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Supply Chain Dynamics and Resilience of the Economy During a Crisis[*]

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Abstract

Recently, supply chain disruptions are prevalent worldwide. When there are disruptions, firms restructure their supply chains to minimize negative impacts. The ability to restructure is the key for firms to be resilient against shocks. However, there is little evidence on how firms react to supply chain disruptions. We exploit large-scale firm-level transaction data and focus on the Great East Japan Earthquake in 2011. It was a massive but local shock in that only firms in the disaster area received direct negative impacts. First, we found a sudden shift of supplier choice diverting away from the disaster area. Second, although firms overall increased the number of suppliers, they geographically concentrated the supply chains outside the disaster area. This finding is robust across different measures of geographic concentration. Finally, we showed that firm productivity is a determinant of the ability to find alternative suppliers. These results suggest that supply chain disruptions would concentrate the spatial distribution of economic activities and that the effect would be driven by productive firms.

Keywords: supply chains; productivity; resilience; natural disaster
JEL classification: E23, F14, O47, R15

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1 Introduction

Supply chain disruptions are prevalent worldwide. There are Brexit, COVID-19 pandemic, more frequent natural disasters due to climate change, and, most recently, war in Ukraine. They incur damages to the economy ranging from grocery shops to manufacturers. To mitigate disruptions, firms restructure their supply chains. Some firms are better at keeping the supplies of inputs, while others fail to continue their operation due to a lack of key inputs. The ability to restructure the supply chains is fundamental for firms to be resilient against supply chain disruptions. However, evidence on how firms respond to supply chain shocks is limited. Hence, we exploit large-scale firm-level transaction data and focus on the Great East Japan Earthquake in March 2011. The earthquake was a local shock, unlike recent macro shocks (e.g., COVID-19 pandemic), and thus suits for examining supply chain restructuring.

The Great East Japan Earthquake is the biggest ever earthquake in Japan thus far. Although Japan is known for frequent earthquakes and Japanese people and firms are typically prepared for earthquakes, the magnitude of this earthquake was well above expectation. The earthquake, subsequent tsunami, and aftershocks resulted in unprecedented level of casualties and demolition of production and sales facilities in the disaster area. The transportation infrastructure was also damaged. The combination of these factors severely negatively affected firms located inside the disaster area. While firms outside the area did not have large direct negative impacts, they incurred indirect impacts propagated through the supply chains. We focus on those firms located outside the disaster area to investigate if and how they found alternative suppliers. Some firms have managed to find alternative suppliers and survived the supply chain disruptions quite well while others fail to manage risks in supply chains. This is a unique study to address how firms restructure the supply chains in response to shocks and what determines firms' ability to restructure.

Japanese large-scale firm-level transaction data allow us to examine how firms select and change their trading partners. The firm-to-firm transaction information is collected by a private credit reporting company, Tokyo Shoko Research (TSR), on an annual basis. We obtain access to the 12-year panel data between 2007 and 2018. While the disaster affected mostly firms inside the disaster area comprising four prefectures, our primary focus is on those firms located outside the area, which were not directly affected by the disaster. A group of firms that had trading relationships with firms inside the area got indirect negative impacts through propagation. The rest of firms would have had much minor impacts. By exploiting the event study design comparing those firms that were indirectly affected through supply chains and those firms that did not have any trading relationship, we examine supply chain restructuring by firms in both short and long terms.

The results are as follows. First, we examined the change in non-disaster-hit buyer firms' choice of suppliers. We found a sudden shift diverting away from suppliers inside the disaster area to those elsewhere. Buyer firms overall expanded their supplier network by increasing the number of suppliers outside the disaster area. Second, we investigated the geography of supply chains. The results show that, while firms overall diversified the supplier network, they simultaneously geographically concentrated their supply chains. This was implemented through regionalization/localization of the network. The finding is robust across different measures of geographic concentration. Third, we investigated the impact of pre-disaster firm-level productivity on firms' ability to restructure the supply chains. We found that more productive firms are more actively restructuring their transaction networks after the shock, compared to those less productive ones. These analyses bring insights into the economy's supply chain dynamics and resilience in times of crisis.

This paper contributes to three strands of the literature. First, this paper fits in to the growing literature on firm-to-firm transactions networks. Among others, Adao et al. (2020), Bernard et al. (2018), Dhyne et al. (2020), and Sugita et al. (2021) exploited the information on international trade to study firm-to-firm transactions. There are also a group of papers which focus on domestic firm-to-firm transactions. Atalay et al. (2011) and Lim (2018) used a propriety dataset, Compustat. Amiti, Konings, and Van Reenen (2022), Alfaro-Ureña et al. (2022), Bernard et al. (2022), Demir et al. (2021), Gadenne et al. (2020), and Panigrashi (2021) used tax administrative data to observe domestic transaction networks. This paper uses Japanese large-scale firm-level transaction data, collected by Tokyo Shoko Research (TSR), and contributes to this literature by focusing on the dynamic ascpect of the firm-to-firm transaction network. This dataset have been used in Bernard, Moxnes, and Saito (2019), Carvalho et al. (2021), Fujii, Saito, and Senga (2017), Furusawa et al. (2018), Miyauchi (2021), and Todo, Nakajima, and Matous (2015). The dataset used in this study is 12-year panel spanning between 2007 and 2018, whereas the existing papers utilized shorter panel data. Hence, it is more fit for examining the dynamics of firm-to-firm transaction networks due to a natural disaster.

Second, this paper contributes to the literature on propagation effects of economic shocks (see, e.g., Acemoglu et al. 2012; Barrot and Sauvagnat 2016; Boehm et al. 2018; Di Giovanni et al. 2014; Heise 2016; Magerman et al. 2016). Carvalho et al. (2021) examined propagation effects using the same dataset during 2010-2012. Our paper differs fundamentally from theirs because we focused on the dynamism of supply chains, whereas they took the network as given. This is feasible in our study because we used the transaction data during 2007–2018, whereas they used the information on the supply chain only in 2010. We believe that supply chain restructuring is a key dimension of firm response to shocks and our paper is novel because it provides the primary evidence about restructuring behavior.

Third, this paper is also related to the literature about spatial distribution of economic activities. Davis and Weinstein (2002, 2008) studied the impacts of the WWII bombing on Japanese regional distribution of economic activities. Ahlfeldt et al. (2015) and Redding, Sturm, and Wolf (2011) took the similar perspective while focusing on the division and reunification of Germany. Miyauchi (2021) proposed a microfoundation for the agglomeration of economic activity by focusing on the matching between suppliers and buyers. In contrast to Miyauchi (2021), our study focused on endogenous network formation and found that buyer firms selected suppliers nearby after the Great East Japan Earthquake, consequently leading to geographic concentration of the supply chains. We believe that the similar phenomena would occur as a consequence of climate change and due to fear of the worsened US-China relationship.

The rest of the paper is structured as follows. Section 2 provides the background information of the Great East Japan Earthquake, and Section 3 explains the dataset we use for empirical analysis. Section 4 presents the evidence of substantial supply chain restructuring after the earthquake. Section 5 concludes.

2 The Great East Japan Earthquake

2.1 The Size of Damage

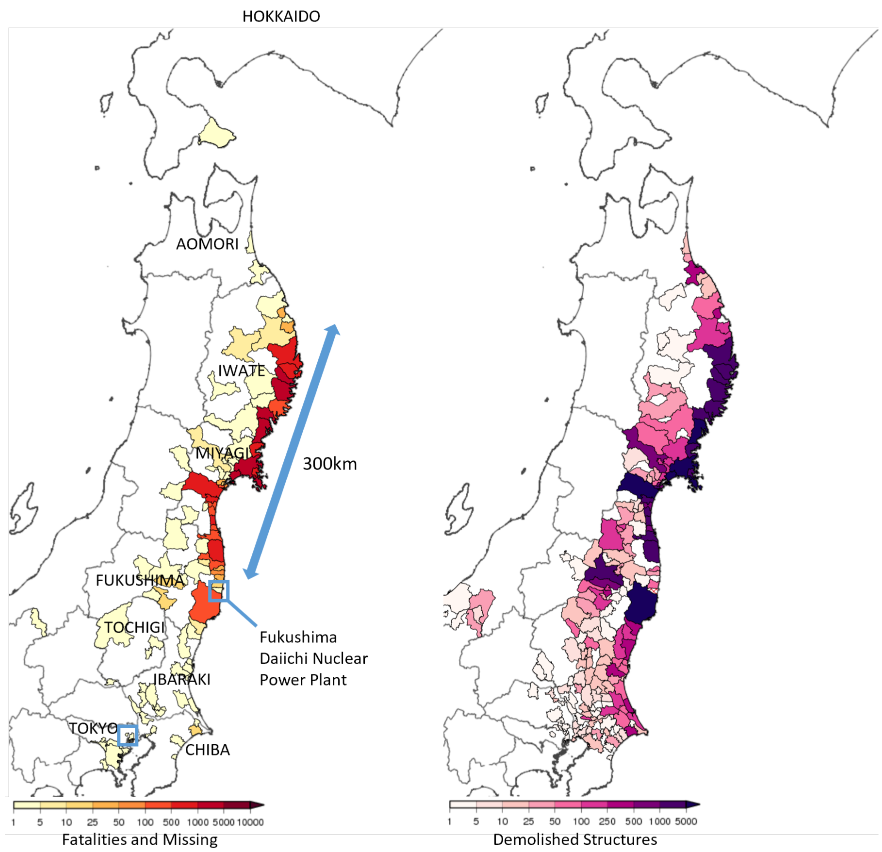
On March 11, 2011, the Great East Japan Earthquake occurred off the Pacific coast of the north-eastern part of Japan called the Tohoku region. With a magnitude of 9.0, it was the largest earthquake ever recorded in Japan and the fourth largest worldwide since 1900.[1] The earthquake, subsequent tsunami, and aftershocks caused tremendous number of casualties and property damage over a wide area, especially in the coastal areas of the Tohoku region. As of May 2012, 15,859 people were lost, and 3,021 people were missing due to the disaster.[2] The government estimated the total capital loss due to the earthquake to be 16.9 trillion yen (0.2 trillion USD) as of June 2011.[3] Among them, damage to buildings (e.g., houses, offices and factories and machinery) is estimated at 10.4 trillion yen, damage to lifelines (e.g., water, gas, electricity, communication and broadcasting facilities) at 1.3 trillion yen, and damage to public capital (e.g., roads, ports and airports) at 2.2 trillion yen. As the Tohoku region itself is not known for frequent earthquakes, the occurrence of such a large earthquake and

[1]Source: U.S. Geological Survey
[2]Cabinet Office, Government of Japan
[3]Cabinet Office, Government of Japan

tsunami was unanticipated by both the government and the residents.

Figure 1 shows the geographical distribution of casualties and damaged buildings in each municipality.[4] As shown in this figure, the impacts were not distributed evenly in the hardest-hit prefectures. Overall, the heavily damaged areas tended to be concentrated in the coastal areas that were exposed to the tsunami. However, some inland areas were also severely damaged. In our empirical analysis, we define the disaster area as the four prefectures in the Tohoku region (i.e., Aomori, Iwate, Miyagi and Fukushima prefecture) that were most severely affected by the earthquake.[5]

Figure 1. The Geographical Distribution of Casualties and Damaged Buildings



Notes: Source from Reconstruction Agency, Government of Japan.

[4]Appendix Figure A1 depicts the size of four measures that highlight the damage of the disaster. The figure includes two measures presented in Figure 1.

[5]The nuclear power plant accident happened in Fukushima.

The earthquake had significant impacts on the economic activities in the affected area.[6][7][8] The real GDP growth rate in the four prefectures along the Pacific coast (i.e., Aomori, Iwate, Miyagi and Fukushima), which were particularly hard hit by the earthquake, was -1.5% in FY2011[9], a significant decrease from 1.3% in the previous year. On the other hand, the GDP growth rate for Japan, excluding these four prefectures, was 2.0% (National Accounts of Japan, 2014).[10] The striking contrast in growth rates in the disaster region and the other regions suggests that the earthquake had huge impacts in the affected area, but had a relatively small effect on Japan's overall economic activity. In fact, the real GDP of the four affected prefectures accounted for only 4.7% of Japan's total GDP in FY2010.

As a measure of the impact on economic activities, we present the monthly lapse of the Indices of Industrial Production (IIP)[11] of the disaster-hit prefectures and that of the entire country during 2010-2017 in Figure 2. The IIP is the synthesized index that indicates the production, shipment, and inventory statuses of manufacturing and mining industries in Japan. Figure 2 shows the drastic drop of the index in March 2011, especially for the disaster-stricken prefectures. The magnitude of the decline was nearly 40% compared to the pre-disaster level. It took about five years for the disaster area to fully return to their original trajectory.

2.2 Share of Suppliers Inside the Disaster Area

We then examine the total number of suppliers, focusing on customer firms which located outside the disaster area and have traded with suppliers inside the disaster area. For those firms, the Great East Japan Earthquake did not incur direct negative impacts for sale or production facilities. Figure 3 below shows the share of suppliers located inside the disaster area. Three factors should be noted. First, the share increased between 2007 and 2010.

[6] Figure A2 shows the share of firms in each prefecture. The data source is Economic Census for Business Frame and Economic Census for Business Activity. Both are conducted to survey all establishments in Japan.

[7] The composition of industries in the Tohoku region is not remarkably different from that in the entire of Japan. Figure A3 shows the share of firms by industry, separately in the disaster area and the entire country. Again, the source is Economic Census for Business Frame and Economic Census for Business Activity.

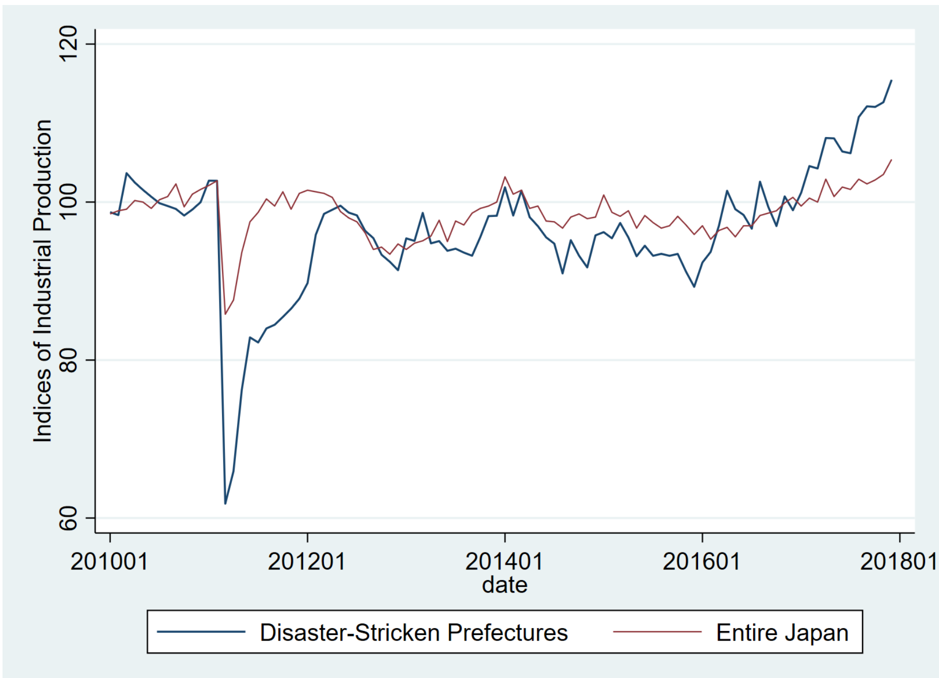
[8] Some studies investigated the economic impacts of the Great East Japan Earthquake through the supply chains. For example, Carvalho et al. (2021), Inoue and Todo (2019), and Inoue et al. (2022) estimated the propagation effects of the disaster through the supply chains for the whole country. Todo, Nakajima, and Matous (2015) focused on firms within the disaster area and investigated how supply chain networks affected the resilience of manufacturing firms to natural disasters.

[9] The fiscal year in Japan is from April to March. As the earthquake occurred at the end of the fiscal year, the economic indicators in FY2010 hardly reflect the impact. Therefore, we focus on the information in FY2011.

[10] Cabinet Office, Government of Japan.

[11] This is released by Ministry of Economy, Trade and Industry (METI) on an annual basis.

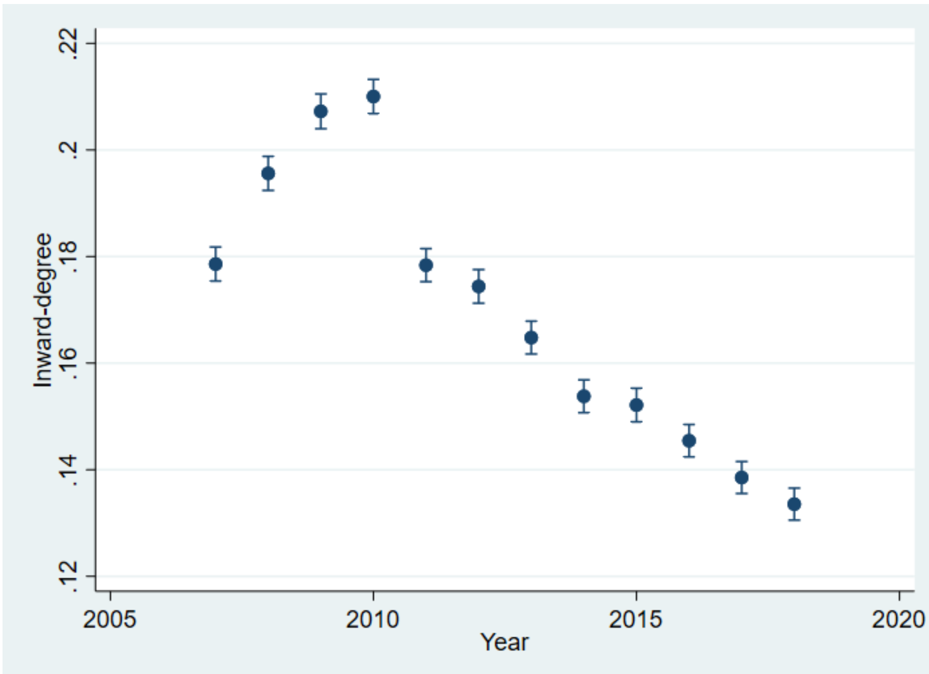
Figure 2. Indices of Industrial Production (IIP): 2010-2017



Notes: The blue line shows the IIP of the disaster-hit prefectures (i.e., Aomori, Iwate, Miyagi, and Fukushima), and the red line shows that of the entire country. The index is seasonally adjusted.
Source: Ministry of Economy, Trade and Industry (METI)

Second, the share drasticaly declined in 2011, when the Great East Japan Earthquake occurred. Third, after 2011, the share never came back to the original level, but rather it kept decreasing. Thus, year 2011 broke the trend, and the shock appears to be permanent.

Figure 3. Share of Suppliers Inside the Disaster Area



Notes: This figure shows the share of suppliers located inside the disaster area.

3 Data

3.1 TSR Data

We exploit large-scale firm-to-firm transaction data from Japan. The data sources are annual surveys by a private credit reporting company, Tokyo Shoko Research (TSR), and we refer to the data as the TSR data. The TSR data are not census but close to comprehensive because it covers about 70% of all incorporated firms in Japan, including both listed and non-listed ones. From the TSR data, we observe (i) basic firm characteristics, including employment, the number of establishments, the number of factories, 4-digit industry, sales, profits and geographical address; (ii) balance sheet information that allows us to observe firm-level inputs and outputs; and (iii) firm-to-firm transaction relationships.

Firms are asked to report up to 48 partners (24 suppliers and 24 customers). Despite the cutoff, we can back up firm-to-firm transaction network quite well by merging all reports from all firms in the survey. For example, a large firm normally has more than 48 partners, and by using reports from other firms that trade with the firm, we can identify the trading partners for the firm. Therefore, we were able to capture the Japanese firm-to-firm transaction network.

3.2 Summary Statistics

The dataset covers the period during 2007–2018. The total sample size is around 9 million indicating that about 0.8 million firms are observed each year. Table 1 below shows the summary statistics. The coverage is high ranging from small to large firms. The minimum number of suppliers and customers are zero. Hence, the data include firms which exist most upstream and downstream in the supply chains.

Table 1. Summary Statistics

	# obs	mean	median	sd	max	min
Firm sales	9300376	1662730.223	115070.5	45592124.016	2.575e+10	1
Firm age	8792327	29.408	27	16.84	148	0
Firm size	9581926	30.423	6	415.112	254177	1
Total links	9690997	8.794	4	48.138	10315	1
# suppliers	9690997	4.397	2	28.445	9946	0
# customers	9690997	4.397	2	29.350	9258	0

Notes: Sales unit is 1,000 yen. Firm size is defined as the # of workers.

4 Empirical Results

4.1 Event Study Design

We exploit the event study design to investigate how firms restructured their supply chains in response to the earthquake. As before, we focus on customer firms located outside the disaster area and have traded with suppliers inside the disaster area. Additionally, we restrict to customer firms that are involved in at least one cross-prefectural transaction to make firms in treatment and control groups more comparable. This resulted in about 4.8 million firms in the analysis sample.

We run the following regression:

$$\text{Outcome}_{ijkt} = \sum_{t=-3}^{8} \beta_t D_i T_t + X_{it}\gamma + \eta_i + \tau_{jkt} + \epsilon_{it}. \quad (1)$$

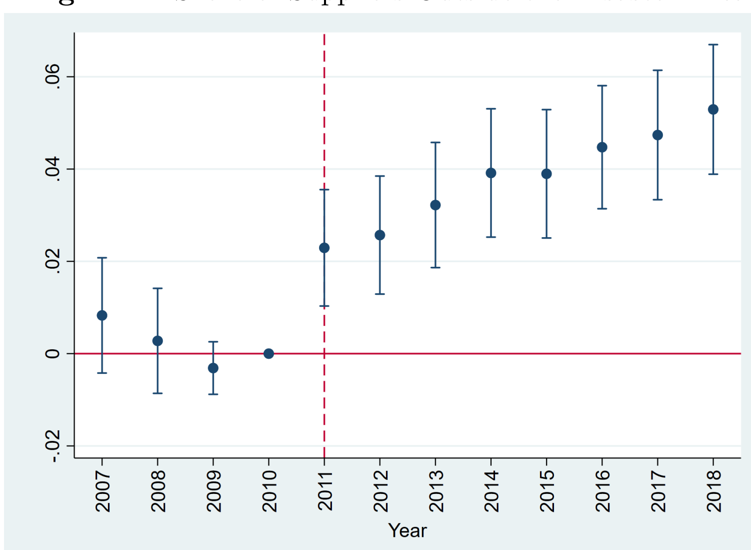
where D_i is a trading experience dummy with seller firms inside the disaster area before the earthquake, T_t is a time dummy excluding 2010, and X_{it} refers to firm covariates including firm age, distance to the disaster area, and total number of trading partners at the level of 2010. We also include firm fixed effects, η_i, and prefecture-industry-year fixed effects, τ_{jkt}. The standard errors are two-way clustered.

4.2 Share of Suppliers Outside the Disaster Area

We first examine the share of suppliers outside the disaster area as an outcome of the regression. The average share for customers that had at least one supplier inside the disaster area was 0.88, whereas by definition, the share is 1 for customers that did not have suppliers inside the disaster area.

Figure 4 plots the coefficients of equation (1). The estimated coefficients are insignificant between 2007 and 2009, but they show a slightly negative trend. Strikingly, the coefficient becomes positive and significant after 2010 and shows positive trend until 2018. Therefore, customers have actively restructured their supplier network since 2011. Also, this is consistent with anecdotes that the Great East Japan Earthquake put a huge damage to the supply chains in Japan.

Figure 4. Share of Suppliers Outside the Disaster Area



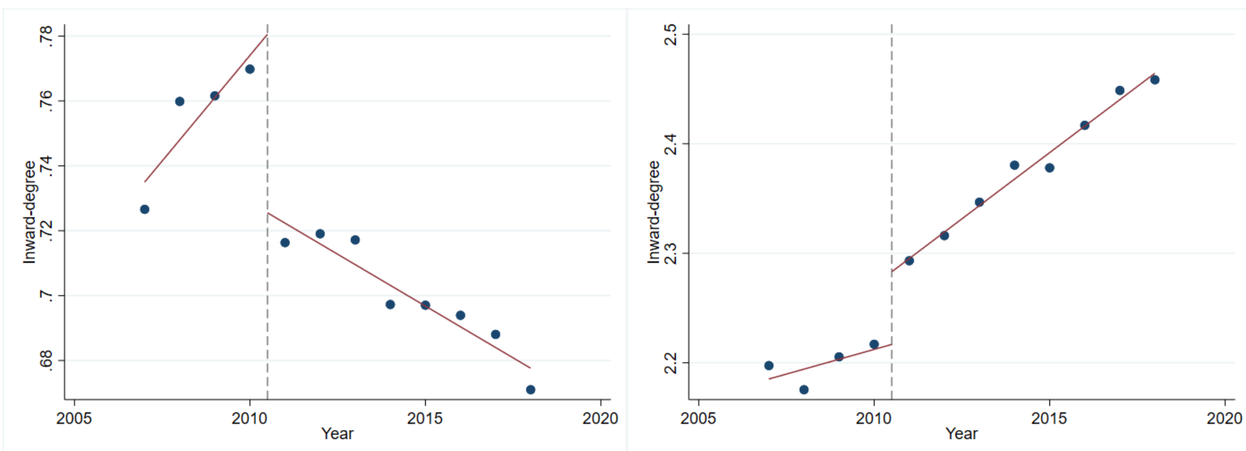
Notes: This figure plots the coefficients of the event study design specification with the share of suppliers located outside the disaster area as an outcome. The whiskers indicate the 95% confidence intervals based on the clustering in the 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

4.3 Suppliers Inside and Outside the Disaster Area

We continue focusing on customers located outside the disaster area and traded with suppliers inside the disaster area. Then, we compare the number of suppliers inside and outside the disaster area. Figure 5 plots the log number of suppliers, separately for firms inside and outside the disaster area. The left panel shows the log number of suppliers inside the disaster area, whereas the right panel shows the log number of suppliers outside the disaster area.

Two panels show opposite patterns, but both suggest discontinuous changes in year 2011. The log number of suppliers inside the disaster area suddenly declined substantially in 2011 and then followed a negative trend. In contrast, the log number of suppliers outside the disaster area increased in 2011 and then followed a positive trend after 2011. Therefore, firms located outside and having had suppliers inside the disaster area before 2011 shrank their supply chains inside the disaster area but expanded their supplier network elsewhere.

Figure 5. Log Number of Suppliers



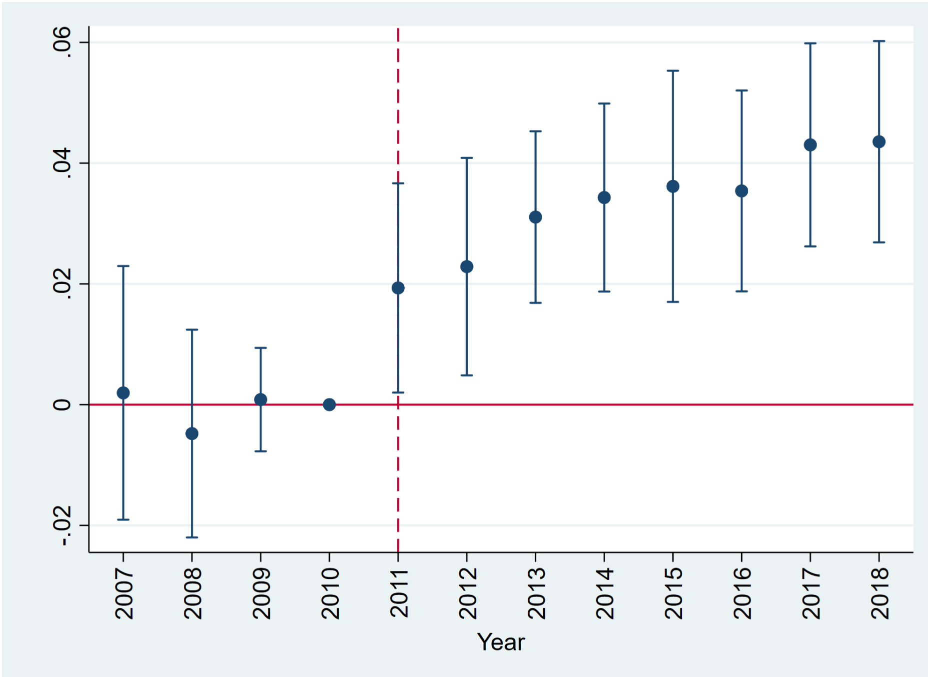
(a) Suppliers Inside (b) Suppliers Outside

Notes: This figure shows the log number of suppliers. The left panel shows the log number of suppliers inside the disaster area, whereas the right panel shows the log number of suppliers outside the disaster area.

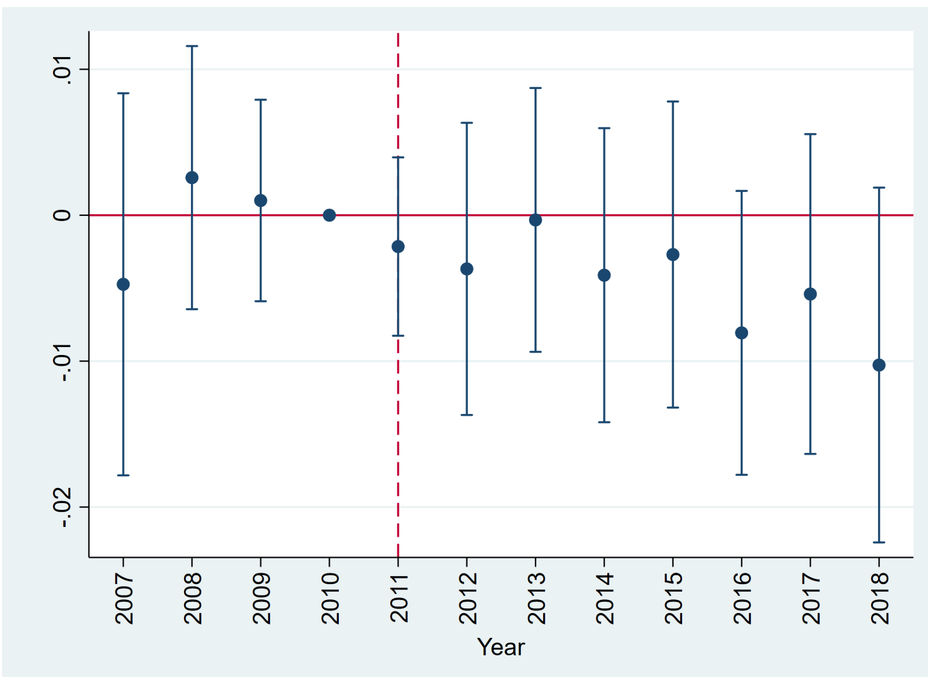
To verify whether the results observed in Figure 4 is driven by the increase in the number of suppliers outside the disaster area, we also break down the share into the denominator and the numerator and again exploit event study design. Figure 6 shows the results. The panel (a) shows the result for the denominator, i.e., the number of suppliers from outside the disaster area. We can observe that the number of suppliers located outside the disaster area increased for the treatment group after the earthquake. Thus, the results are purely driven by the increase in sourcing from suppliers outside the disaster area since 2011. Conversely, the panel

(b) with the total number of suppliers shows negative coefficients, but it is not statistically significant. This is understandable as the treatment group firms exploited opposite strategies between sourcing from inside and outside the disaster area as seen in Figure 5, and this resulted in slower growth in the total number of suppliers, compared to the control group firms.

Figure 6. Log Number of Suppliers



(a) The Number of Suppliers Outside



(b) Total Number of Suppliers

Notes: These figures plot the coefficients of the event study design specification with (a) the log number of suppliers outside the disaster area, and (b) the log total number of suppliers as outcomes. The whiskers indicate the 95% confidence intervals based on the clustering in the 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

4.4 Geography of Supply Chains

In this subsection, we narrow down our focus to examine the mechanism of the change in supply chains. In particular, we address the geography of the supply chains. Although we observed the expansion of the supply chains, this could imply both geographic diversification or concentration. We investigate whether firms regionalized (localized) their supply chains after a huge shock.

To investigate the structural change in the geography of supply chains due to the Great East Japan Earthquake, we construct a measure of concentration.

$$\text{Concentration}_{it} = \sum_j p_{ijt}^2, \tag{2}$$

where p_{ijt} is a share of suppliers in a prefecture j.[12] In the baseline, the average concentration of the treatment group is 0.17, and that of the control group is 0.39.

The measure could mechanically increase when a firm only loses a supplier and does not add an alternative one. To eliminate these cases, we restrict the sample to those firms that lost at least one supplier inside the disaster area and added at least one supplier outside the disaster area between 2007–2010 and 2011–2014.

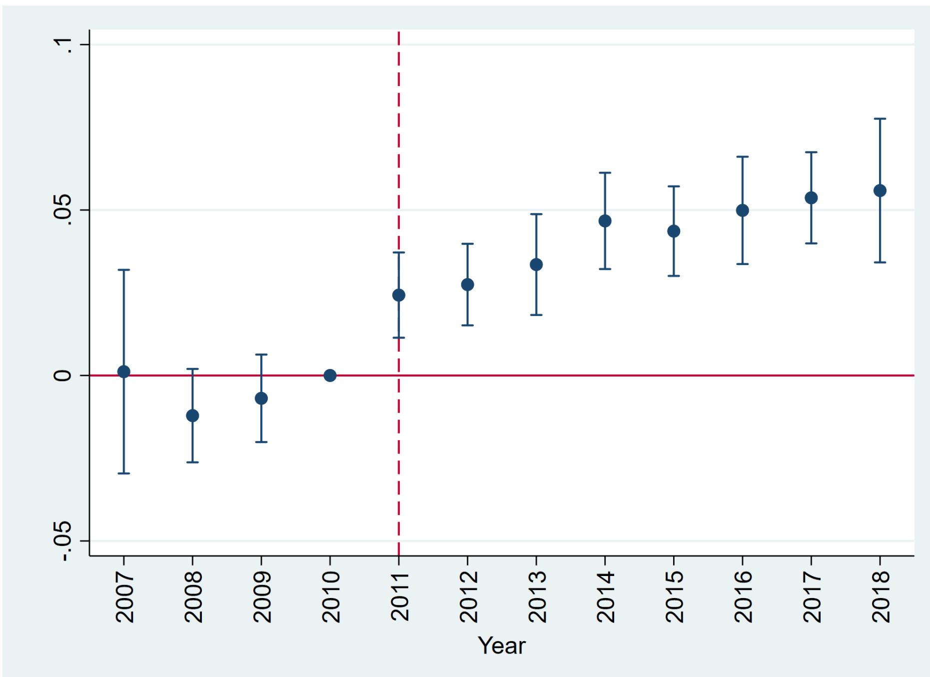
Figure 7 plots the coefficients of equation (1) while using the concentration measure defined in equation (2) as the outcome. The estimated coefficients are insignificant between 2007 and 2009. Strikingly, the coefficient becomes positive and significant after 2010 and shows a positive trend until 2018. The coefficient for 2011 is about 0.2 and that for 2018 becomes about 0.5. The mere 0.2 change in concentration measure could result from change in prefecture-wise supplier share by 10% and should be interpreted as a large change.[13] This finding implies that firms concentrated the supply chains prefecture-wise. Therefore, they overall expanded but geographically concentrated the supply chains simultaneously. This was implemented through regionalization/localization of the supply chains. We obtained similar results without the sample restriction.

We also conduct three additional robustness checks. First, we examine the distance to suppliers. The outcomes are median, maximum, minimum and standard deviation of the distance to suppliers. Figure 8 shows the results. The four panels confirm that the distance to suppliers became smaller since 2011. The maximum and minimum distance lowered,

[12] There are 47 prefectures in Japan.

[13] Suppose that a firm has 40% of suppliers in Prefecture A, 20% in Prefecture B, 20% in Prefecture C, 10% in Prefecture D, and the rest 10% in Prefecture E. This leads to concentration of 0.26. Then, suppose that the firms restructure the supply chains to have 40% of suppliers in Prefecture A, 20% in Prefecture B, 20% in Prefecture C, and 20% in Prefecture D, and no more in Prefecture E. This leads to concentration of 0.28. The change by 0.02 is driven by moving 10% of suppliers away from a prefecture.

Figure 7. Geographic Concentration



Notes: This figure plots the coefficients of the event study design specification with the concentration measure as an outcome while restricting the sample to those firms that lost at least one supplier inside the disaster area and added at least one supplier outside the disaster area between 2007–2010 and 2011–2014. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

which resulted in the decline in median distance and the standard deviation of the distance. Second, we examine the regional share of suppliers. Figure 9 shows the results. The share of suppliers in the same prefecture increased since 2011, whereas that in the same region does not show a clear pattern.

Third, we investigate whether new suppliers were concentrated in proximate areas. Specifically, we created a dummy variable that takes the value of one if a customer firm had a supplier that did not trade with in year $t-1$ but does in year t. Then, we split the dummy variable exclusively for the geographic distance bands: 0–10 km, 10–50 km, 50–100 km, 100–200 km, 200–300 km, 300–400 km, 400–500 km, and farther than 500 km from firms' headquarters. Figure 10 shows the estimated results for each distance in 2011, sorted by distance. The probability of having a new supplier after the earthquake is highest in the 10–50 km range, with estimates decreasing gradually as the distance goes beyond 50 km, and becoming insignificant beyond 400 km. In Figure A4 and A5, we plot the estimates for each year with a dummy defined for each distance band as an outcome. The overall trend is as follows. (i) There is a sharp jump in 2011. (ii) After 2011, the estimates become smaller and, in some cases, insignificant. (iii) Then, the estimates become significantly positive and either remain constant or gradually increase. However, the size of the effect is larger for dummies with smaller distances, confirming our finding that the earthquake led to the geographic concentration of the supply chains.

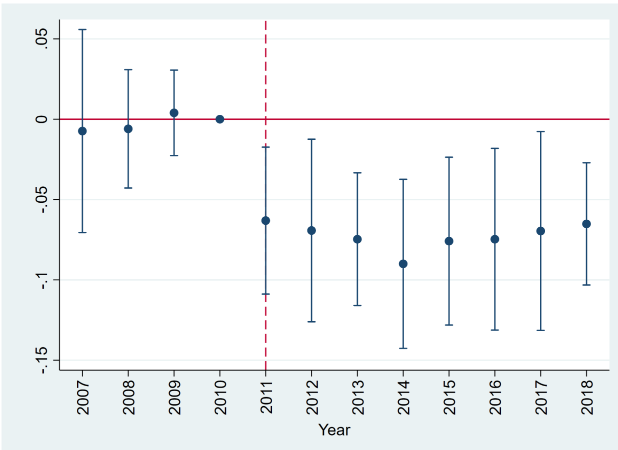
In addition, Appendix B show another set of robustness checks with propensity score matching (PSM) estimation. The details of the PSM estimation are explained in the Appendix. The results with PSM estimation are consistent with the results shown thus far and further confirm that firms in the treatment group geographically concentrated their supply chains.

Here, we would also like to mention the persistence of the effects. Figure 7 shows that the geographic concentration measure jumped immediately after the earthquake and continued to rise during the sample period. This is in line with Figure 5 panel (b) and Figure 6 panel (a), where we observe the number of suppliers outside the disaster area increased immediately after the earthquake and then followed a certain degree of an upward trend.

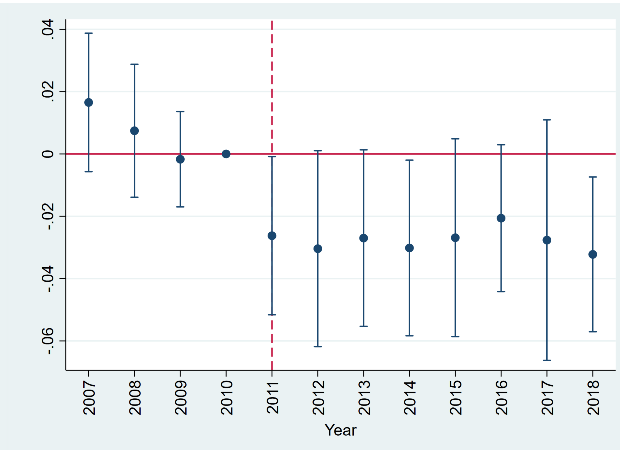
In contrast, Figure 8 shows that the distance measures followed rather flat trend since the earthquake. This can be explained along with the constant rise in concentration because there were constant churning of the supply chains, i.e., both creation and separation of new transactions. Figure 5 panel (b) shows that treatment firms substantially reduced the transactions with suppliers inside the disaster area immediately after the earthquake and continued to do so until 2018. Also, Figure 8 shows that firms found nearby suppliers immediately after the earthquake and continued to do so. Two opposite forces of separating with suppliers inside the disaster area and finding alternative ones nearby result in a sharp drop in distance measures in 2011 and a flatter trend since then.

Therefore, the results in Section 4.3 and 4.4 overall show an immediate jump and the positive trend afterwards of the concentration measure because of the increase in the number of suppliers located in close distance, i.e., the same or neighboring prefectures.

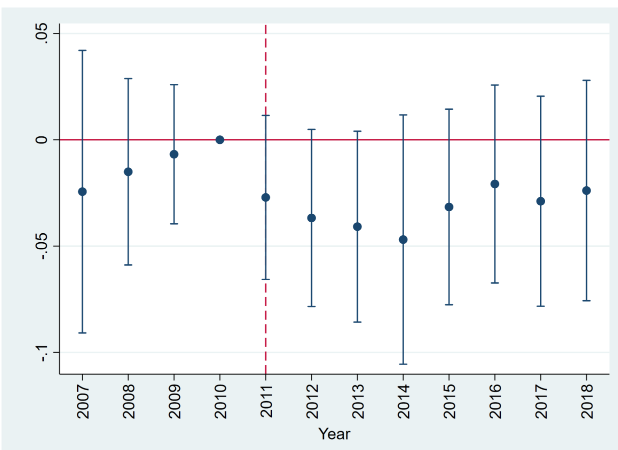
Figure 8. Distance to Suppliers



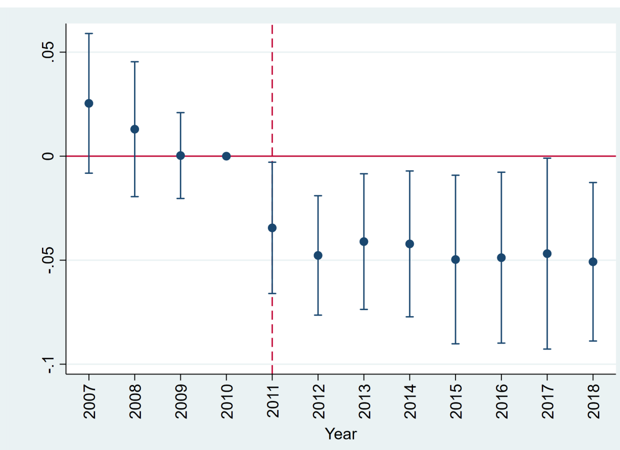
(a) Median Distance



(b) Maximum Distance



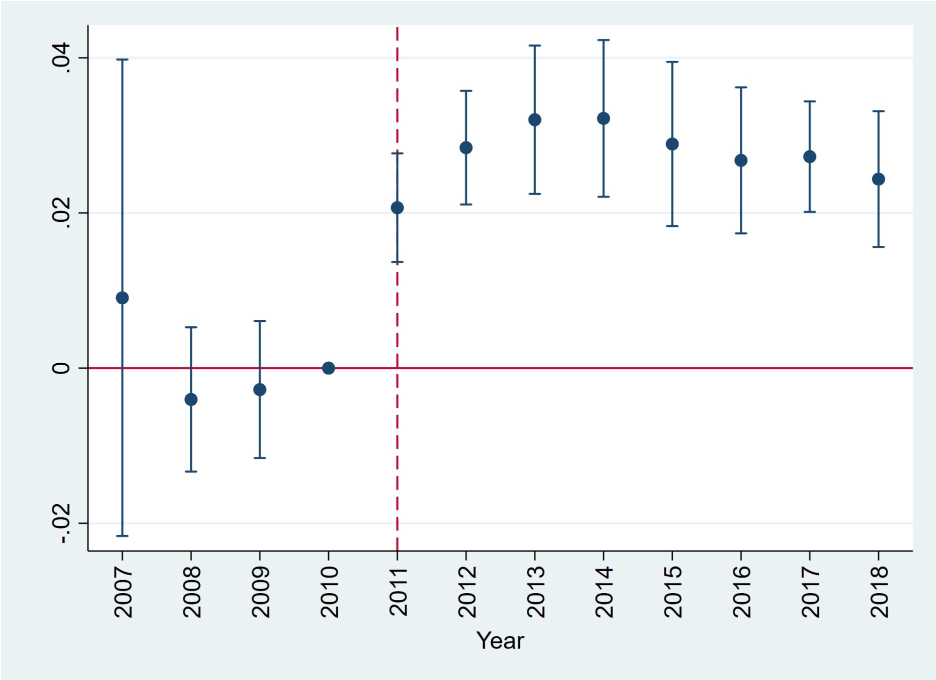
(c) Minimum Distance



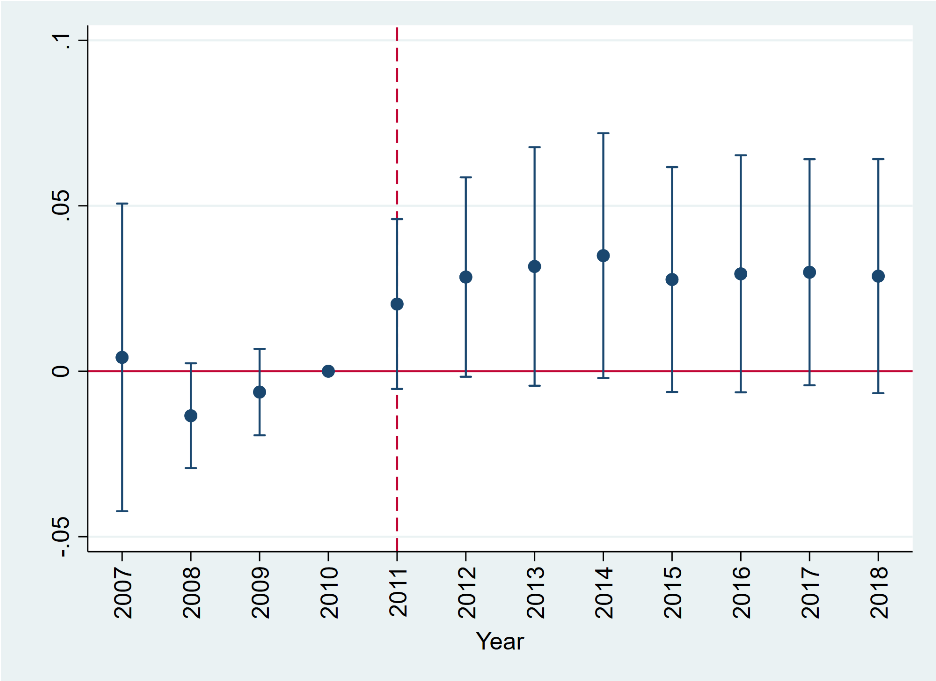
(d) SD of Distance

Notes: This figure plots the coefficients of the event study design specification with the distance to suppliers as an outcome. We restrict the sample to those firms that lost at least one supplier inside the disaster area and added at least one supplier outside the disaster area between 2007–2010 and 2011–2014. Four panels correspond to median, maximum, minimum, and standard deviation of the distance. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

Figure 9. Share of Suppliers in the Same Regional Unit



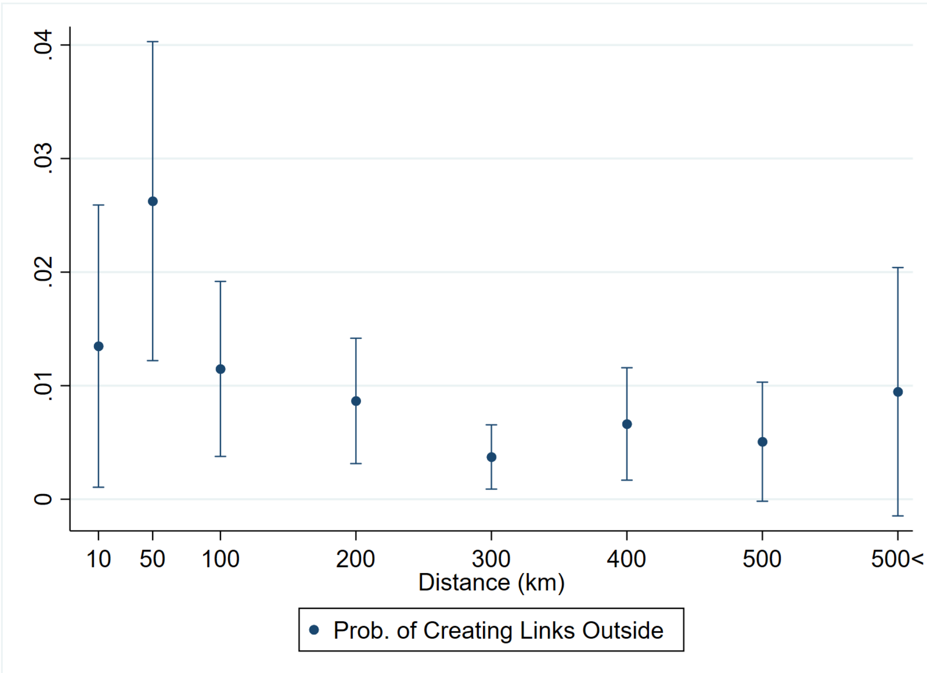
(a) Same Prefecture



(b) Same Region

Notes: This figure plots the coefficients of the event study design specification with the share of suppliers in the same regional unit as an outcome. We restrict the sample to those firms that lost at least one supplier inside the disaster area and added at least one supplier outside the disaster area between 2007–2010 and 2011–2014. Two panels correspond to the shares of suppliers in the same prefecture and that in the same region. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

Figure 10. Probability of Having A New Supplier Within Geographic Distance Bands



Notes: This figure plots the 2011 coefficients of the event study design with dummies of having a new supplier within geographic distance band as outcomes. The dummy variable takes the value of one if a firm had a new supplier that it did not trade with in year $t-1$ but newly do in year t. we split the dummy variable exclusively for the geographic distance bands: 0–10 km, 10–50 km, 50–100 km, 100–200 km, 200–300 km, 300–400 km, 400–500 km, and farther than 500 km from firms' headquarters. The x-axis 10 refers to "0–10 km", 50 refers to "10–50 km", 100 refers to "50–100 km", 200 refers to "100–200 km", 300 refers to "200–300 km", 400 refers to "300–400 km", 500 refers to "400–500 km", 500< refers to "over 500 km." The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates.

These provide a novel finding that, since the Great East Japan Earthquake, firms overall expanded their supplier network outside the disaster area but geographically concentrated the supply chains simultaneously. This may be in contrast to the belief that firms would only diversify their supply chains when risks and uncertainty exist. However, the finding should be understood with the context of radical changes. First, recently deglobalization has been discussed. Facing the deterioration of the US-China relationship, reportedly large firms in the US bring production and key facilities back to their home country.[14] Second, climate change increases the frequency of natural disasters and mounts the level of uncertainty. This is another force behind regionalization of the supply chains. Under these circumstances, firms have an incentive to geographically concentrate their supply chains. This paper contributes to the discussion by providing novel empirical evidence.

4.5 Role of Productivity

Here, we examine the impacts of firms' own productivity on supply chain restructuring. The question here is whether more productive firms are keeping the supply chains as they are or restructuring the supply chains after shocks. We run the following regression:

$$\begin{aligned} \text{Outcome}_{it} = & \sum_{t=-3}^{8} \beta_t^A D_i T_t \times \mathbf{1}\{\text{Prod}_i^{2010} \text{ above median}\} \\ & + \sum_{t=-3}^{8} \beta_t^B D_i T_t \times \mathbf{1}\{\text{Prod}_i^{2010} \text{ below median}\} \\ & + X_{it}\gamma + \eta_i + \tau_t + \epsilon_{it}. \end{aligned} \tag{3}$$

where D_i is a trading experience dummy with seller firms inside the disaster area before the earthquake, T_t is a time dummy excluding 2010, and X_{it} refers to firm covariates. $\mathbf{1}\{\text{Prod}_i^{2010} \text{ above median}\}$ is an indicator function that takes the value of one if the productivity level of firm i in 2010 is higher than the median productivity level, within the treatment group. Similarly, $\mathbf{1}\{\text{Prod}_i^{2010} \text{ below median}\}$ is an indicator function that takes the value of one if the productivity level of firm i in 2010 is lower than the median within the treatment group. Using balance sheet information, we estimate firm productivity following Ackerberg, Caves, and Frazer (2015). We also include firm fixed effects, η_i, and year-industry-prefecture fixed effects, τ_{jkt}. The standard errors are two-way clustered. We separately estimate β_t^A and β_t^B to compare how more productive firms behave differentially when compared to less

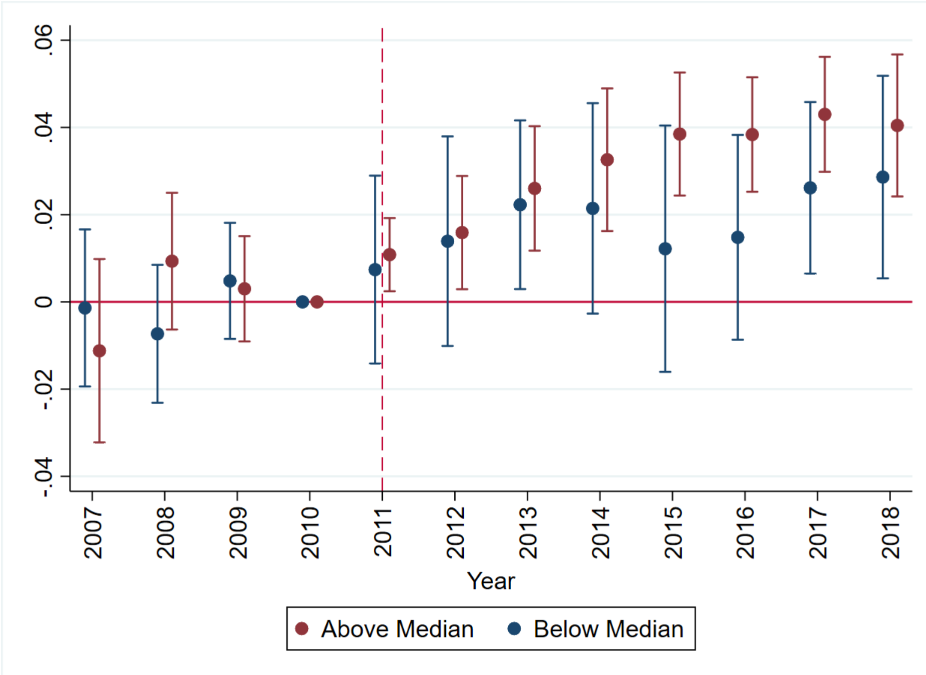
[14] Beene, R. July 5, 2022. "American Factories Are Making Stuff Again as CEOs Take Production Out of China." Bloomberg UK. https://www.bloomberg.com/news/articles/2022-07-05/us-factory-boom-heats-up-as-ceos-yank-production-out-of-china

productive ones. Finally, the outcomes are the number of suppliers from outside the disaster area and the total number of suppliers.

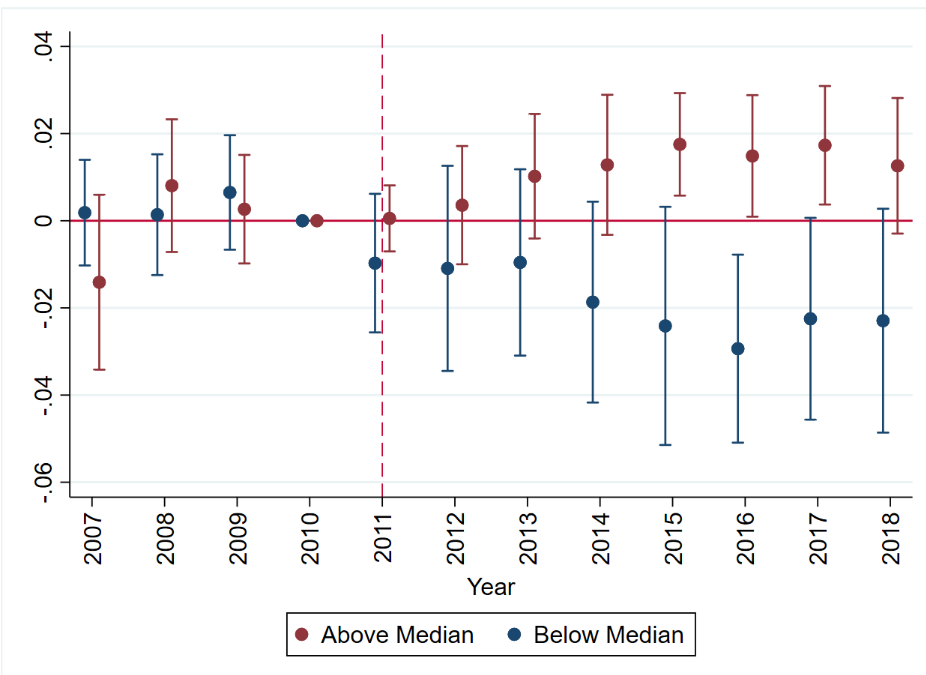
Figure 11 plots the coefficients of equation (4). Panel (a) shows the number of suppliers from outside the disaster area, and Panel (b) shows the total number of suppliers. In both panels, the estimated coefficients are insignificant between 2007 and 2009. In Panel (a), we observe that more productive firms increased the number of suppliers outside the disaster-hit area, while less productive firms did not increase the number as much. In Panel (b), we observe that firms with higher productivity either maintained or increased the number of suppliers after the earthquake. In comparison, firms with lower productivity tended to decrease the number of transactions in the long run.

From this result, we can argue that more productive firms more actively restructure supplier networks, rather than keeping the supply chains as they used to be. This suggests that more productive firms are superior to less productive ones not only in that they are better at production activities but also in that they are better at adjusting the supplier network. This would suggest one important factor behind superior performance by productive firms.

Figure 11. Role of Productivity: Log Number of Suppliers



(a) Log Number of Suppliers Outside



(b) Log Total Number of Suppliers

Notes: These figures plot the coefficients of the event study design specification with (a) the log number of suppliers outside the disaster area, and (b) the log total number of suppliers as outcomes. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code. The red dots indicate the point estimates of firms whose productivity is above the median among treated firms, and the blue dots indicate those of firms whose productivity is below the median. The red vertical dotted line represents the year when the earthquake occurred.

5 Conclusion

This paper is among the first ones to investigate supply chain restructuring after a huge exogenous shock to the existing supply chains. In particular, we studied the impacts of the Great East Japan Earthquake in 2011 on supply chain restructuring. To this end, we exploited a long-year panel of Japanese firm-to-firm transaction data between 2007 and 2018. We first found that the earthquake had large impacts on the existing supply chains and forced firms to restructure their supplier network. Further, firms outside the disaster area took two opposite supply chain strategies. On one hand, they suddenly decreased the number of suppliers inside the disaster area. On the other hand, they rapidly increased the number of suppliers outside the disaster area, leading to the overall diversification of their supply chains outside the disaster area. Moreover, we found that the earthquake worked as a persistent shock, rather than a temporary shock. Buyer firms continued to find suppliers outside the disaster area even after 7 years. It would be our future work to determine how the isolation from supply chains affected the disaster area, adding to the original damages caused by the Great East Japan Earthquake.

Second, we investigated the geography of the supply chains. The results show that firms geographically concentrated their supply chains while they overall expanded the network outside the disaster area. This is a novel finding regarding the impacts of the Great East Japan Earthquake and may be in contrast to the existing view. The long panel of firm-level transaction data enabled us to depict this unexpected result. The finding is robust across different measures of geographic concentration. Note also that the finding is in line with the recent discussion on deglobalization. Due to higher risks and mounting uncertainty, firms are motivated to bring not only production and key facilities but also suppliers nearby. This is also relevant to the discussion on the so-called headquarter effect (see, e.g., Kalnins and Lafontaine, 2013; Giroud, 2013). We could anticipate that climate change would also further accelerate the force for geographic concentration. This is an interesting topic to investigate with few preceding papers.

Finally, we addressed how firm productivity matters for the ability to restructuring the supply chains. We found that more productive firms are more actively adjusting supply chains compared to those less productive ones. This suggests that more productive firms are not only better at producing things but also better at adjusting their supply chains when shocks occur. This could be because of superior management capabilities that serves as an important factor behind their performance.

These results are informative in terms of supply chain dynamics and resilience of the economy during a crisis. We believe that more research should be conducted to address what policies could mitigate supply chain disruptions at the macro level and support firms to keep their operations at the micro level.

6 Reference

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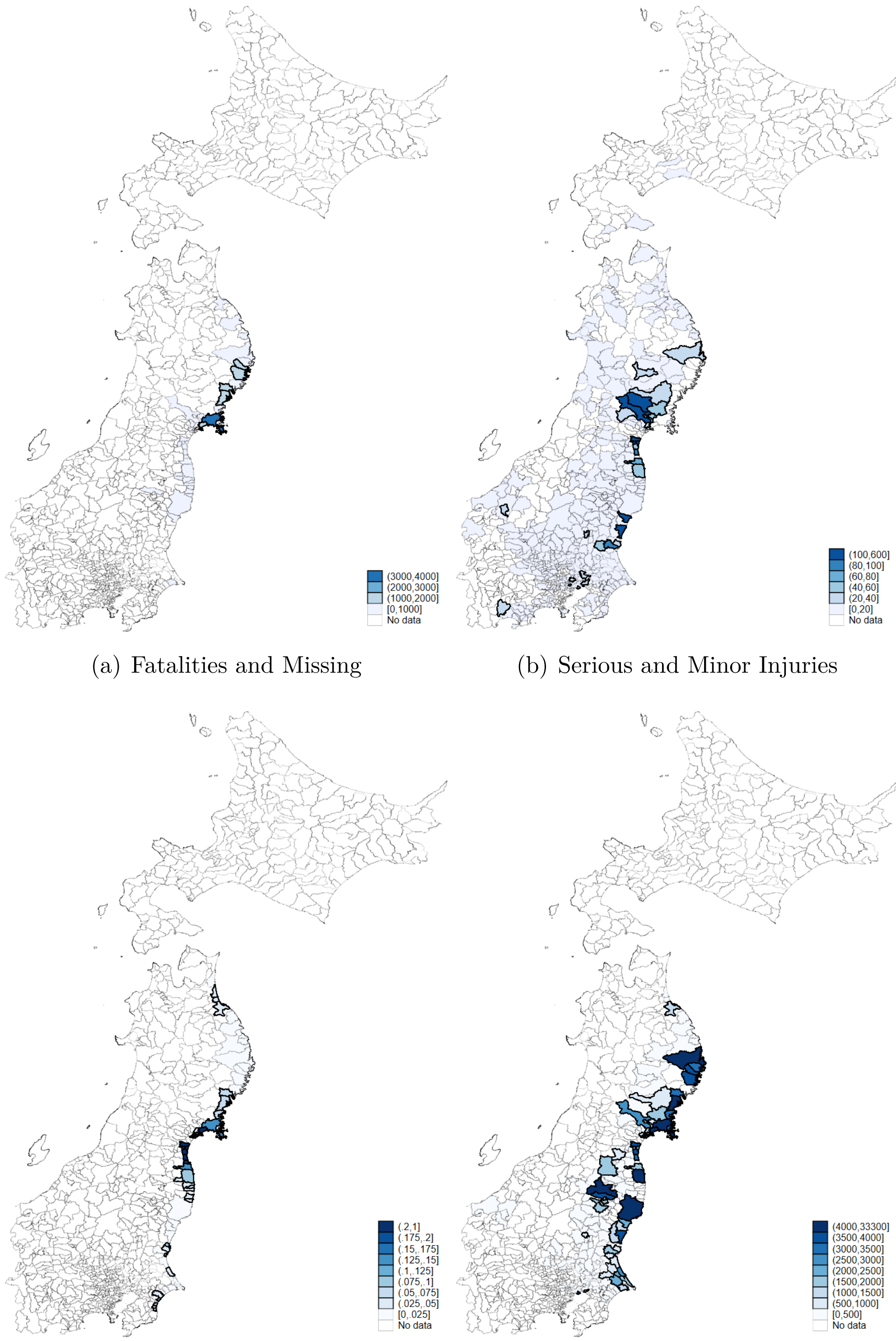
A Appendix Tables and Figures

Figure A1. The Geographical Distribution of Disaster Damages



(a) Fatalities and Missing

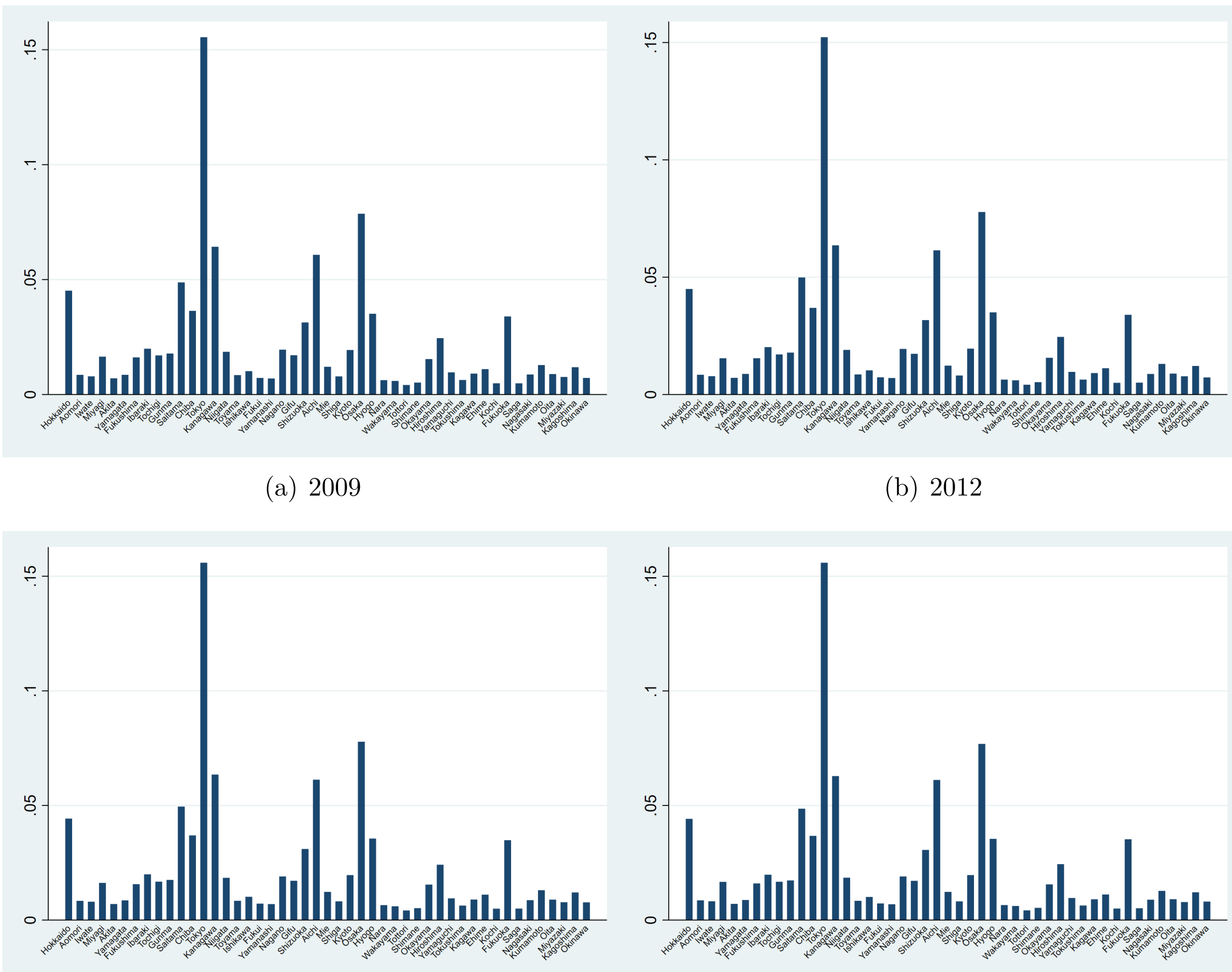
(b) Serious and Minor Injuries

(c) Share of Flooded Area

(d) Demolished Structures

Notes: The figure depicts the geographic distribution of the damages caused by the disaster. Panel (a) shows the number of fatalities and missing, (b) shows the number of serious and minor injuries, (c) shows the share of flooded area, and (d) shows the number of demolished structures in each municipality, respectively. *Source*: Reconstruction Agency, Government of Japan.

Figure A2. Share of Firms by Prefecture

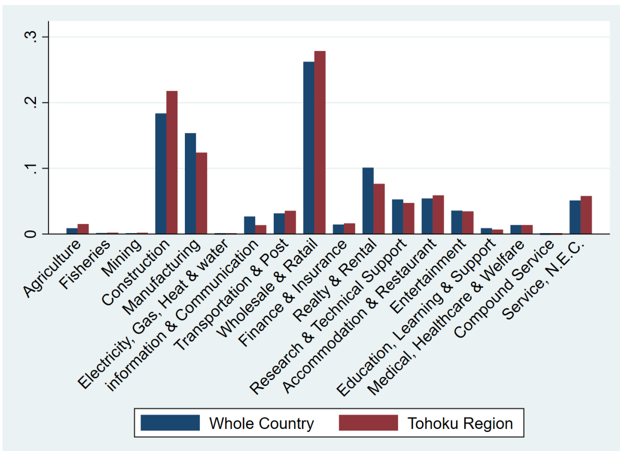


(a) 2009 (b) 2012

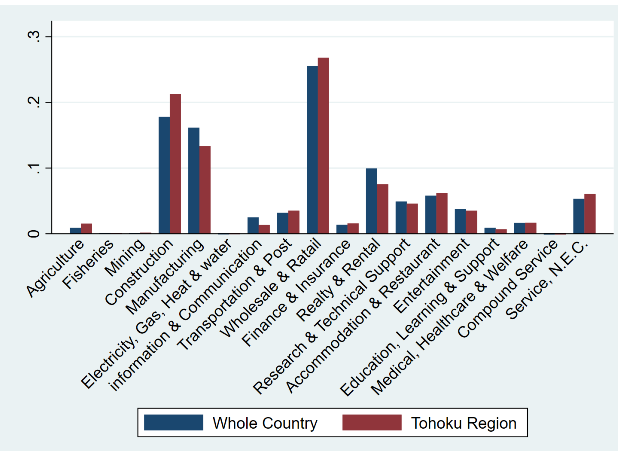
(c) 2014 (d) 2016

Notes: Each panel shows fraction of firms by prefecture. Panel (a) corresponds to 2009, panel (b) corresponds to 2012, panel (c) corresponds to 2014, and panel (d) corresponds to 2016.
Source: Economic Census for Business Frame and Economic Census for Business Activity conducted by Ministry of Economy, Industry and Trade (METI) and Ministry of Internal Affairs and Communications (MIC).

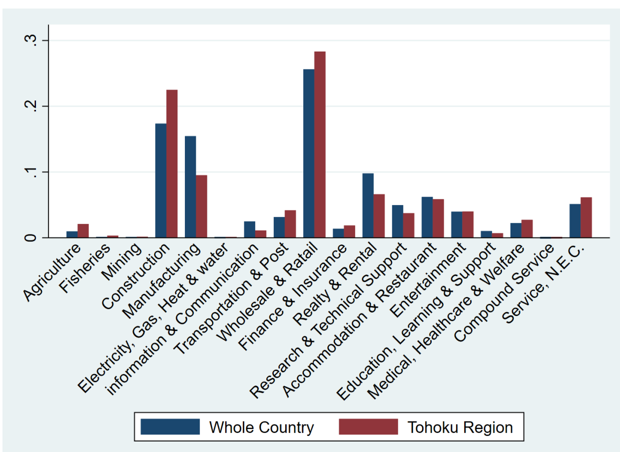
Figure A3. Share of industries: Entire Country and Disaster-hit Area



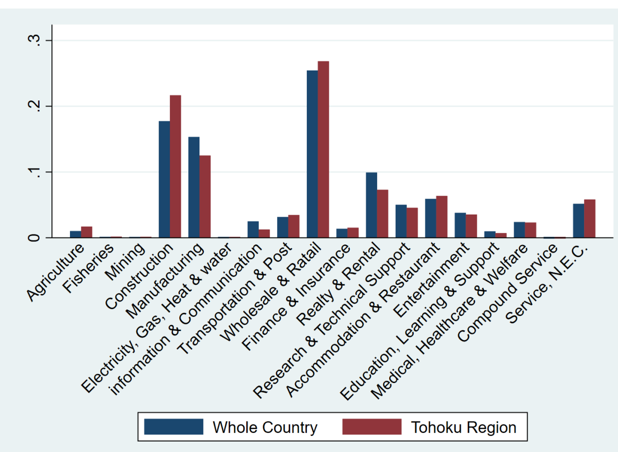
(a) 2009



(b) 2012



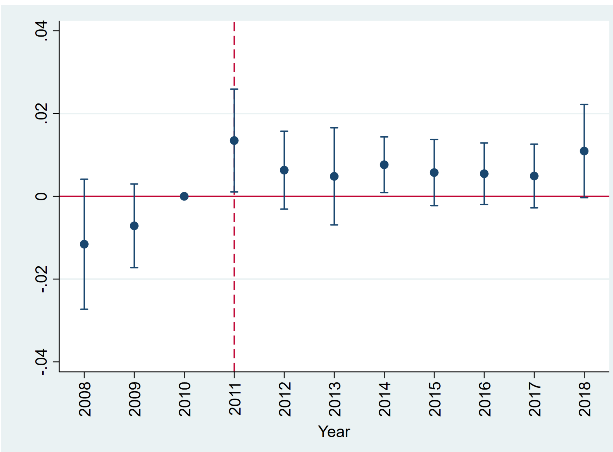
(c) 2014



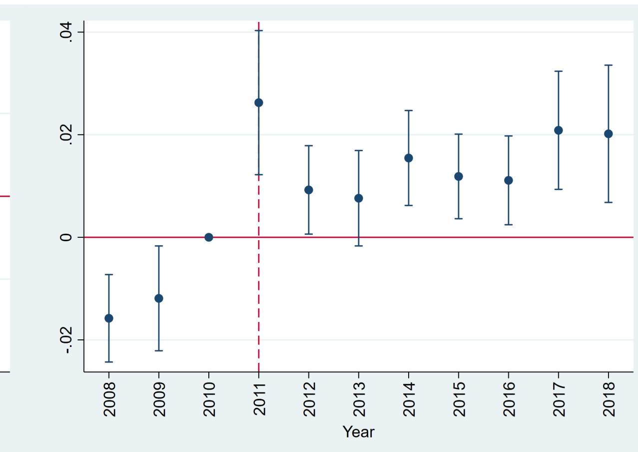
(d) 2016

Notes: Each panel shows fraction of firms by industry in the disaster area and entire country, respectively. Red bars are for the disaster area, and blue bars are for the entire country. Panel (a) corresponds to 2009, panel (b) corresponds to 2012, panel (c) corresponds to 2014, and panel (d) corresponds to 2016.
Source: Economic Census for Business Frame and Economic Census for Business Activity conducted by Ministry of Economy, Industry and Trade (METI) and Ministry of Internal Affairs and Communications (MIC).

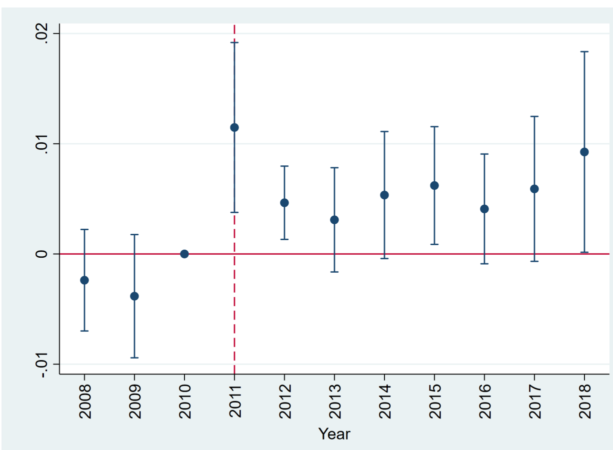
Figure A4. Probability of Having A New Supplier Within Geographic Distance Bands



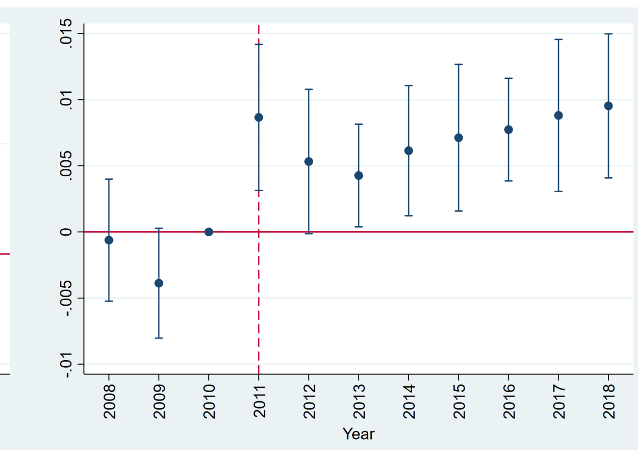
(a) 0–10km



(b) 10–50km



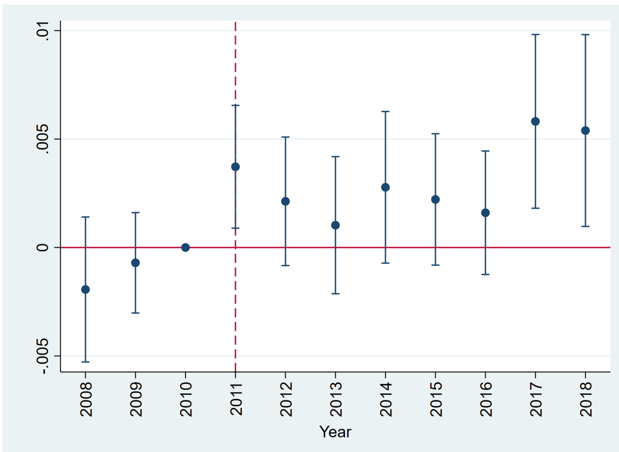
(c) 50–100km



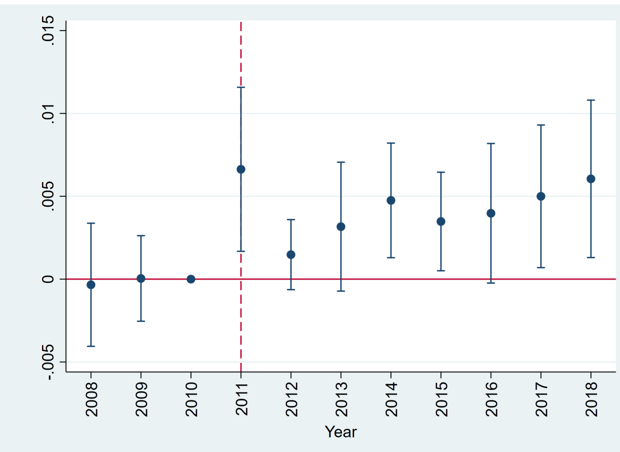
(d) 100–200km

Notes: This figure plots the coefficients of the event study design with the newly created link dummies as outcomes. The dummy variable takes one if a firm has a link that did not exist in year $t-1$ but was created in year t. We split the geographical distance of links as follows: 0–10 km, 10–50 km, 50–100 km, 100–200 km, 200–300 km, 300–400 km, 400–500 km, and more than 500 km from firms' headquarters. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

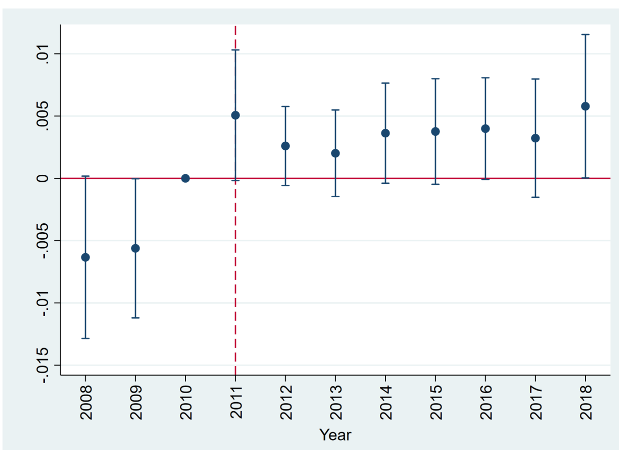
Figure A5. Probability of Having A New Supplier Within Geographic Distance Bands, *Cont'd*



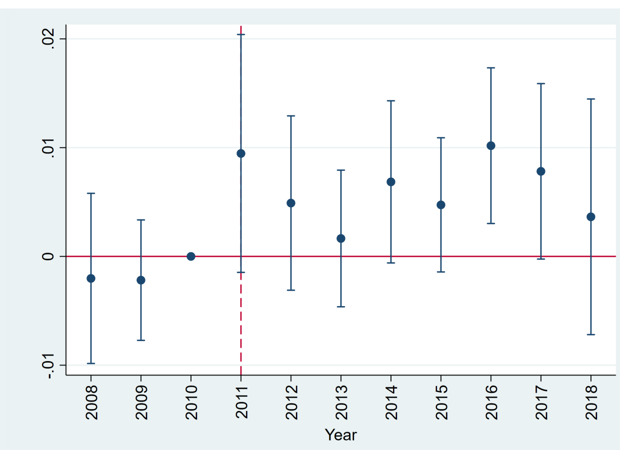
(a) 200–300km



(b) 300–400km



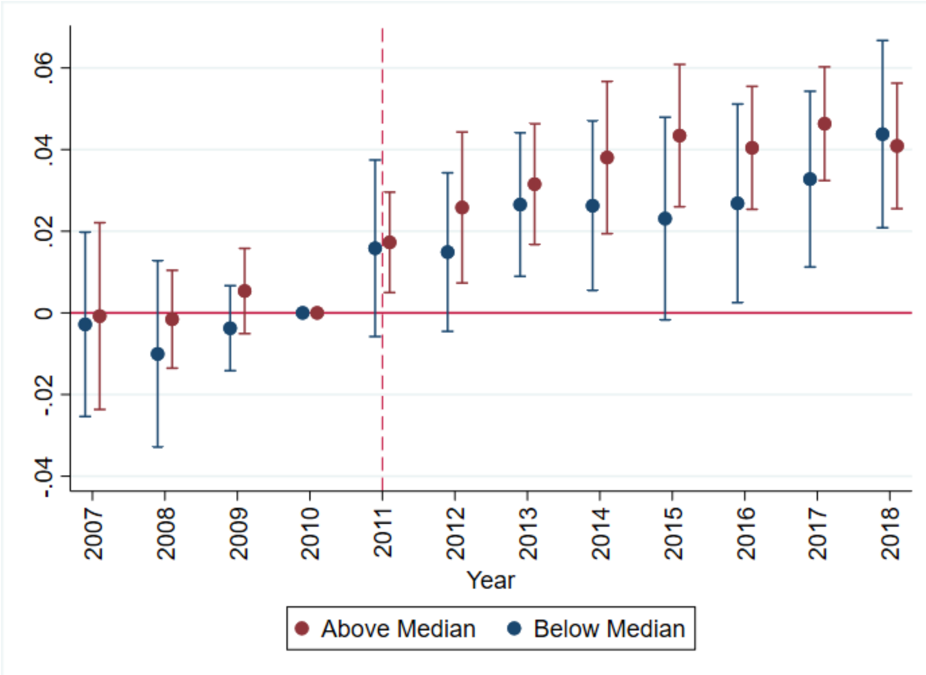
(c) 400–500km



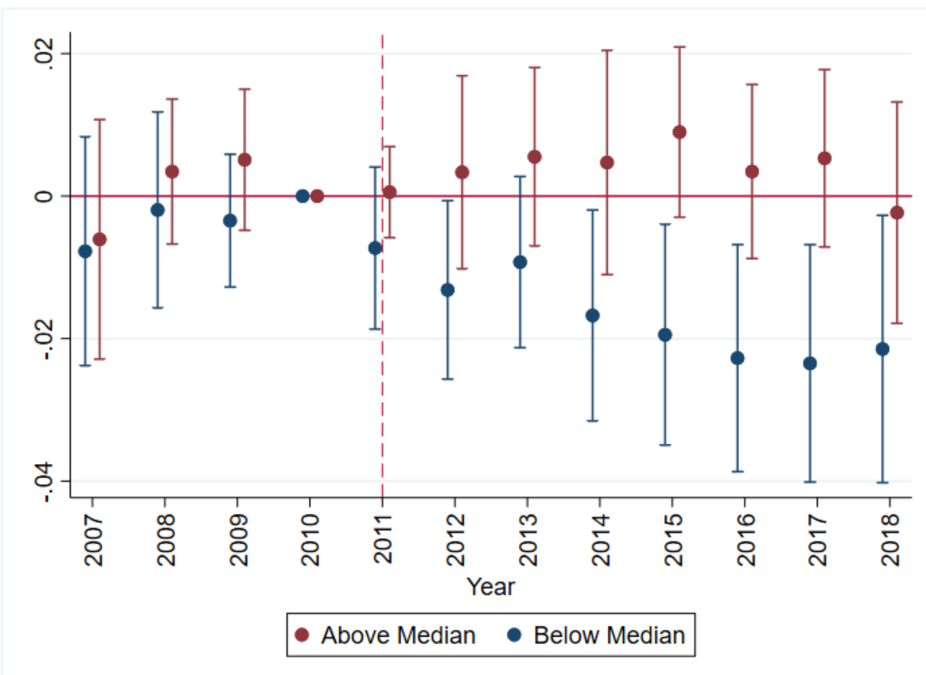
(d) 500km–

Notes: This figure plots the coefficients of the event study design with the newly created link dummies as outcomes. The dummy variable takes one if a firm has a link that did not exist in year $t-1$ but was created in year t. We split the geographical distance of links as follows: 0–10 km, 10–50 km, 50–100 km, 100–200 km, 200–300 km, 300–400 km, 400–500 km, and more than 500 km from firms' headquarters. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

Figure A6. Role of Productivity: Log Number of Suppliers, Labor Productivity



(a) Log Number of Suppliers Outside



(b) Log Total Number of Suppliers

Notes: These figures plot the coefficients of the event study design specification with (a) the log number of suppliers outside the disaster area, and (b) the log total number of suppliers as outcomes. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code. The red dots indicate the point estimates of firms whose productivity is above the median among treated firms, and the blue dots indicate those of firms whose productivity is below the median. The red vertical dotted line represents the year when the earthquake occurred.

B Appendix Propensity Score Matching Estimation Results

This section provides the results with Propensity Score Matching (PSM) estimation as robustness checks. The treatment and control groups may differ regarding firm size and other characteristics. This difference between both groups could result in biased estimates since firms' supplier choice may be different between the two groups even after controlling for firms' characteristics. The purpose of this section is to mitigate these concerns, and we conduct PSM estimation.

First, we estimate propensity scores with a logit model that controlled for firm age, size, the total number of customers and suppliers, and distance to the disaster area, which we also controlled for in the baseline estimation. We took the average values of each covariate between 2007–2010, i.e., the period before the earthquake. We also controlled for the 2-digit industry dummy and the prefecture dummy in the estimation. Second, based on the estimated propensity scores, we selecte firms in the control group to correspond one-to-one to those firms in the treatment group. Table B1 shows the mean values of each variable before and after matching separately in Unmatched (U) and Matched (M) rows. We can see a difference in the mean values of each variable between the treatment and control groups. The right-most column shows the results of the balancing t-test. After matching, we find that the sample has much smaller difference in covariates between treatment and control groups, suggesting that the matching works effectively.

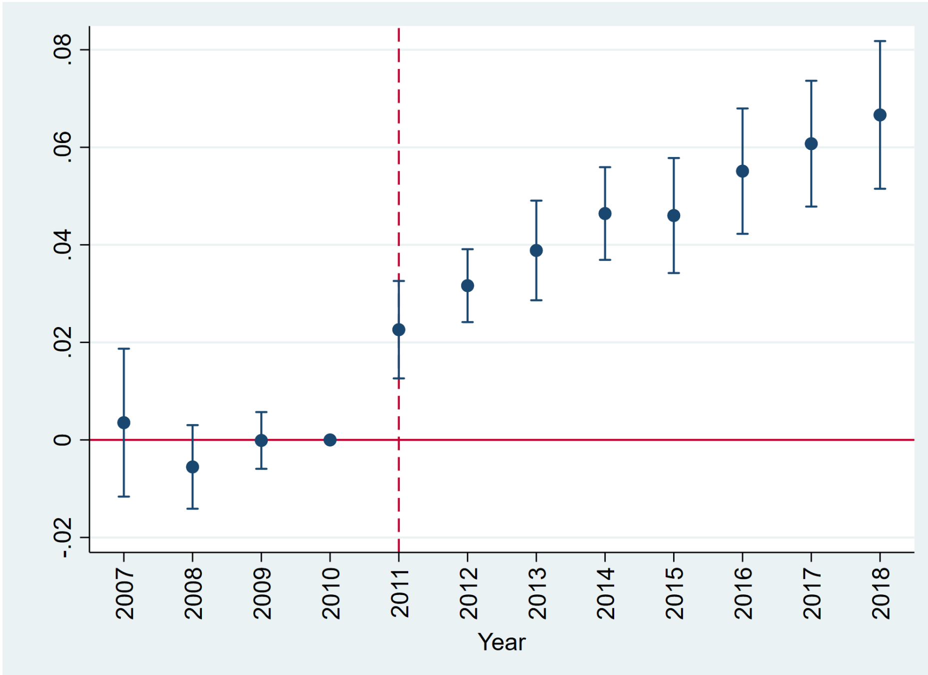
Figure B1 and B2 presents the estimation results which corresponds to Figure 4 and 6. Figure B3 shows the results of the event study estimation with the concentration measure as an outcome. The concentration measure increased sharply since the Great East Japan Earthquake, as shown in Figure 7. The results of Figure B4 correspond to the baseline result of Figure 8. Similarly, Figure B5 shows the result with the share of suppliers in the same regional unit as an outcome, corresponding to Figure 9. Figure B6 is the PSM estimation result that corresponds to the baseline result shown in Figure 10. Figures B7 and B8 show the PSM estimation results corresponding to Appendix A Figures A4 and A5. Figure B9 shows the results corresponding to Figure 11. Figures B10 show the results corresponding to the estimation results using labor productivity instead of ACF productivity (Appendix A Figures A6). All results shown here are similar to those obtained in the baseline estimation and confirm that our findings are robust.

Table B1. Balancing t-Test After Propensity Score Matching

Variable	Match	Treated	Control	Bias	t-stat
Firm Size	U	3.142	2.287	57.8	44.93***
	M	3.134	3.152	-1.2	-0.52
Number of Transaction Partners	U	2.481	1.901	64.9	50.11***
	M	2.474	2.491	-1.9	-0.79
Firm Age	U	31.76	28.861	17.6	12.08***
	M	31.706	32.11	-2.5	-1.13
Distance to The Disaster Area	U	260.79	484.28	-73.4	-42.25***
	M	261.36	259.74	0.5	0.31

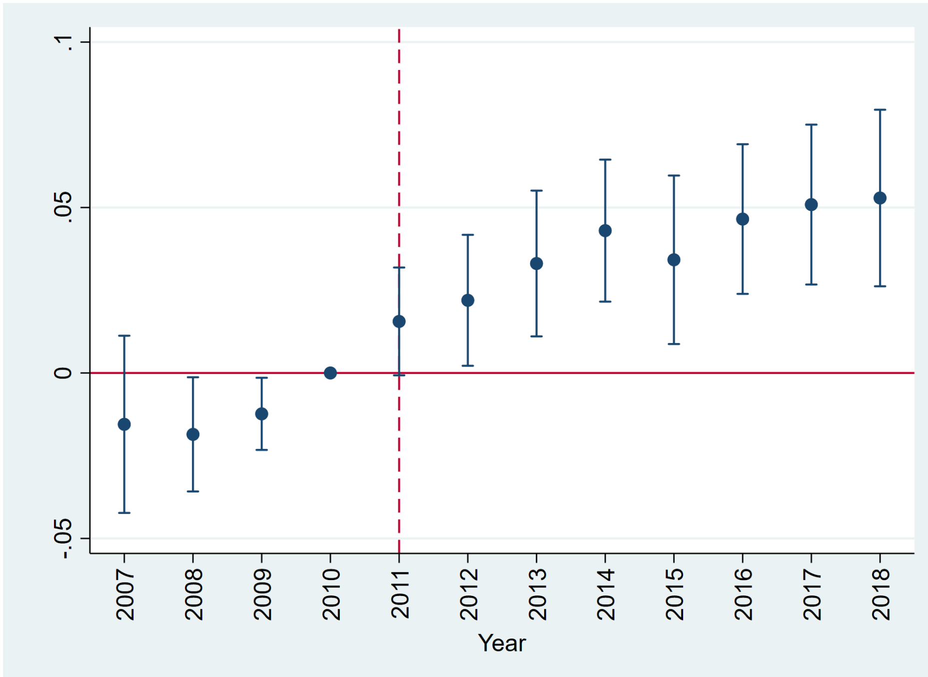
Notes: Firm Size and Number of Transaction Partners refer to the log number of workers and the total number of suppliers and customers, respectively. Columns of Treated and Control show the mean values of each variable. ***, **, and * denotes statistical significance at the 1%, 5%, and 10% levels, respectively. t-stat denotes the results of balancing t-test for each matched and unmatched sample.

Figure B1. Share of Suppliers Outside the Disaster Area

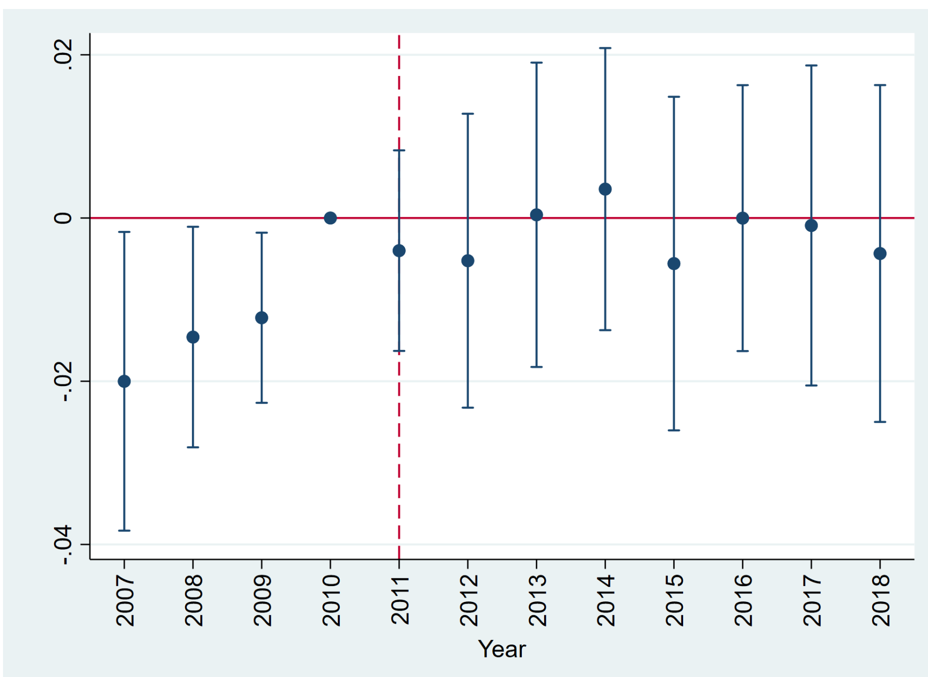


Notes: This figure plots the coefficients of the event study design specification with the share of suppliers located outside the disaster area as an outcome. The whiskers indicate the 95% confidence intervals based on the clustering in the 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

Figure B2. Log Number of Suppliers



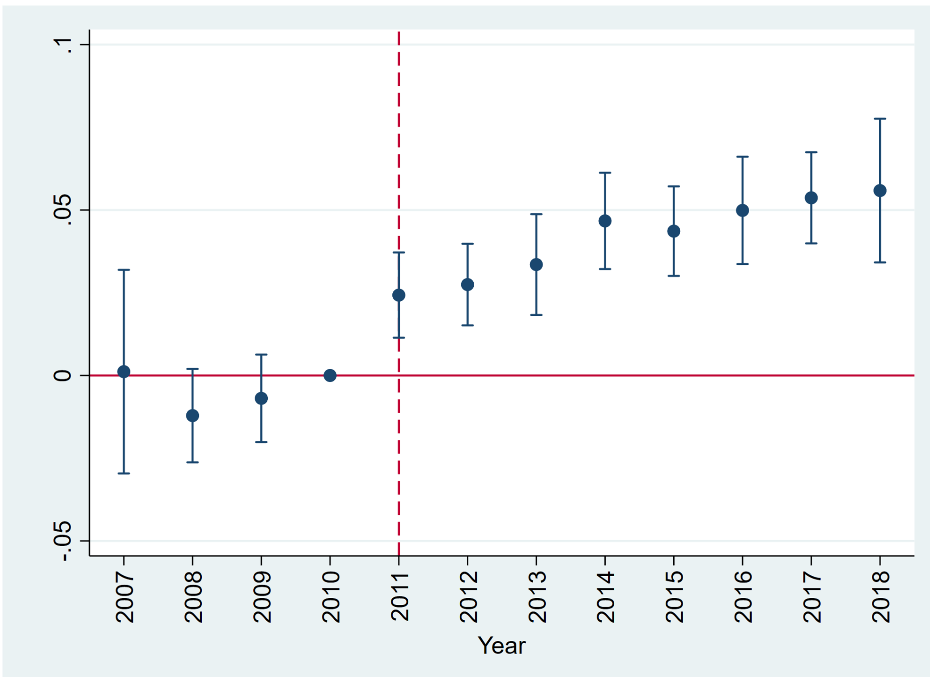
(a) The Number of Suppliers Outside



(b) Total Number of Suppliers

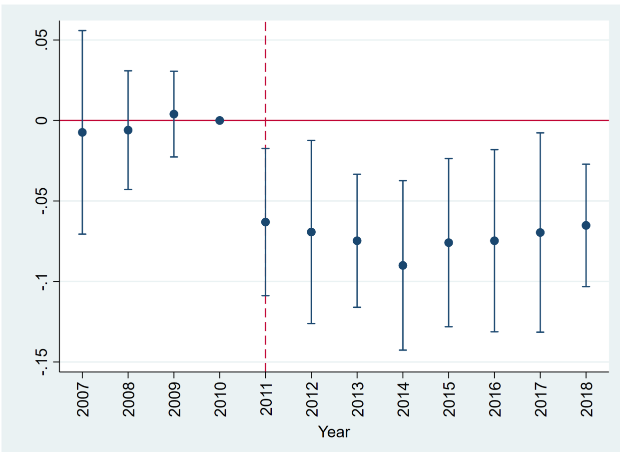
Notes: These figures plot the coefficients of the event study design specification with (a) the log number of suppliers outside the disaster area, and (b) the log total number of suppliers as outcomes. The whiskers indicate the 95% confidence intervals based on the clustering in the 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

Figure B3. Geographic Concentration

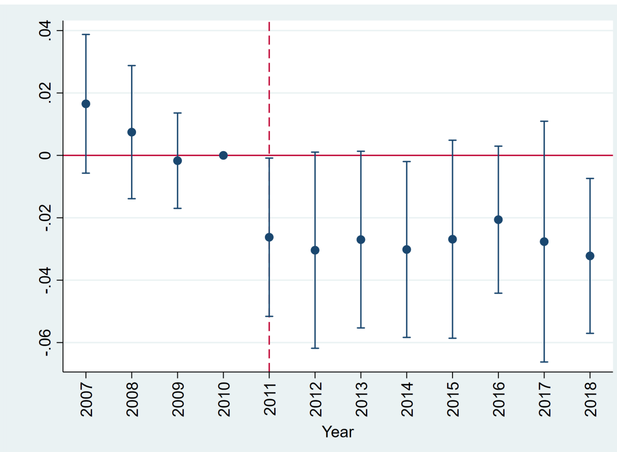


Notes: This figure plots the coefficients of the event study design specification with the concentration measure as an outcome while restricting the sample to those firms that lost at least one supplier inside the disaster area and added at least one supplier outside the disaster area between 2007–2010 and 2011–2014. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

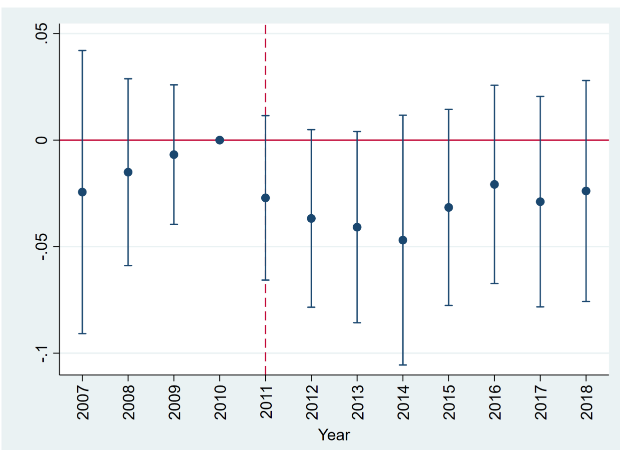
Figure B4. Distance to Suppliers



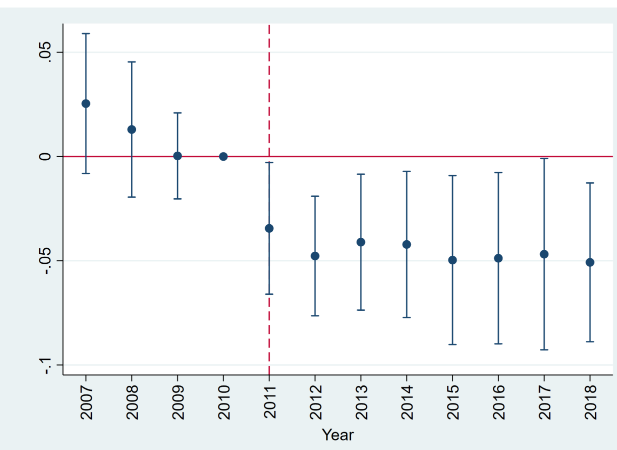
(a) Median Distance



(b) Maximum Distance



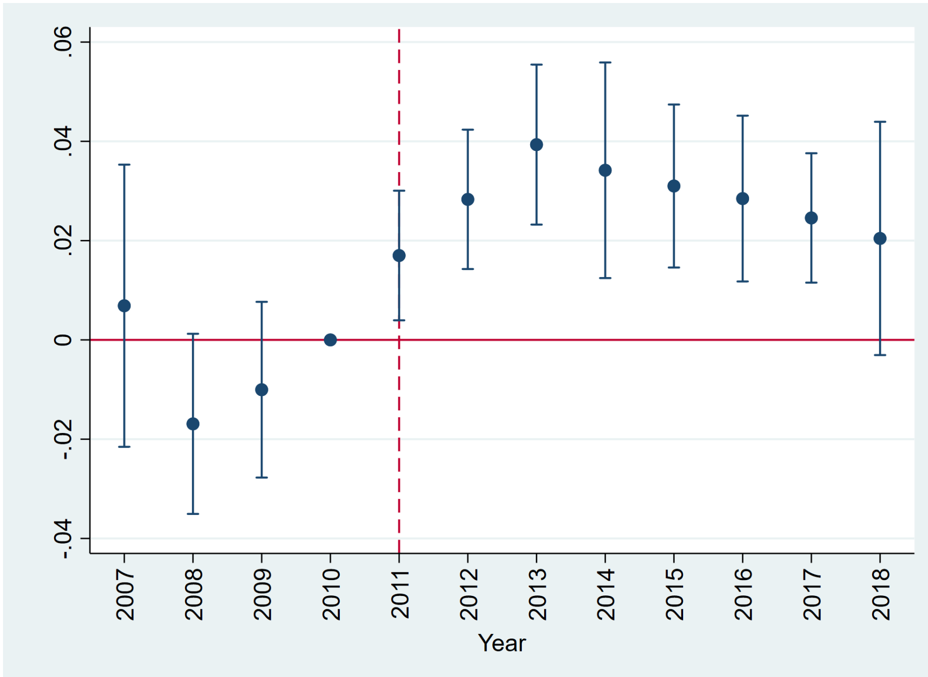
(c) Minimum Distance



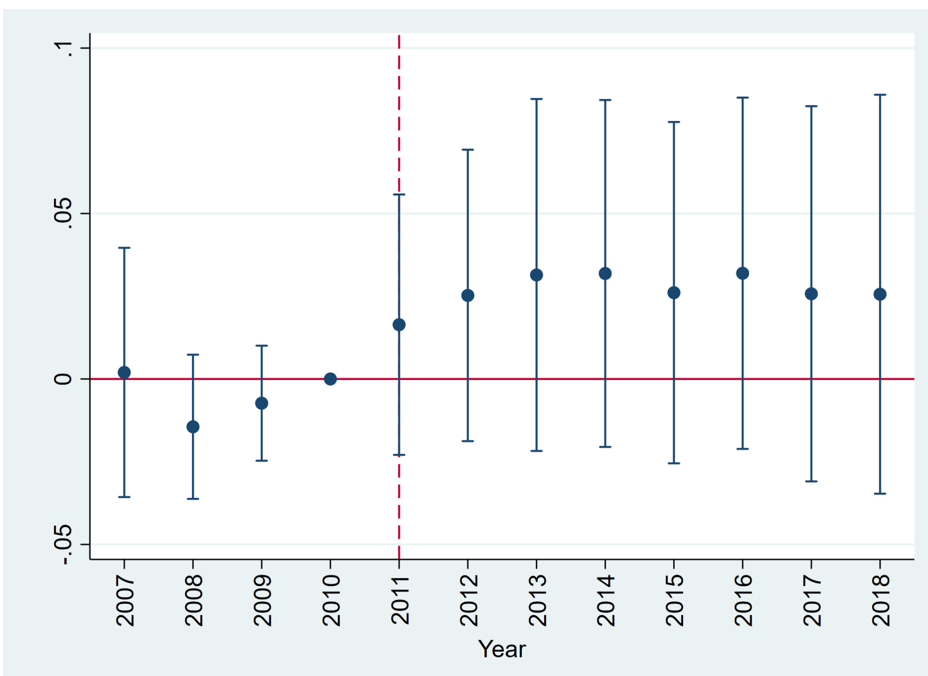
(d) SD of Distance

Notes: This figure plots the coefficients of the event study design specification with the distance to suppliers as an outcome. We restrict the sample to those firms that lost at least one supplier inside the disaster area and added at least one supplier outside the disaster area between 2007–2010 and 2011–2014. Four panels correspond to median, maximum, minimum, and standard deviation of the distance. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

Figure B5. Share of Suppliers in the Same Regional Unit



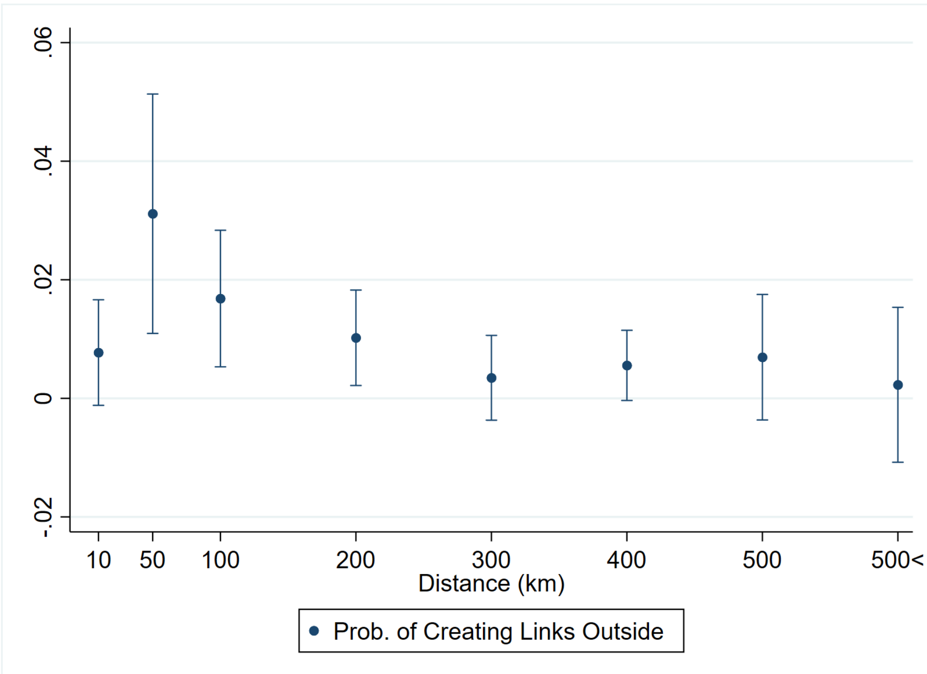
(a) Same Prefecture



(b) Same Region

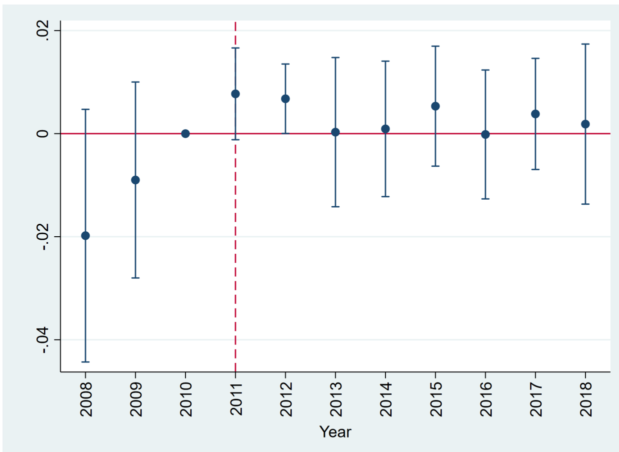
Notes: This figure plots the coefficients of the event study design specification with the share of suppliers in the same regional unit as an outcome. We restrict the sample to those firms that lost at least one supplier inside the disaster area and added at least one supplier outside the disaster area between 2007–2010 and 2011–2014. Two panels correspond to the shares of suppliers in the same prefecture and that in the same region. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

Figure B6. Probability of Having A New Supplier Within Geographic Distance Bands

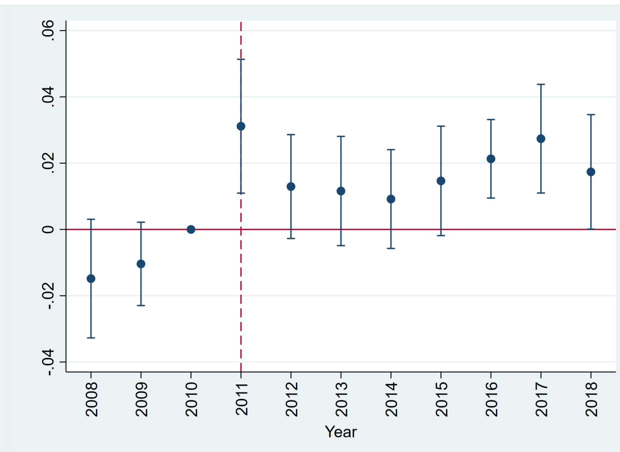


Notes: This figure plots the 2011 coefficients of the event study design with dummies of having a new supplier within geographic distance band as outcomes. The dummy variable takes the value of one if a firm had a new supplier that it did not trade with in year $t-1$ but newly do in year t. we split the dummy variable exclusively for the geographic distance bands: 0–10 km, 10–50 km, 50–100 km, 100–200 km, 200–300 km, 300–400 km, 400–500 km, and farther than 500 km from firms' headquarters. The x-axis 10 refers to "0–10 km", 50 refers to "10–50 km", 100 refers to "50–100 km", 200 refers to "100–200 km", 300 refers to "200–300 km", 400 refers to "300–400 km", 500 refers to "400–500 km", 500$<$ refers to "over 500 km." The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates.

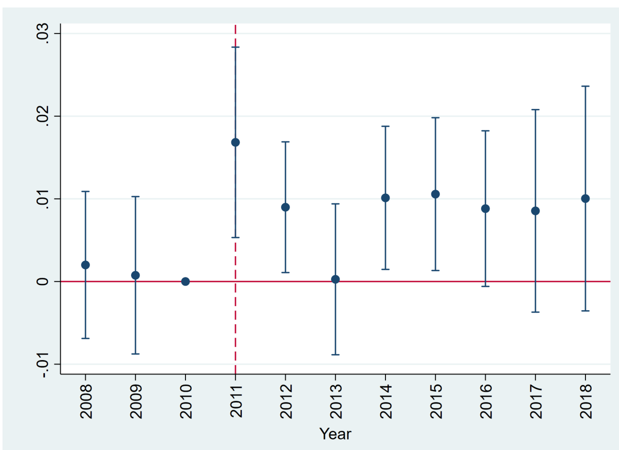
Figure B7. Probability of Having A New Supplier Within Geographic Distance Bands



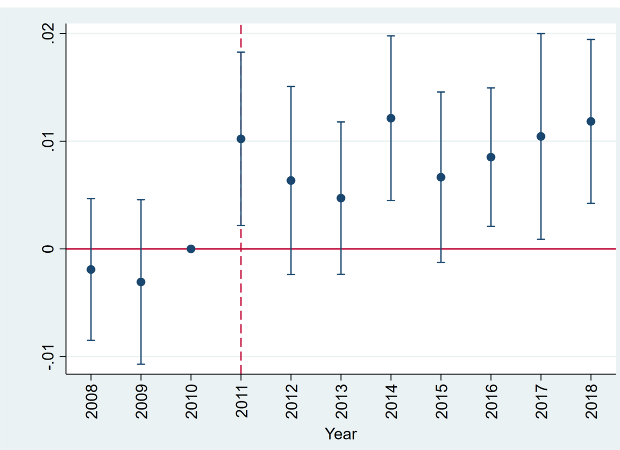
(a) 0–10km



(b) 10–50km



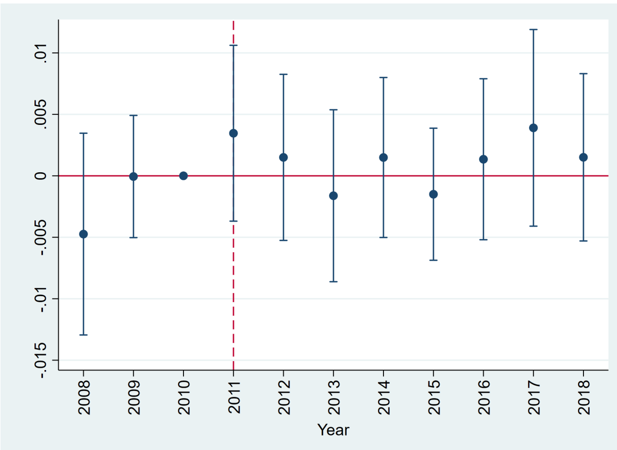
(c) 50–100km



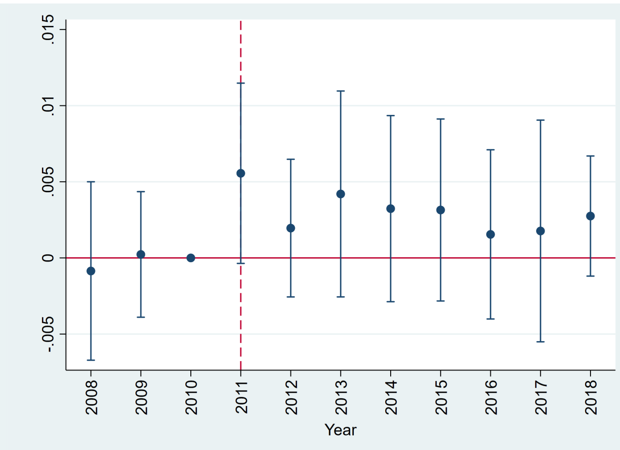
(d) 100–200km

Notes: This figure plots the coefficients of the event study design with the newly created link dummies as outcomes. The dummy variable takes one if a firm has a link that did not exist in year $t-1$ but was created in year t. We split the geographical distance of links as follows: 0–10 km, 10–50 km, 50–100 km, 100–200 km, 200–300 km, 300–400 km, 400–500 km, and more than 500 km from firms' headquarters. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

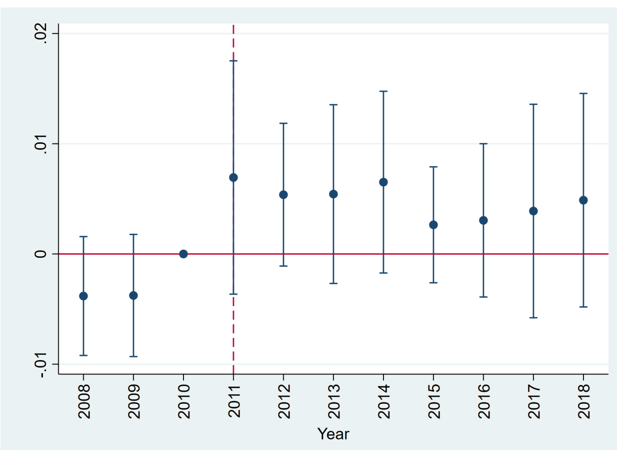
Figure B8. Probability of Having A New Supplier Within Geographic Distance Bands, *Cont'd*



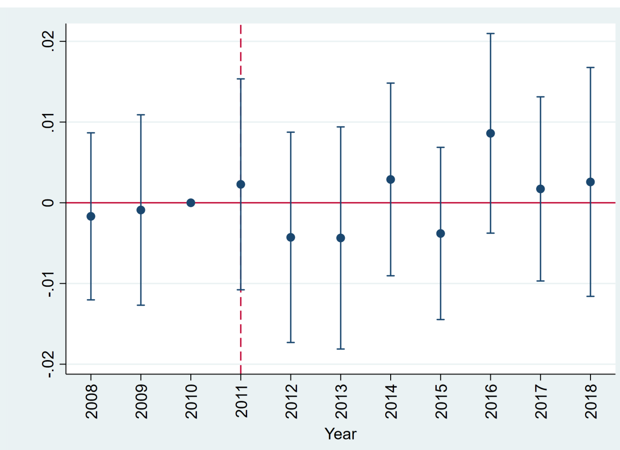
(a) 200–300km



(b) 300–400km



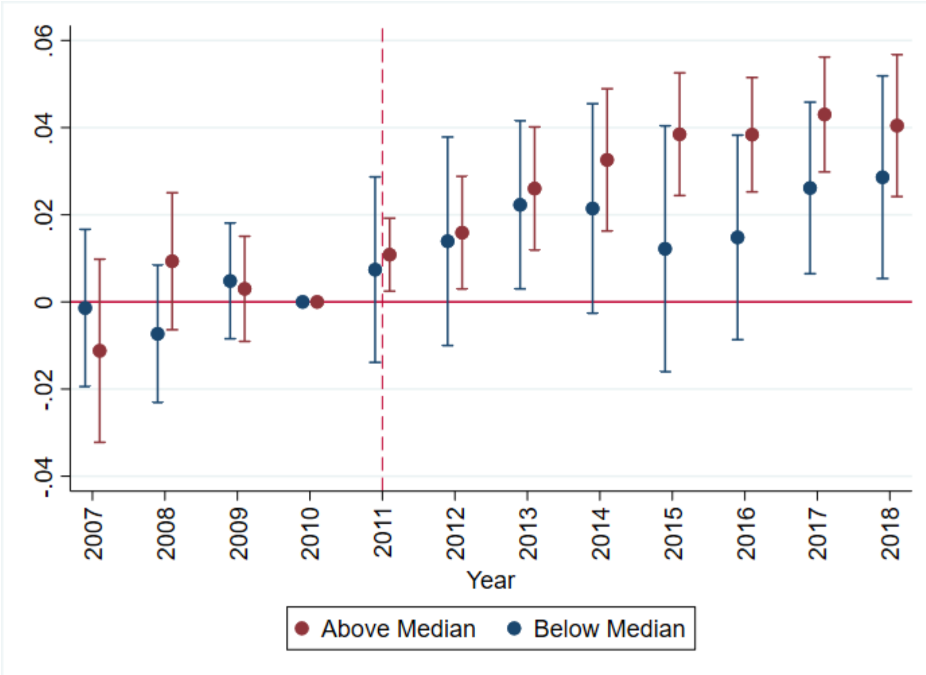
(c) 400–500km



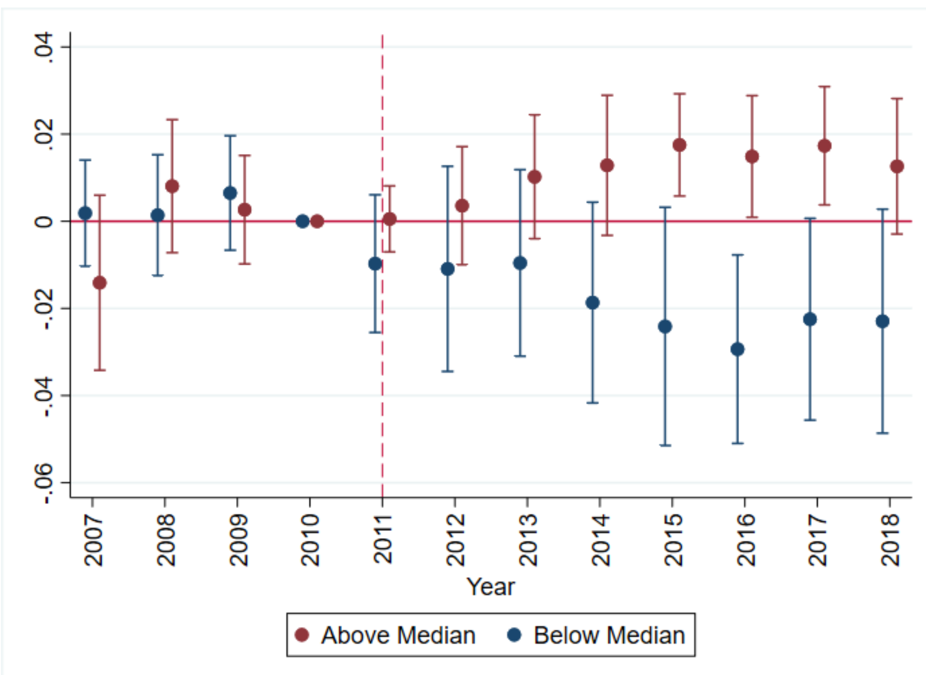
(d) 500km–

Notes: This figure plots the coefficients of the event study design with the newly created link dummies as outcomes. The dummy variable takes one if a firm has a link that did not exist in year $t-1$ but was created in year t. We split the geographical distance of links as follows: 0–10 km, 10–50 km, 50–100 km, 100–200 km, 200–300 km, 300–400 km, 400–500 km, and more than 500 km from firms' headquarters. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code, and the dots indicate the point estimates. The red vertical dotted line represents the year when the earthquake occurred.

Figure B9. Role of Productivity: Log Number of Suppliers



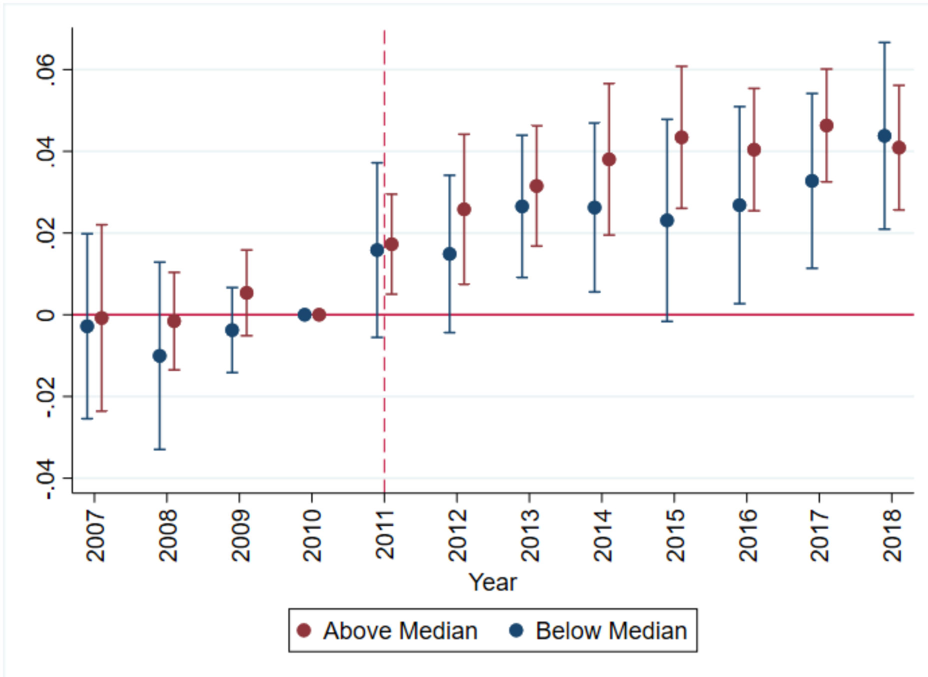
(a) Log Number of Suppliers Outside



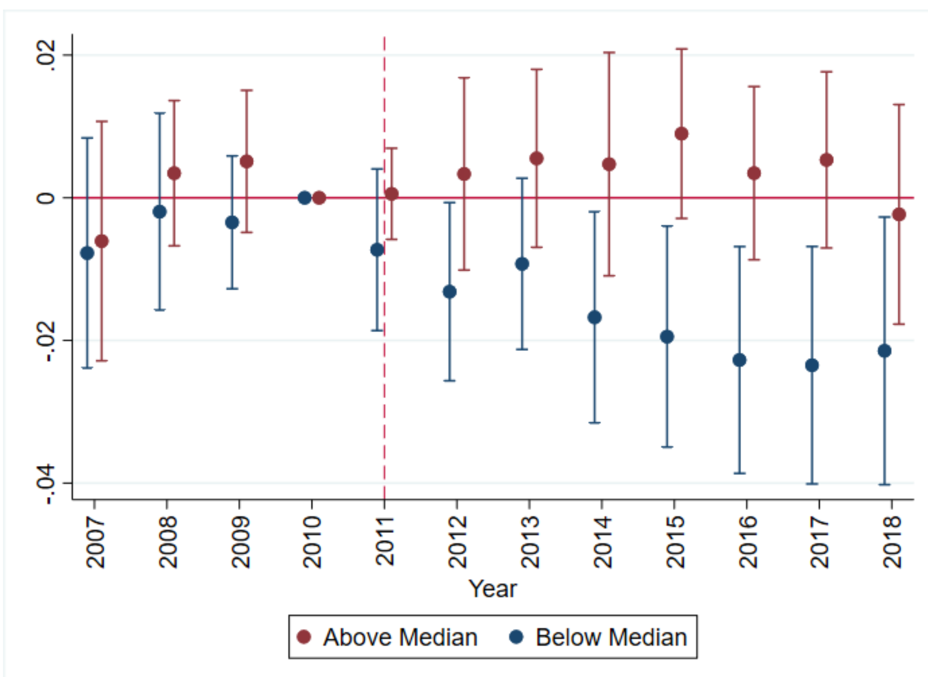
(b) Log Total Number of Suppliers

Notes: These figures plot the coefficients of the event study design specification with (a) the log number of suppliers outside the disaster area, and (b) the log total number of suppliers as outcomes. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code. The red dots indicate the point estimates of firms whose productivity is above the median among treated firms, and the blue dots indicate those of firms whose productivity is below the median. The red vertical dotted line represents the year when the earthquake occurred.

Figure B10. Role of Productivity: Log Number of Suppliers, Labor Productivity



(a) Log Number of Suppliers Outside



(b) Log Total Number of Suppliers

Notes: These figures plot the coefficients of the event study design specification with (a) the log number of suppliers outside the disaster area, and (b) the log total number of suppliers as outcomes. The whiskers indicate the 95% confidence intervals based on the clustering in 2-digit industry code and prefecture code. The red dots indicate the point estimates of firms whose productivity is above the median among treated firms, and the blue dots indicate those of firms whose productivity is below the median. The red vertical dotted line represents the year when the earthquake occurred.