

These hypotheses have already been supported empirically by Barrot and Sauvagnat (2016) and Carvalho et al. (2016) using data for supply chains within a country. The present study extends their analysis to incorporate global supply chains, focusing on possible differences between intra-national and international propagation. One possible cause of the difference is related to the difficulty finding

substitutes for damaged suppliers and customers. Barrot and Sauvagnat (2016) and Carvalho et al. (2016) find theoretically and empirically that shocks propagate more through supply chains when inputs are more specific and substitution is more difficult. Recently, theoretical and empirical analyses by Allen (2014), Antras, Fort, and Tintelnot (2017), and Bernard, Moxnes, and Saito (2018) incorporate costs of searching for transaction partners and find that the search cost is an important determinant of partners. In our context, their results imply that when a firm's suppliers or customers are affected by a negative shock, the firm can substitute new partners for damaged ones only if the expected benefit from having new partners exceeds the search cost.

Under these circumstances, substitution of suppliers and customers within a country may or may not be more difficult than substitution across countries. On one hand, internationalized firms using a wide variety of inputs, including those from foreign countries, may have greater ability to collect information in the world market than firms with only domestic partners. Therefore, internationalized firms' costs of searching for new partners are lower than non-internationalized firms. In addition, as internationalized firms are likely to be more productive, as argued by the heterogeneous-firm trade model of Melitz (2003) and evidenced by many empirical studies, such as Bernard and Jensen (2004), internationalized firms can obtain larger benefits from continuing production by finding new partners and thus are willing to pay search costs. Therefore, internationalized firms may find it easier to substitute for inputs from firms affected by a shock. If this is the case, international propagation of shocks is smaller in size than intra-national propagation. On the other hand, inputs from a foreign country may be more specific to the exporting country and unavailable domestically. If so, international substitution for the inputs is more difficult than intra-national, and thus shocks propagate more across countries than within a country. These arguments lead us to opposing hypotheses.

Hypothesis 5a: The negative effect of damaged suppliers (customers) in a country on their customers (suppliers) in the same country is larger than the effect on their customers (suppliers) outside the country.

Hypothesis 5b: The negative effect of damaged suppliers (customers) in a country on their customers (suppliers) in the same country is smaller than the effect on their customers (suppliers) outside the country.

Finally, we investigate the role of network density in propagation of shocks. The egocentric network of a particular firm is considered to be dense when partners linked with the firm are also linked with each other. Theoretically, there are two conflicting views of the effect of network density on propagation. On one hand, in a dense network, shocks are circulated and thus may be amplified. In the context of diffusion of behaviors, Centola (2010) empirically finds quicker diffusion in dense networks than sparse ones. On the other hand, in a dense network, individuals and firms are more

likely to trust each other, creating social capital (Coleman 1988). In this situation, firms in dense supply chains may help each other absorb shocks in the wake of a disaster. Such dense supply chains are typically found in the *keiretsu* relationship among Japanese firms where each large final assembler and its direct and indirect suppliers form an exclusive group of firms (Ahmadjian and Lincoln 2001; Aoki 1988). After the Great East Japan earthquake in 2011, the *keiretsu* supply chains are found to have quicker recovery from the disaster (Todo, Nakajima, and Matous 2015).

In practice, the two opposing forces of network density result in mixed results of its effect on propagation both theoretically and empirically. For example, Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) use a theory of interbank networks and find that dense networks are resilient to a sufficiently small financial shock because the shock is absorbed. However, they find that when a shock is sufficiently large, dense networks are not resilient because the shock cannot be absorbed but is instead circulated and amplified. In literature on the effect of networks of research collaboration on knowledge diffusion, several studies, such as Rost (2011) and Gilsing et al. (2008), find an inverted U-shaped relationship between network density and diffusion. Accordingly, our last set of hypotheses is as follows.

Hypothesis 6a: The negative effect of damaged suppliers (customers) on their customers (suppliers) is larger when the customers' (suppliers') ego network is denser.

Hypothesis 6b: The negative effect of damaged suppliers (customers) on their customers (suppliers) is smaller when the customers' (suppliers') ego network is denser.

2.2. Estimation Methodology

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

$$SalesGrowth_{i(2011-t)} = \beta_0 + \beta_1 Shock_{i2011} + \beta_2 X_{i2011} + \varepsilon_{it} \quad (1)$$

The dependent variable, $SalesGrowth_{i(2011-t)}$, 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. Because we examine possible differences between domestic and international propagation, firm i can be either in the US but outside the disaster area or in any other country in the world.

Shock is a 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 using the log of the number

of damaged suppliers of firm i plus one. In addition to firm i 's direct ties, *Shock* includes measures of suppliers of firm i 's suppliers, or firm i 's two-step suppliers, that were directly hit by the hurricane. 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 from customers to suppliers, we use the number of firm i 's damaged customers and damaged two-step customers. The vector of the control variables X includes firm attributes and network related variables, as described in Subsection 3.2.

To estimate equation (1), we use ordinary least squares (OLS) estimations, following Barrot and Sauvagnat (2016) and Carvalho et al. (2016). 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 focal firm. We check the exogeneity of the shock by testing the correlation between the shock and pre-disaster sales growth, as shown in Section 4.1.

3. Data

3.1. Data Sources

This study uses two datasets, LiveData of FactSet Revere and Osiris of Bureau van Dijk. LiveData includes information on supply chain relationships collected from public sources, such as financial reports, websites of firms, and news articles. Because LiveData relies on public information, it includes mostly publicly listed firms. Supply-chain information has become widely available through the Internet. Most importantly, in the US, the Financial Accounting Standards Board requires publicly listed firms to disclose customers who account for at least 10% of total sales, including foreign customers. After automatically collecting information from the Internet and identifying the identification number of each supplier and customer, trained analysts of FactSet Revere manually verify it. Therefore, the quality of supply-chain information in LiveData is sufficiently high. Although LiveData focused on US firms in earlier periods, it has recently expanded its coverage to other regions, mostly Europe and Asia. We utilize LiveData for 2011, one year before Hurricane Sandy, to identify pre-disaster 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, and 2,499 in the United Kingdom (UK). Because the average number of suppliers per firm is approximately one, it should be noted that this dataset includes only major supply-chain ties for major firms worldwide.

The other dataset, Osiris, includes firm-level data for mostly publicly listed firms in a number of countries. Because Osiris contains detailed and globally comparable financial information, we extract from Osiris each firm's information about sales, value of total assets, number of employees, firm age, industry code, and fiscal year end.

We merge LiveData and Osiris using the International Securities Identification Number (ISIN). Thus, we have to omit 67,814 firms without ISINs in LiveData, which are mostly non-listed firms. We also restrict our sample for regressions to firms that were not directly hit by Hurricane Sandy to examine propagation from damaged firms only to firms that were not directly damaged by the hurricane. Therefore, we exclude 1,709 firms in areas damaged at least moderately, as defined by the Federal Emergency Management Agency (FEMA) (Federal Emergency Management Agency (2014)). The excluded area is outlined in Figure 2 by a yellow border. 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 exclude firms without sufficient information. Accordingly, the number of observations for our benchmark regression is 8,906, among which 1,660 are in the US, 1,855 in Japan, 1,559 in China, and 541 in the UK, as shown in Table 1. The same table presents the number of publicly listed firms in 2011 in each of the top five countries in our sample in column (4) and the ratio of firms in our sample (for the US, we add the number of firms in the disaster areas that are dropped from the sample) to publicly listed firms in column (5), showing that the coverage for most countries is reasonably high.

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 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 FEMA (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 one meter in depth, and their exterior walls collapsed (FEMA(2013, 2014)). 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 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 log of the number of suppliers, two-step suppliers, customers, two-step customers, and those in the US in the set of independent variables. We also control for the internationalization of the focal firm and existence of other inter-firm networks, using the logs of the number of suppliers and customers in the country in which the focal firm is located, the number of transaction links with capital shareholding links, and transaction links with patent co-ownership links. We also incorporate another measure, PageRank, developed by Page et al. (1999) to represent each firm's centrality in the global supply chain. Although the number of supply chain partners is also a measure of network centrality, it captures only

direct links and ignores indirect links. PageRank of node u , $R(u)$, is defined as $R(u) = c \sum_{v \in B_u} R(v) / N_v$ where c , B_u , N_u , are a normalization factor, the set of nodes that are linked to (pointing at) node u , and the number of links pointing from u , respectively. In short, PageRank, originally developed to evaluate the centrality of websites on the Internet, takes into account all links within a network, not only the number of those directly linked to the focal node. When a firm is not linked with any other firm, we define PageRank as zero, and include it in estimations with a dummy variable for no link.

In some specifications, we incorporate density of firms' egocentric networks, measured by the local clustering coefficient. The density of ego network is defined as the ratio of the number of actual supply-chain ties between partners of the focal firm to the number of all possible ties between them (Barabási 2016; Jackson 2010). For example, if a firm has three partners and two among the three are also connected with supply chains, its density is 1/3. When a firm is not linked with any other firm or linked with only one firm, we define the density as zero. In the estimations, we also include dummy variables for no link and one link to account for any possible bias due to the arbitrary definitions.

The dependent variable is sales growth from 2011 to 2012 and from 2011 to 2013. Sales growth is calculated as $SalesGrowth_{t(2011-t)} = (netsales_t / netsales_{2011})^{1/(t-2011)} - 1$. Control variables include sales growth in the pre-disaster period from 2006 to 2011 to capture the pre-disaster characteristics, sales per worker in 2011 in log form to represent productivity, and the number of workers and value of total assets in 2011 in log form to represent firm size, firm age, industry dummies, country dummies, and geographical distance from the damaged area (New York). When the country code is available but a detailed address is not available for a firm, we use the address of the center of the capital city of the country. In cases where the country code is not available, we use the average distance and include it with a dummy indicating the code is unavailable. The dependent variable and controls are constructed based on Osiris data. We use industry dummies based on the firms' four-digit industry group codes in the Global Industry Classification Standard (GICS). Country dummies are classified by the location of the firm headquarters.

Each firm in Osiris also reports the end of its accounting period, which varies across countries. Because sales of each firm in our sample cover different time periods depending on its fiscal year end, the effect of supply-chain ties with directly affected firms on sales growth should also be affected by the fiscal year end. For example, suppose that the end of the accounting period for a firm is December. Then, our measure of short-term sales growth indicates the change in sales from the period January-December 2011 to the period January-December 2012 and covers two months after the hurricane, which hit the US at the end of October 2012. Now, suppose that the fiscal year end for another firm is March. Then, short-term sales growth for this firm represents the change from the period April 2011-March 2012 to the period April 2012-March 2013 and includes five months after the hurricane (i.e., from November 2012 to March 2013). The difference in the period covered should result in differences in sales growth and the effect of links with firms hit by the disaster. Therefore, we

include dummies for different fiscal year end months and interaction terms between these dummies and the key variables for supply-chain ties, setting December as the base month. That is, our actual estimation equation is given by:

$$SalesGrowth_{i(2011-t)} = \beta_0 + \beta_1 Shock_{i2011} + \sum_{k=January}^{November} \gamma_{1k} D_{ik} \times Shock_{i2011} + \sum_{k=January}^{November} \gamma_{2k} D_{ik} + \beta_2 X_{i2011} + \varepsilon_{it}, \quad (2)$$

where D_{ik} is the dummy variable that takes a value of one if firm i 's fiscal year end month is month k .

3.3. Descriptive Statistics

The upper rows of Table 2 show the 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 data is mostly limited to links between major firms and their transaction partners. 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. The high degree of internationalization of firms in our sample is because they are, again, mostly publicly listed firms. 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 our global sample 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.

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 pre-disaster 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 large, established, and growing firms.

Table 3 reports the share of each of the four-digit industries classified by the GICS, as explained in Section 3.2. The major industries in our sample are the capital goods, materials, and technology hardware, and equipment industries.

4. Results

4.1. *Balancing Tests*

We first test the exogeneity of direct damages of the hurricane because our OLS estimations rely on this assumption. For this purpose, we run OLS estimations to examine whether a firm's supply chain links to damaged suppliers or customers can predict sales growth before the disaster, including only country and industry dummies as control variables. Panel (A) of Table 4 shows that neither the number of suppliers nor two-step suppliers is correlated with sales growth before the hurricane. Panel (B) indicates no correlation between the number of direct or two-step customers and pre-disaster growth. These results suggest that direct and indirect supply-chain links with damaged firms are randomly allocated to firms in our sample and hence our key variables of interest, the number of links with damaged firms, should be uncorrelated with the error term in equation (2). 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 5. In columns (1) and (2), the dependent variable is sales growth of undamaged firms from 2011 to 2012 to examine immediate propagation effects, whereas sales growth from 2011 to 2013 is used in columns (3) and (4) to examine longer-term effects. In all estimations, we include the interaction terms between each of the dummies for the end of the accounting period and the key independent variables for links with damaged firms but do not present the results for the interaction terms for brevity of presentation. Because the base case for the fiscal year end is December, the coefficient of the key independent variable represents the effect on the change rate of sales from calendar year 2011 to calendar year 2012 in the case of short-term effects and to calendar year 2013 in the case of long-term effects.

Columns (1) and (2) of Table 5 show negative and significant effects of links with damaged suppliers on sales growth of their customers in the US. This result suggests that negative shocks of the hurricane propagated downstream along supply chains to US customers and supports hypothesis 1 in Section 2.1. According to the size of the coefficient, US firms linked with a supplier damaged by the hurricane experienced sales growth 13 percentage points lower ($-0.181 \times [\ln 2 - \ln 1] = -0.13$) than those not linked with damaged suppliers. Thus, the propagation effect is not only statistically significant but also economically quite large. In columns (3) and (4) of Table 5, the effect of the number of damaged suppliers on the longer-run sales growth of US firms is also negative and significant, while it is substantially smaller in size and less significant than the immediate effects shown in columns (1) and (2). This finding suggests that the negative propagation effect through supply chains diminished in a year, probably either because of recovery of or substitution for damaged partners.

Furthermore, in columns (1) and (2) of Table 5, we observe that the coefficients of the links with damaged suppliers for non-US customers are positive but statistically insignificant, indicating no immediate effect on non-US customers. This evidence implies that the negative shock from the hurricane did not propagate downstream beyond the US borders. 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 from 2011 to 2013, indicating no international propagation in the long run. Therefore, hypothesis 5a is supported in the case of downstream propagation. These results are less likely to be driven by the share of non-damaged suppliers because the average share of non-damaged suppliers is not smaller for US customers linked with damaged firms (78%) than for non-US correspondents (70%).

In addition, the coefficients of indirect two-step links with damaged suppliers in columns (2) and (4) of Table 5 are insignificant for both US and non-US customers, both in the short and longer run. This result does not support hypothesis 2, implying that there is no propagation of the negative shock from the hurricane beyond direct customers. However, hypothesis 2 also states the effects on indirect customers would be smaller than those on direct customers because negative shocks are absorbed along supply chains due to substitution of partner firms. Our results indicate that negative shocks substantially diminish along supply chains and disappear in two steps. Barrot and Sauvagnat (2016) also find no downstream propagation beyond direct customers based on firm-level panel analysis for the US. By contrast, Carvalho et al. (2016) find propagation beyond direct customers up to customers four steps away from damaged suppliers after the Great East Japan Earthquake. One possible reason for the variation among the three studies is that the direct impact of the Great East Japan Earthquake was extremely large, the largest natural disaster worldwide since 2010 in terms of economic loss (Center for Research on the Epidemiology of Disasters 2017) and the fourth largest earthquake in the world since 1900 (Cabinet Office of Japan 2012), and thus did not fade away quickly.

The results for upstream propagation from damaged customers to their suppliers in Table 6 demonstrate that upstream propagation is similar to downstream propagation. Columns (1) and (2) of Table 6 show negative and significant effects of links with damaged customers on short-run sales growth of US suppliers, which is consistent with hypothesis 3. Columns (3) and (4) of Table 6 indicate either a smaller effect or no significant effect in the longer run. The magnitude of the negative and significant effect is large in the short run. If a firm with no link with damaged customers was linked with a damaged customer, its sales growth rate would decline by 12 percentage points ($-0.169 \times [\ln 2 - \ln 1] = -0.12$) because of propagation of negative shocks. This finding suggests that domestic suppliers of directly damaged firms are affected by a lack of demand from damaged customers immediately after the earthquake, although the negative effect diminishes in a year either through recovery or replacement of the damaged customers.

By contrast, we do not find any significant effect of links with damaged customers on non-US suppliers in Table 6, as in the case of the effect of links with damaged suppliers in Table 5. This result

supports hypothesis 5a in the case of upstream propagation, suggesting that negative shocks did not propagate from damaged customers in the US to their suppliers outside the US. The stark difference between the presence of propagation within the US and absence of propagation beyond the US is our major finding, and hence we examine the mechanism of this contrast further in Subsection 4.5.

Last, two-step links with damaged customers have an insignificant effect on US suppliers both in the short and long run (columns [2] and [4], respectively, of Table 6) , partly supporting hypothesis 4. For non-US suppliers, we find a substantial positive effect from two-step customers in the short 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. This result, a positive effect of disasters, is hard to interpret. One possible reason is that damages from the hurricane lead to creative destruction, as suggested by Skidmore and Toya (2002). However, as we cannot further examine the possibility of creative destruction using our dataset, we simply conclude that damaged customers did not negatively and substantially affect their indirect suppliers.

4.3. *Robustness Checks*

This subsection experiments with several alternative specifications to check the robustness of the benchmark results presented in the previous subsection.

Dummies for supply-chain links

Although we have used the number of suppliers or customers in various types as the key independent variables in our estimations, the effect of supply-chain links with damaged suppliers may not be increasing in the number of such suppliers. Suppose, for example, that any material or part is necessary for production of the focal firm's products and further that it cannot be substituted for because of its specificity. Then, if any material or part is not supplied due to the hurricane, the firm should completely stop its production. If this is the case, whether the firm is linked with any damaged supplier, rather than the number of damaged suppliers of the firm, matters to sales growth. Therefore, we experiment with dummy variables for the various types of supply-chain links examined in the previous subsection.

Table 7 presents the results from these alternative specifications. Columns (1) and (2) suggest that when firms have a link with any damaged supplier, the sales growth of US firms is 16.1 percentage points lower than when they are not directly linked with any damaged supplier, while no significant effect is observed for non-US firms. The results are qualitatively and quantitatively similar to the baseline results in Table 5. However, some results in Table 7 differ from the benchmark results. For example, the effect of the dummy for any direct link with damaged suppliers for US firms in the long run is insignificant in column (3) of Table 7 and positive and significant in column (4), while the corresponding effect using the number of links is negative and significant in columns (3) and (4) of

Table 5. In addition, the dummy for any two-step link with damaged suppliers for US firms has a negative and significant effect both in the short and long run (columns [2] and [4], respectively, of Table 7), while the number of such two-step links has no significant effect in either the short or long run (columns [2] and [4], respectively, of Table 5). However, our main result showing the presence of intra-national propagation in the short run and the absence of international propagation persists in these alternative estimations.

Alternative definition of damaged firms

In the benchmark estimations, we define firms directly damaged by the hurricane as those in "very highly damaged areas" identified by FEMA (2014) (Figure 2). However, in these "very highly damaged areas," there must have been a variation in the level of damages across firms and households. If this is the case, some of the firms defined as damaged in our data were not heavily damaged, and accordingly, the effect of links with "damaged firms" in our data underestimates the effect of links with truly damaged firms.

To identify links with truly damaged firms, we assume that when a firm is extremely damaged and thus could not recover or needed a very long time to recover, supply-chain links with the firm should have been lost after the hurricane. Therefore, we alternatively define links with damaged firms as those with firms in the very highly damaged areas that were dropped after the hurricane. Then, we conduct OLS estimations as before, using the number of damaged firms alternatively defined and report the results in Table 8. Columns (1) and (2) indicate that the short-run effect of direct suppliers and customers on sales growth of US firms is negative and significant, while their effect on firms outside the US is insignificant. Columns (3) and (4) show damaged customers negatively affect long-run sales growth of their suppliers in the US to a smaller extent than their short-run effect, while no other effect is significant. These are mostly consistent with the benchmark results, confirming propagation within the country but no propagation beyond the country.

Placebo tests

We confirmed the exogeneity of the negative shock from the hurricane using the balancing tests for sales growth in the pre-disaster period, as shown in Table 4. However, we are still concerned about whether our results are generated by the peculiar characteristics of damaged firms, because the hurricane hit the industrial areas on the east coast of the US around New York City. To check whether this is the case, we experiment with two sets of placebo tests. First, we estimate the effect of supply-chain links with firms that are not in the damaged areas of the hurricane but are similar in attributes to those in the damaged areas, which are selected from all US firms not directly damaged by the hurricane using a propensity score matching (PSM) technique. That is, we estimate how the dummy variable for damaged firms is correlated with the number of workers, amount of total assets, and industry dummies using logit and match each damaged firm with another with the closest

predicted probability. Second, we estimate the effect of links with firms in neighboring states of the very highly damaged areas, such as Vermont, New Hampshire, Maryland, the District of Colombia, Ohio, Virginia, and West Virginia. In this placebo test, we assume that firms geographically close to damaged firms are similar in attributes to damaged firms.

The results from the first and the second placebo tests are shown in Tables 9 and 10, respectively. In the tables, some of the effects of the links with firms similar in attributes to or geographically close to damaged firms are positive and significant, while no effect is negative and significant at the 5-percent level. These results suggest that because firms in the damaged areas around New York City are likely to be more advanced than those in other areas in the world, a firm's links with firms similar to the damaged firms are often positively correlated with the firm's sales growth. Therefore, although our benchmark results may underestimate the propagation effect, in other words, the true negative effect of links with damaged firms may be larger in absolute terms than our estimates, it is unlikely that our results overestimate the propagation effect.

4.4. *Mechanism of No International Propagation*

Our major finding in the previous sections is that the negative shock of the hurricane propagated downstream and upstream within the country but not beyond the national borders. To examine the mechanism behind this finding, we further test what firm attributes mitigate or amplify the propagation and thus identify the source of the difference in the propagation effect between firms in the same country and outside the country.

Geographic distance

A natural candidate for the source of the difference is geographic distance to damaged firms. Therefore, we estimate whether the effect of links with damaged firms decays as the distance to the damaged areas becomes greater, using a nonlinear equation following Keller (2002):

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

where *distance* is the distance from New York in kilometers, calculated from the address of each firm. The results shown in Table 11 clearly indicate distance does not significantly affect propagation of the shock, while the difference between propagation within and beyond the US is still present. Therefore, we conclude that geographic distance itself does not play a major role in the absence of international propagation.

Substitution of suppliers and customers

Another possible reason for the absence of international propagation is related to substitution of supply-chain partners, as argued in Section 2.1 based on the finding of Barrot and Sauvagnat (2016).

When suppliers or customers of a particular firm are damaged by a disaster, the firm tries to seek substitutes for the damaged partners. However, finding appropriate partners requires a certain search cost, as suggested in an offshoring model in Antras, Fort, and Tintelnot (2017) and a production networks model in Bernard, Moxnes, and Saito (2018). Hence, facing negative shocks to their partners, only firms with sufficiently high productivity or with sufficiently high ability to gather information can pay the search cost and find substitutes for damaged partners to mitigate the propagation of shocks. This argument is analogous to that of the heterogeneous-firm models of trade initiated by Melitz (2003), who concludes that only productive firms can export because of the initial costs. Our argument is also in line with Allen (2014), who employs a search model and concludes that larger producers can sell their products to destinations with higher prices because of the fixed search cost.

These arguments suggest a possible reason for no international propagation. Because non-US firms linked with damaged US firms are internationalized by definition and thus may be more productive and have greater ability to collect information in the world market, they can substitute for damaged partners more easily and mitigate the propagation of shocks. If this mechanism works, the same mechanism should be applied to US firms, and thus we should observe smaller propagation to US firms that can more easily substitute for damaged suppliers and customers.

For this purpose, we incorporate measures of the US firm's capability to substitute for damaged partners, such as productivity and search costs. As we have no precise measure for productivity or search costs, we experiment with two proxies. First, we employ the share of foreign firms in all suppliers and customers, assuming that internationalized firms are likely to be more productive than non-internationalized firms, following the theoretical consideration of Melitz (2003) and empirical evidence of Bernard and Jensen (2004) and many others. Second, we utilize the number of workers, following Allen (2014), who finds that firm size is negatively correlated with search costs. Then, we include the interaction term between the number of damaged suppliers or customers for each US firm and one of the two measures to examine whether firms' ability to substitute for supply-chain partners mitigates propagation of shocks.

The results shown in columns (1) and (2) in panel (A) of Table 12 indicate that the negative effect of links with damaged suppliers on their customers in the US is substantially alleviated when the US firms' share of foreign links or number of workers is larger. As before, columns (3) and (4) indicate that the long-run effect is less significant and smaller in size. Panel (B) of Table 12 presents results for upstream propagation. The effect of the interaction term with the number of workers is positive and significant only at the 10-percent level in the short run (column [2]), whereas the interaction term with the share of international links has a significant effect at the five-percent level only in the long run (column [3]). Although weaker, the results for upstream propagation are consistent with those for downstream propagation in panel (A).

Overall, our results in Table 12 point to the important role of the capability of substituting for

damaged partners in mitigating propagation of shocks. Accordingly, we conclude that the negative shock from the hurricane did not propagate internationally because internationalized firms are more productive and have greater ability to collect information and thus can find new partners when current partners are damaged by a disaster. This conclusion is consistent with Barrot and Sauvagnat (2016), who find that the propagation effect is larger when inputs are more specific, because input specificity implies difficulty substituting partners.

4.5. *Network Density*

Furthermore, we investigate the effect of network structure on propagation of shocks. In particular, we focus on the density of each firm's egocentric network, as explained in Section 2.1 and summarized as hypotheses 6a and 6b. Network density is measured by the local clustering coefficient defined by the ratio of the actual number of links between the focal node's partners/neighbors to the number of all possible pairs among the partners, representing how densely the focal node's partners/neighbors are linked with each other (Section 3.2). Using network density and its interaction term with links with directly damaged firms, we test how network density affects the propagation effect. Because we do not observe clear inverted U-shape relationships between density and propagation of disaster shocks, the results presented do not include the square term of density.

In columns (1) and (2) of Table 13, we find that the interaction term between the number of links with damaged suppliers or customers for US firms and the local clustering coefficient is negative and significant. This finding implies that the negative effects of damaged suppliers and customers are circulated within dense networks in the US and intensified. This supports hypothesis 6a for US firms and is consistent with the theoretical finding of Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) when shocks are sufficiently large. By contrast, columns (1) and (3) of Table 13 show the interaction term for non-US firms has a positive and significant effect, supporting hypothesis 6b. This contrasting finding suggests that denser networks between US and non-US firms create social capital among them, leading to higher sales growth, a finding that is consistent with the empirical results of Durlauf and Fafchamps (2005) and Centola (2010).

5. **Conclusions**

In this study, we take Hurricane Sandy, which struck the east coast of the US in 2012, as a source of negative economic shocks and examine whether the shock propagated to the world economy through global supply chains. Specifically, using firm-level data on global supply chains, we analyze how sales growth of firms in and outside the US is affected by their direct and indirect suppliers and customers directly damaged by the hurricane.

Our results show that direct links with damaged suppliers and customers decreased the sales growth of firms within the US, while we do not observe any negative effect on non-US firms.

Therefore, we conclude that negative economic shocks are less likely to propagate internationally than within a country. Our further analysis shows a smaller propagation effect on US firms that are linked with foreign firms or larger in size than other US firms. These results suggest that internationalized or large firms can mitigate propagation of shocks through supply chains because they can substitute for damaged partners more easily due to their high productivity and low search costs. In addition, we find that the propagation effect on US firms is larger when their ego network is denser, that is, their partners are connected with each other. All these findings imply that supply-chain links with diverse partners, including foreign partners and partners that are not linked with each other, lead to economic resilience to propagation of negative shocks.

Although our study is unique in that we investigate the difference between intra- and international propagation, which has not been studied owing to the lack of data on global supply chains, there are several limitations. First, our data are limited mostly to publicly listed firms and their major supply-chain relationships because our major data source relies on public information such as financial reports and websites. Thus, our results ignoring minor links may have underestimated propagation of shocks. Second, because our data is not at the establishment level but at the firm level, we identify firms directly damaged by the hurricane by the location of their headquarters. If a major plant of a firm whose headquarters is not located in the disaster area is in the disaster area and heavily damaged by the hurricane, we classify this firm as one not directly damaged by the hurricane. This may also have resulted in underestimation of the true effect of the hurricane. However, it should be emphasized that our major conclusion that negative shocks propagate to a lesser extent across countries than within a country is not affected by the two caveats, because major links of US firms with foreign firms are identified through their financial reports in the same way as those with US firms and the two caveats affect intra-national and international propagation in the same way. Finally, although our results imply benefits of internationalization and network diversification in terms of economic resilience, we did not conduct any cost-benefit analysis. Thus, the investigation of the optimal level of diversification is left for future study.

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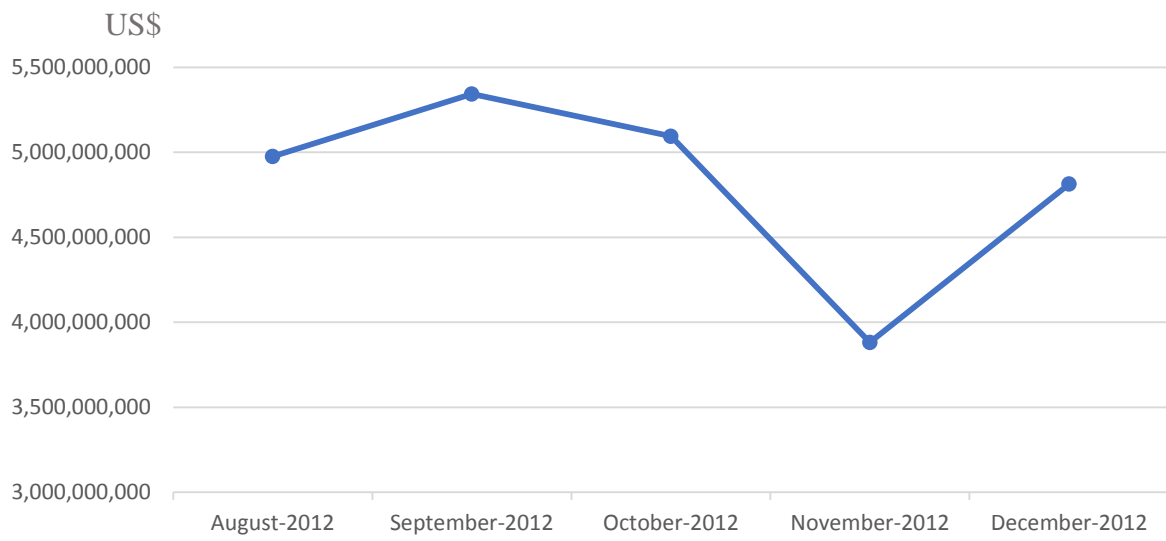
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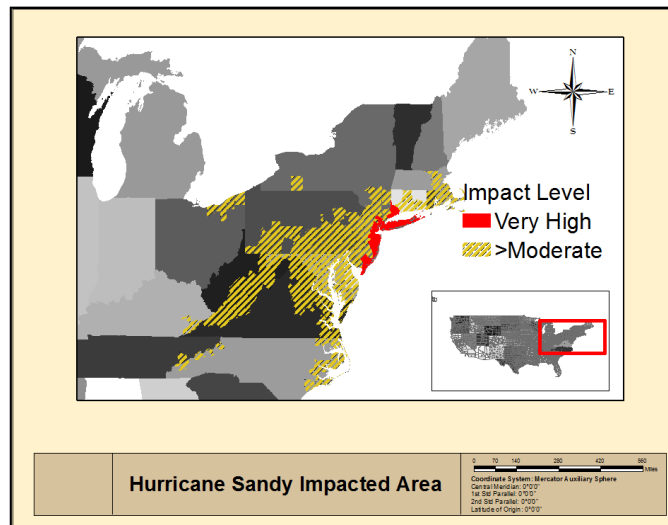
Figure 1: Exports from Seaports in New York and New Jersey



Data Source: United States Census Bureau (2017)

Notes: This figure shows the amount of monthly exports from New York and New Jersey from August to December, 2012. Hurricane Sandy hit the east coast of the US, including New York city, in October 2012.

Figure 2: Area Damaged by Hurricane Sandy



Data Source: FEMA (2014).

Notes: This map is drawn by the author using ArcGIS Desktop. Red and yellow areas indicate counties that were impacted by the hurricane at the "very high" and "high"- "moderate" level defined by FEMA (2014), respectively.

Table 1: Number of Firms by Country of Location (Top 5 Countries)

	(1)	(2)	(3)	(4)	(5)
Country	Number of firms in the sample	Share in the sample (%)	Number of firms in the disaster areas dropped from the sample	Number of publicly listed firms in 2011	(1+3)/(4)
Japan	1,855	20.83		2,280	0.814
United States	1,660	18.64	1,709	4,171	0.808
China	1,559	17.51		2,342	0.666
United Kingdom	541	6.07		1,987	0.272
France	397	4.46		586	0.677

Data Source: World Bank (2018)

Table 2: Summary Statistics

Variable	Mean	S.D.	Min.	Median	Max
<i>Links with suppliers in 2011</i>					
# 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
<i>Links with damaged suppliers in 2011</i>					
# 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
<i>Links with customers in 2011</i>					
# 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
<i>Links with damaged customers in 2011</i>					
# 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
<i>Other networks measure in 2011</i>					
PageRank	0.000057	0.0001	0.000017	0.000026	0.003018
<i>Firm attributes</i>					
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

(A) Downstream propagation

	(1)	(2)	(3)	(4)
	Dependent variable: Sales growth 2006-2011Sales 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

	(1)	(2)	(3)	(4)
	Dependent variable: Sales growth 2006-2011Sales 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

(B) Upstream propagation

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: Effects of the Number of Damaged Suppliers

	(1)	(2)	(3)	(4)
Dependent variable: Sales growth				
	2011-2012		2011-2013	
# of links with damaged suppliers (log)				
Direct links for US firms	-0.181*** (0.0339)	-0.192*** (0.0249)	-0.0274*** (0.00770)	-0.00850* (0.00477)
Direct links for non-US firms	0.114 (0.146)	0.0623 (0.215)	0.00808 (0.0248)	-0.00988 (0.0352)
2-step links for US firms		0.0198 (0.0506)		-0.0173 (0.0134)
2-step links for non-US firms		0.0621 (0.0948)		0.00828 (0.0190)
Observations	8,906	8,906	8,593	8,593
R-squared	0.036	0.036	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, but the results are not reported for the brevity of presentation.

Table 6: Effects of the Number of Damaged Customers

	(1)	(2)	(3)	(4)
	Dependent variable: Sales growth			
	2011-2012		2011-2013	
# of links with damaged customers (log)				
Direct links for US firms	-0.169** (0.0674)	-0.162** (0.0778)	-0.0303** (0.0142)	-0.00520 (0.00917)
Direct links for non-US firms	0.166 (0.141)	0.0473 (0.130)	0.0262 (0.0305)	-0.0141 (0.0321)
2-step links for US firms		0.0531 (0.0487)		-0.0108 (0.00715)
2-step links for non-US firms		0.148** (0.0602)		0.0302** (0.0106)
Observations	8,906	8,906	8,593	8,593
R-squared	0.036	0.036	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, but the results are not reported for the brevity of presentation.

Table 7: Effects of the Dummy Variable for the Link with Damaged Suppliers

	(1)	(2)	(3)	(4)
Dependent variable: Sales growth				
	2011-2012		2011-2013	
Dummy for any link with damaged suppliers				
Direct links for US firms	-0.183*** (0.0327)	-0.161*** (0.0246)	-0.0114 (0.00695)	0.00789** (0.00306)
Direct links for non-US firms	0.0903 (0.124)	0.0589 (0.159)	0.00727 (0.0206)	-0.00141 (0.0250)
2-step links for US firms		-0.173*** (0.0316)		-0.0654*** (0.0207)
2-step links for non-US firms		-0.0192 (0.0830)		-0.0170 (0.0267)
Observations	8,906	8,906	8,593	8,593
R-squared	0.036	0.036	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, but the results are not reported for the brevity of presentation.

Table 8: Results from Alternative Definition of Damaged Firms

	(1)	(2)	(3)	(4)
	Dependent variable: Sales growth			
	2011-2012		2011-2013	
# of direct links with damaged firms using alternative definition				
With suppliers for US firms	-0.218*** (0.0338)		-0.0151 (0.0141)	
With suppliers for non-US firms	0.112 (0.193)		0.0420 (0.0423)	
With customers for US firms		-0.180** (0.0782)		-0.0516** (0.0222)
With customers for non-US firms		-0.0256 (0.238)		-0.0168 (0.0604)
Observations	8,906	8,906	8,593	8,593
R-squared	0.036	0.036	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 9: Effects of Links with Firms Similar in Attributes to Damaged Firms

	(1)	(2)	(3)	(4)
	Dependent variable: Sales growth			
	2011-2012		2011-2013	
# of links with suppliers similar in attributes to damaged firms (log)				
Direct links for US firms	0.426*** (0.0576)		0.0151** (0.00631)	
Direct links for non-US firms	0.101 (0.252)		0.0551* (0.0306)	
2-step links for US firms	-0.0723 (0.0747)		-0.0110 (0.0215)	
2-step links for non-US firms	0.0898 (0.0924)		-0.00378 (0.0200)	
# of links with customers similar in attributes to damaged firms (log)				
Direct links for US firms		0.00970 (0.0447)		0.0190* (0.0106)
Direct links for non-US firms		0.0162 (0.109)		0.0251 (0.0359)
2-step links for US firms		-0.0140 (0.0311)		-0.00993 (0.0104)
2-step links for non-US firms		0.163*** (0.0447)		0.0360** (0.0162)
Observations	8,906	8,906	8,593	8,593
R-squared	0.036	0.036	0.078	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, but the results are not reported for the brevity of presentation.

Table 10: Effects of Links with Firms Geographically Close to Damaged Firms

	(1)	(2)	(3)	(4)
Dependent variable: Sales growth				
	2011-2012		2011-2013	
# of links with suppliers geographically close to damaged firms (log)				
Direct links for US firms	0.0877*		0.0477***	
	(0.0447)		(0.00633)	
Direct links for non-US firms	-0.0115		0.0317	
	(0.166)		(0.0890)	
2-step links for US firms	-0.125*		-0.0154	
	(0.0724)		(0.0184)	
2-step links for non-US firms	0.0798		0.0133	
	(0.112)		(0.0237)	
# of links with customers geographically close to damaged firms (log)				
Direct links for US firms		0.143		0.0298*
		(0.119)		(0.0150)
Direct links for non-US firms		0.116		0.0751*
		(0.196)		(0.0450)
2-step links for US firms		0.103		-0.00110
		(0.0621)		(0.00990)
2-step links for non-US firms		0.306***		0.0597***
		(0.0798)		(0.0141)
Observations	8,906	8,906	8,593	8,593
R-squared	0.036	0.036	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, but the results are not reported for the brevity of presentation.

Table 11: Effects of Geographic Distance

	(1)	(2)	(3)	(4)
Dependent variable: Sales growth				
	2011-2012		2011-2013	
# of links with damaged suppliers (log)				
Direct links for US firms	-0.179*** (0.042)		-0.026*** (0.004)	
Direct links for non-US firms	0.057 (0.285)		-0.003 (0.013)	
δ (distance effect for non-US firms)	4.20E-5 (5.15E-4)		-1.31E-4 (2.36E-4)	
# of links with damaged customers (log)				
Direct links for US firms		-0.227*** (0.048)		-0.033** (0.016)
Direct links for non-US firms		0.784 (0.678)		0.010 (0.021)
δ (distance effect for non-US firms)		2.56E-4 (1.96E-4)		-9.72E-5 (8.99E-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, but the results are not reported for the brevity of presentation.

Table 12: Effect of Capability of Substitution for Damaged Partners

(A) Downstream propagation				
	(1)	(2)	(3)	(4)
Dependent variable: Sales growth				
	2011-2012		2011-2013	
# of links with damaged suppliers for US firms	-0.269*** (0.0497)	-1.788** (0.708)	-0.0365*** (0.00772)	-0.242** (0.119)
--- × share of links with foreign suppliers	0.300** (0.133)		0.126*** (0.0319)	
--- × # of workers (log)		0.183** (0.0814)		0.0270* (0.0140)
# of links with damaged suppliers for non-US firms	0.0741 (0.215)	0.161 (0.265)	-0.00693 (0.0351)	0.00856 (0.0437)
Observations	8,906	8,906	8,591	8,591
R-squared	0.036	0.038	0.078	0.081

(B) Upstream propagation				
	(1)	(2)	(3)	(4)
Dependent variable: Sales growth				
	2011-2012		2011-2013	
# of links with damaged customers for US firms	-0.131*** (0.0486)	-1.139** (0.521)	-0.0230*** (0.00741)	-0.0850 (0.0934)
--- × share of links with foreign customers	-0.216 (0.163)		0.0741** (0.0351)	
--- × # of workers (log)		0.129* (0.0716)		0.0107 (0.0123)
# of links with damaged customers for non-US firms	0.0635 (0.128)	0.0461 (0.129)	-0.0130 (0.0316)	-0.0146 (0.0317)
Observations	8,906	8,906	8,591	8,591
R-squared	0.036	0.038	0.078	0.081

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 13: Effect of Network Density

	(1)	(2)	(3)	(4)
Dependent variable: Sales growth				
	2011-2012		2011-2013	
Downstream propagation				
# of links with damaged suppliers for US firms	-0.125*** (0.0255)		-0.00909 (0.00864)	
--- × local clustering coefficient	-0.724** (0.278)		0.0285 (0.0895)	
# of links with damaged suppliers for non-US firms	-0.0262 (0.222)		-0.0283 (0.0344)	
--- × local clustering coefficient	1.676** (0.771)		0.381*** (0.117)	
Upstream propagation				
# of links with damaged customers for US firms		-0.0846 (0.0822)		-0.000808 (0.00970)
--- × local clustering coefficient		-1.475*** (0.203)		-0.0909 (0.0647)
# of links with damaged customers for non-US firms		0.0594 (0.116)		0.0137 (0.0254)
--- × local clustering coefficient		-0.458 (1.190)		-0.553** (0.260)
Local Clustering Coefficient	-0.281 (0.176)	-0.221 (0.187)	-0.109*** (0.0318)	-0.0788** (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, but the results are not reported for the brevity of presentation.