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Damage to the Transportation Infrastructure and Disruption of Inter-firm Transactional Relationships*

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Abstract

We investigate the effects of an exogenous increase in transportation costs caused by the disruption of a highway due to the Tohoku Earthquake in Japan, on inter-firm transactional relationships and firm performance. We find that as the transit time to partner firms (suppliers and customers) increased due to the disrupted highway, the likelihood of continued transactional relationships decreased. This effect is more pronounced when the corresponding partner is a customer with a lower share of sales. We also find that the disruption to the transactional relationships deteriorates the firms' ex-post business conditions and credit scores.

Key words: Transportation infrastructure; Firm Transaction; Earthquake.

JEL Classification Numbers: R40, L14, Q54.

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1. Introduction

Natural disasters adversely affect the activities of firms directly through the damages to their physical and human capital as well as indirectly through damages, for example, to their transactional partners, local demand, and infrastructure. Among these indirect channels, this paper focuses on the effect through the disruption of the transportation infrastructure. This disruption increases the time and costs to transport products, services, people, and information that in turn, could adversely affect transactional relationships and consequently firm performance.

The Tohoku Earthquake occurred on March 11, 2011, and severely affected the northeastern region of Japan. Its adverse impact was huge not only because a devastating tsunami followed it, but also because it caused severe damage to the Fukushima Daiichi nuclear plant. Due to the radiation contamination, the Japanese government set up a no-go zone around the plant and closed a part of a major highway, the Jobando Highway, and nearby national roads for almost three years. As a result, firms around the area had to detour their products from their usual routes. Thus, this detour increased the time and costs of transportation for firms in this area.

In the present paper, we use this detour as a natural experiment to investigate the effect of the earthquake on the firms' activities and performance through an increase in transportation costs. The closure of the Jobando Highway was caused by an unpredictable nuclear accident, and as such we can safely regard it as an exogenous shock to the affected firms. We exploit this shock to identify the causal impact of an increase in transportation costs on interfirm transactions and firm performance. We should note that the identification of a causal impact that runs from the existence or absence of highways to firm activities is generally difficult simply because highways and other transportation infrastructures are built in places where firms actively transact with each other. To the extent that such a selection exists, reverse causality runs from active transactions to the building of highways and infrastructure, which in turn decreases transportation costs. In our case, the exogenous nature of the closure of the highway enables us to clearly identify the causal impact from an increase in transportation costs to the firms' transactions.

The main source of the data used in this study is a firm-level survey that the Regional Innovation Research Center (RIRC) of the Graduate School of Economics and Management at Tohoku University of Japan designed and conducted in August and September of 2013 in collaboration with the authors of the present paper. Using the responses to this survey, we can identify the location of the responding firms and their suppliers and customers. With this information, we can calculate the transit time between them with and without the closure of the Jobando Highway. We use as our main explanatory variable the detour time ratio that is the difference in these transit times (with and without the closure) to the original transit time (without the closure) to investigate whether and how it contributes to the disruption of the firms' transactional relationships with their suppliers and customers. We also examine whether the disruption of transactional relationships, if any, has an adverse impact on firm performance.

From our analyses, we obtain the following findings: First, as the detour time ratio increases, the probability of continuing relationships with their suppliers and customers decreases. This effect is the largest in the case of a customer with a relatively low sales share, that is, the third customer among the top three that we identify in our dataset. Second, the disruption to the relationships with their partners worsens the firms' business conditions and credit scores. These findings indicate that the disruption to the transportation infrastructure deteriorates firm performance through the disruption to interfirm transactional relationships.

This paper proceeds as follows: Section 2 is a review of the preceding studies and clarifies our contribution. In Section 3, we briefly describe the Tohoku Earthquake and its associated damage. Section 4 presents the data and the empirical approach. Section 5 reports the estimation results, first on the effects of an increase in transit time on transactional relationships, and further on firm performance. Section 6 concludes.

2. Related studies

2.1 Natural disasters and firm dynamics

This study is closely related to the literature on the economic consequences of, and recovery from, major natural disasters. On the one hand, natural disasters damage physical and human capital (Kahn, 2005; Stromberg, 2007; Toya and Skidmore, 2007). They also disrupt upstream and downstream supply chains.[1] Such human and economic losses from natural disasters are likely to deter economic growth (Strobl, 2012). On the other hand, destroyed capital can be replaced, and firms' output and productivity will eventually recover (Skidmore and Toya, 2002; Sawada et al., 2011). While the cross-country studies show that these economic impacts of natural disasters depend on the type of disasters, economic sectors, and the degree of economic development (Cuaresma et al., 2008; Loayza et al., 2012), it is largely suggested that updating technology and/or changes in the composition of production factors as well as in factor accumulation play positive roles in the recovery (Skidmore and Toya, 2002).

In addition to these studies on the macroeconomic impact of natural disasters, some studies that explore the firm-level impact and subsequent recovery are also emerging. The direct impacts of natural disasters on firms and corporate finance are examined by, for example, Leiter et al. (2009) and De Mel et al. (2012). Leiter et al. (2009) find that employment growth and the accumulation of physical capital are significantly higher in regions in Europe that have experienced a major flood. De Mel et al. (2012) examine the recovery of firms from the 2004 tsunami in Sri Lanka and find that direct aid had a

[1] Kashiwagi, et al. (2018) provide firm-level evidence on the disruption of supply chains due to a natural disaster (Hurricane Sandy in the US in 2012).

significant and positive impact on the profits of tsunami-affected enterprises in the retail industry. As a potential channel in which natural disasters negatively affect firm activities, Uchida et al. (2015) and Hosono et al. (2016) examine the impacts of natural disasters on firms through the financial constraints caused by the damage to banks. Uchida et al. (2015) use the data on the bankruptcy of firms after the Tohoku Earthquake and find that damages to lender banks reduce the probability of bankruptcy and weaken the natural selection of firms. Hosono et al. (2016) use the data after Japan's Great Hanshin-Awaji Earthquake in 1995 and find that the investment ratio of firms located outside the earthquake-affected areas but with a main bank inside was significantly smaller than that of firms located outside the areas and having a main bank outside the areas. Although there is certain accumulation of those studies using firm-level data to examine the implication of natural disasters, we should note that there are still very few studies on the impacts of natural disasters on firms through the destruction of the transportation infrastructure, which the present paper does.[2]

2.2 Economic impacts of the transportation infrastructure

Another related strand of the literature concerns the effects of inter-city transportation infrastructure, highways, and high-speed railroads, on economic activities such as urbanization and suburbanization (Baum-Snow, 2007; Duranton and Turner, 2012; Garcia-López, Holl, and Viladecans-Marsal, 2015), labor demand (Michaels, 2008), productivity (Hall, 2016), resource allocation (Ghani, Goswami, and Kerr, 2015), exports (Martincus and Blyde, 2013; Coşar and Demir, 2016), innovation (Inoue, Nakajima, and Saito, 2016), and firms' transactions (Datta, 2012; Bernard, Moxnes, and Saito, 2016). Most of these studies find positive impacts running from the inter-city transportation infrastructure on economic activities.[3] For comprehensive surveys on the economic impacts of

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[2] A rare exception is Martincus and Blyde (2013), which we will discuss below.

[3] Studies on suburbanization find a negative impact from highways on the population of central cities (Baum-Snow, 2007; Garcia-López, Holl, and Viladecans-Marsal, 2015).

infrastructure, see Gramilch (1994), Melo, Graham, and Brage-Ardao (2013), and Redding and Turner (2015).

A major empirical challenge to studying the impacts of infrastructure is how to identify the causality running from the existence or absence of infrastructure to economic activities. A reverse causality can arise if the infrastructure is built in or between the areas where economic activities and transactions are (expected to be) active. Selection bias can also arise if firms that are very active and hence gain many benefits from using the infrastructure choose to locate in an area where they can easily access it. The above-mentioned studies alleviate the reverse causality and selection problems mainly using the following two approaches.

First, a group of studies focus on specific types of infrastructure whose location was shaped by historic reasons or military considerations (Baum-Snow, 2007; Duranton and Turner, 2012; Banerjee, Duflo, and Qian, 2012; Garcia-López, Holl, and Viladecans-Marsal, 2015; Holl, 2016; Donaldson, 2018). For identification, these studies assume that an old, or military transportation infrastructure does not directly affect current economic activities, although that infrastructure affects the location of the current one. To the extent that this assumption is valid, the estimation results show the causal impacts from infrastructure to economic activities.

Second, another group of studies analyze the economic activities in areas along nationwide highways (Michaels 2008; Chandra and Thompson, 2010; Datta, 2012; Banerjee, Duflo, and Qian, 2012; Ghani, Goswami, and Kerr, 2015). These studies are based on the identification assumption that nationwide highways are built to connect major cities, and hence the access to these highways are exogenous for economic activities that take place in smaller cities located along the highways.

As compared to these preceding studies, we use an accidental, and thus purely exogenous, negative shock to infrastructure due to a natural disaster. As one notable paper that follows this identification strategy, Martincus and Blyde (2013) use the damage to highway networks due to the earthquake in Chile as an exogenous shock and analyze the causal effect of the transportation infrastructure on economic activities. While both their study and ours focus on the damage to highways caused by a large-scale earthquake, there are clear differences between those. First, Martincus and Blyde (2013) analyze the impacts on exports while we investigate the impacts on domestic interfirm transactions and firm performance. Second, while they analyze highways with different degrees of damage that range from mud slides on the shoulder of the road to complete collapses of bridges, we focus on the complete closure of a highway. Third, while most of the damage to the Chilean highways was repaired within several months and only a minor portion continued to restrain transportation after one year, the closure of the Jonbando Highway continued for almost three years.[4] Therefore, this complete closure over such a long period of time should affect the firms' decision on whether to terminate or suspend their transactions with existing suppliers and customers. Since we use data from two and a half years after the earthquake, we expect to observe significant changes in interfirm transactional relationships.

Our study is also related to Bernard, Moxnes, and Saito (2016) who analyze the impact of the opening of a high-speed railway in Japan (Kyushu Shinkansen) on firms' transactions and performance. For identification, they use the fact that a substantial time lag and uncertainty existed between the opening and the planning of the railway. Their identification assumption is that such a time lag makes it less likely that firms would choose their location by anticipating the opening of the railway. Although they try to deal with a selection bias based on this assumption, they do not account for the endogeneity issue that arises from the location choice of the railway. Regarding this point, we do not need to be concerned with this endogeneity issue in our case due to the exogenous nature of the disrupted highway.

[4] The Chilean earthquake occurred on February 28, 2010. Referring to the reports by Ministerio de Obras Públicas (MOP), Martincus and Blyde (2013) writes "717 points of the public road network were affected, including 396 roads and highways, 90 access roads, and 212 bridges. [omitted] As of February 2011, 20 bridges and more than 30 roads and access roads continued to cause partial restrictions on transit." (Martincus and Blyde, 2013, p. 150).

Having said that, their study is also close to ours in the sense that they analyze the effects of a *decrease* in passenger transportation costs through the opening of the high-speed railway, while we investigate the impacts of an *increase* in passenger and freight costs due to the closure of the highway.

Finally, our study is related to Datta (2012) who shows that firms in cities that are located along the upgraded highways in India are more likely to switch the supplier who provides their primary input and are more likely to reduce their average stock of input inventories. Compared with his study, we conduct a more comprehensive analysis by focusing on interfirm transactions not only with the primary supplier but also with other suppliers and customers.

3. The Tohoku Earthquake in Japan

The Tohoku Earthquake, also known as the Great East Japan Earthquake, occurred on March 11, 2011. It had a magnitude of 9.0 on the Richter scale that made it the fourth strongest earthquake in the world since 1900. The earthquake hit the northeastern region of Japan especially hard because of both the tremor and the tsunami it triggered. There were more than 19,000 casualties, with about 2,600 people not accounted for, and about 120,000 or 280,000 housing units were either completely or partially destroyed (see, e.g., Uesugi, et al., 2018).

The earthquake hit a large number of firms and establishments located in the affected areas. According to the Small and Medium Enterprise Agency (2011), 817,266 firms were located in the areas under the Disaster Relief Law. Of this total, 779,261 firms were damaged by the earthquake and 38,005 firms were damaged by the tsunami. In addition, 5,341 firms were located in the no-go zone that was created by the accident at the Fukushima Daiichi nuclear plant. According to the 2009 Economic Census of Japan (Statistics Bureau, Ministry of Internal Affairs and Communications), the number of establishments located in the municipalities designated as damaged was 189,470 and the number of employees in these establishments was 1,770,087.[5]

Nishiyama et al. (2013) summarize the types of damages based on a corporate survey conducted in July of 2012. They report that among the 5,240 firms that responded, the damages to physical and human capital were from the earthquake, tsunami, and nuclear plant accident and accounted for, respectively, 62.5%, 39.4%, and 12.1% of the causes of the damages (multiple answers were allowed). They also report from the same question that 36.5% and 44.0% of the damaged firms were affected indirectly through damages to their suppliers and customers respectively.[6]

In addition to the direct damages and the indirect damages through the supply chains, firms were also affected by damages to the transportation infrastructure. Major highways and national roads, high-speed and other railways, and ports and airports in the coastal areas of northeastern Japan were temporarily disrupted. While most of them recovered within a month, the suspension of roads and local railways that went through the no-go zone of the Fukushima Daiichi nuclear plant lasted for about three years or more.[7] The Jobando Highway was especially affected as one of the major highways that runs along the east coast of the northeastern region of Japan and is an integral part of its transportation infrastructure. The Jobando Highway was closed for over 16.4 kilometers from the Joban Tomioka exit to the Hirono exit until February 22, 2014 (see Figure 1). Nearby local roads were also closed due to the radioactive contamination, including National Road No. 6 that runs parallel to the Jobando Highway.[8] Due to the closure of this highway and these roads, the transports that had

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[5] Based on the Severe Disaster Law, the Ministry of Land, Infrastructure, Transport and Tourism designated the 50 municipalities (cities, towns, and villages) in Aomori, Iwate, Miyagi, and Fukushima prefectures as the damaged areas.

[6] The other types of damages that this question identifies were reputational damages due to the nuclear plant accident (22.3%), indirect damages from financial institutions that firms transacted with (4.8%), and compulsory relocation due to the tsunami and nuclear plant accidents (4.5%).

[7] Cabinet Office (2011) reports that the recovery rates for all types of transport infrastructure reached over 90% at the end of April 2011. By this point in time, all the temporarily suspended high-speed railways had already resumed, but suspension of some local railways lasted for more than three years.

[8] The closed zone of National Road No. 6 between Tomioka and Futaba cities was reopened on September 15, 2014.

been using the coastal Jobando Highway had to detour to the Tohoku Highway, which is another major highway that runs through the inland areas of northeastern Japan in parallel with, and about 60 kilometers west of, the Jobando Highway (Figure 1). Below we use this detour as an exogenous shock to transport costs and examine its effect on interfirm transactional relationships and firm performance.

4. Data and Methodology

4.1 Data Source and Sample Selection

Our main data source is the second *Survey on Firm Recoveries from the Earthquake* that was designed and conducted by the Regional Innovation Research Center (RIRC) of the Graduate School of Economics and Management at Tohoku University of Japan in collaboration with the authors of the present paper. The four waves of this survey were conducted annually from July 2012 to October to November 2015. We use the second one that was conducted from August to September of 2013, which is two and a half years after the earthquake. This wave contains information on whether the responding firms changed their top three suppliers or customers after the earthquake.

The initial target of this survey was the 56,101 firms that were recorded in the KJ (*Kigyo Joho* or firm information) file of the Tokyo Shoko Research (TSR), which is a major credit reporting company in Japan. This file showed that these firms had their headquarters in the affected areas (Iwate, Miyagi, and Fukushima Prefectures, and Hachinohe City in Aomori Prefecture). The sample firms were randomly chosen from this population using stratified sampling based on firm size and on whether the firm is located inland or in coastal areas. In the first wave of this survey, the questionnaire was sent to 30,000 randomly chosen firms, and 7,119 of them responded for a response rate of 23.7%. For the second wave, the survey targeted two groups of firms. The first group consisted of the firms that responded to the first wave and were able to respond to the second wave. There were 6,983 of them. The firms in the second group were those that did not respond to the first wave but were still in the database. With stratification based on location and size, the survey randomly chose 23,017 firms to send the questionnaire. In total, 7,481 firms responded to the survey, 3,971 of them from the first group and 3,510 from the second group. The total response rate was 24.9%.

The second wave of the survey provides us with pieces of information that are useful for our analysis. It identifies the ranking of the top three suppliers or customers of each responding firm at the time just before the earthquake. This ranking is based on the purchase and sales share. It also provides information on whether transactions with the top three suppliers or customers that existed just before the earthquake are currently (i) continued, (ii) interrupted but resumed, or (iii) terminated. Other pieces of useful information are the addresses of the headquarters of the surveyed firms and those of their top three suppliers and those of their top three customers.

In our analysis, we use firm-to-firm, match-level data for the 7,481 firms that responded to the second wave of the survey. We augment the data from the survey with those obtained from the KJ file and the Credit Score file of TSR. We set the following four criteria for our sample selection. First, we choose the transactional relationships (firm-to-firm matches) that have complete information to construct all the variables we use for our analysis. Second, we choose the transactional relationships for the responding firms that did not relocate their headquarters. We impose this criterion to avoid any effects from the firms' relocation choices after the earthquake because firms that relocated, though few (only 101 firms), may have behaved quite differently from those that did not. Third, we use the transactional relationships of responding firms when the location of the headquarters of their suppliers and customers just before the earthquake were in coastal Tohoku or Kanto (Aomori, Iwate, Miyagi, Fukushima, Ibaraki, or Chiba). This criterion is to focus on the transaction relationships that likely had used Jobando for transporting goods or services before the earthquake. Finally, we eliminate the firm-to-firm matches if the responding firms answered that their headquarters were not located in either of the three affected prefectures or the one city (Iwate, Miyagi, and Fukushima Prefectures, and

Hachinohe City in Aomori Prefecture).[9]

As a result of these four sample selection criteria, the numbers of responding firms and firm-to-firm matches in our analyses are reduced to about more than half of the number of the original survey responses. The number of observations depends on the specification of the analyses. At the maximum, we have 14,097 matches (transactional relationships) for the 4,124 responding firms. The locations of the firms in our sample are plotted in Figure 1.

4.2 Variables

In this subsection, we describe the main variables that we use for the analyses.

Detour time ratio

Our main independent variable is a proxy for an exogenous increase in transit time and costs due to the highway disruption caused by the Tohoku Earthquake. We calculate this proxy to indicate the time that the detour takes due to the disruption when firms transit goods from their places to the places of their transaction partners. In doing so, we first use Google Maps to compute the transit time by car. We compute the time in two ways: one for the route that uses the Jobando Highway; and the other for the route that uses the Tohokudo Highway as the detour. Using the computed time, we define the detour time ratio between the respective pairs of cities as follows:

$$Detour = (\textit{Time through Tohokudo-Time through Jobando}) \,/\, \textit{Time through Jobando}.$$

We calculate this detour time ratio only for the pairs of cities when one of them is in the northern

[9] As we have explained above, although the questionnaire was sent to firms that were recorded as having their headquarters in these areas, there are some firms that responded that their headquarters were located outside these areas. This criterion is to eliminate such firms from the sample.

area of the closed zone of the Jobando Highway and the other is in its southern area (see Figure 1). For the other pairs of cities, both of which are located either in the north or in the south of the disrupted zone of the Jobando Highway, no detour is expected, so we simply set the detour time ratio to zero. We then link the resulting detour time ratio at the city-pair level with the firm-to-firm, match-level data by using the addresses of the headquarters of the responding firms and of their suppliers or customers.

For *Time through Tohokudo* and *Time through Jobando*, we should respectively use the actual time required *just after* and *just before* the earthquake. However, they are not available because Google Maps only offers the current transit time. Thus, we use the time that is available as of this research (during 16:00-18:00, November 30, 2018). This means that the measured *Time through Tohokudo* and therefore *Detour* are likely to be smaller than the actual because the actual traffic on the Tohokudo highway just after the earthquake should have been much heavier due to many detours from the Jonbando Highway. If the actual *Time through Tohokudo* was proportionally larger than the measured one, the absolute value of the estimated coefficient on *Detour* should be larger than the true value. However, the statistical significance of the coefficient should be unaffected by this mismeasurement.[10] .

Continuation dummy

In our first analysis, we examine the effect of the detour time ratio for a pair of a responding firm and one of its transaction partners on the continuation or disruption of the transactional relationship between them. Using information from the survey responses, we define $CONT$ as a continuation dummy that takes the value of one if the transaction between a firm and a respective

[10] The quantitative impact of *Detour* on the probability of the continuation of transactional relationship should be unaffected either as long as we use the standard deviation in *Detour* and its estimated coefficient, because the standard deviation should be underestimated.

supplier or customer continues, and zero if the transaction is either temporarily suspended or permanently terminated. This variable captures the change in the interfirm relationships over the two and a half year period.

Change in business conditions

In the second analysis, we examine whether the continuation or disruption of transactional relationships affects the responding firms' ex-post performance. The unit of observations for this analysis is at the firm level. As the dependent variable, we define *Change in business conditions* as the difference in business conditions between the time just before the earthquake and the time of the survey. The survey asks the responding firms to specify their business conditions as one of five options: 1 very bad, 2 bad, 3 normal, 4 good, and 5 very good. The variable takes one of these values, and so its increase indicates an improvement in business conditions.

Change in credit scores

As another measure of firms' performance in the second analysis, we use firms' credit score to examine whether and to what extent the disruption of transactional relationships worsens firms' creditworthiness. For this aim, we use the change in credit scores stored in the KJ and Credit Score files of TSR from the pre-earthquake period (on or before December 31, 2010) to the survey period (on or after January 1, 2013).

4.3 Methodology

First analysis: highway disruption and relationship disruption

As indicated above, we first analyze the effect of the detour time ratio on the probability of continuing the transactional relationship, and then examine the effect of termination on business conditions. For the first analysis, we estimate the following Probit model using the firm-to-firm, match -level data:

$$\text{Prob}\left(CONT_{ij} = 1\right) = \alpha Detour_{ij} + \beta X_{ij} + \gamma Y_i + \delta Z_j + u_{ij} \tag{1}$$

where $CONT_{ij}$ is the continuation dummy for the transactional relationship between responding firm *i* and transaction partner *j* where partner *j* is either the first, second, or third supplier or customer. $Detour_{ij}$ is the detour time ratio between *i* and *j*, X_{ij} is a vector of match-level variables between *i* and *j* , Y_i is a vector of responding firm *i*'s characteristics, and Z_j is partner firm *j*'s characteristics variable. All the explanatory variables are measured at the time just before the earthquake. We expect that $\alpha < 0$, or the higher the detour time ratio, the lower the probability of continuing the transactional relationship. We estimate Eq. (1) by using the whole sample as well as by splitting the sample depending on whether the first, second, or third suppliers or customers are the relevant transaction partner.

For the match-level variables, X_{ij}, we use the natural logarithm of the geographical distance (to be precise, distance in terms of kilometers plus 0.001) between the cities where firm *i* and partner *j* are located.[11] We also use the dummy variables to identify the ranking of the relevant supplier or customer (first to third). We expect that the continuation probability increases as the distance becomes shorter and the ranking becomes higher.

As for the firm characteristics variables, Y_i, we use the four damage-related variables: the damage dummy that indicates whether the firm responded that the disaster damaged it; the severely damaged area dummy that indicates whether the Japanese government designated the city where the

[11] We add 0.001, one meter, to the distance because the distance between the firms in the same city equals zero.

firm's headquarters was located as a severely damaged area; the flood area dummy that indicates whether the headquarters was located in an area flooded by the tsunami; and the nuclear plant dummy that indicates whether the headquarters was located within a 20 kilometers radius of the Fukushima Daiichi nuclear plant.

We expect these damage-related dummies to have negative effects on the probability of continuing the transactions. As other variables for Y_i, we use the debt-to-asset ratio, the credit score reported by the Tokyo Shoko Research, the business conditions index (prior to the earthquake), the firm's age, and the log of the number of workers. We expect that the less levered, the more highly scored, the larger, and the older the firm is, the more likely it is to continue their relationships with their partners. Specifically, we expect that the continuation probability is higher if the debt-to-asset ratio is lower, and if the score, the business conditions, the age, and the log of the number of workers are higher. We also use the following seven industry dummies for Y_i to control for industry-level unobservable heterogeneity affecting the continuation probability of transaction relationships: (1) agriculture, fisheries, and mining; (2) construction; (3) manufacturing; (4) utilities, information and communication, and transportation; (5) wholesale; (6) retail; and (7) other services.

For the variables for the characteristics of transaction partners, Z_j, we use a dummy variable accounting for whether the responding firm reported that the relevant partner was damaged by the disaster. We expect this variable to have a negative effect on the probability of continuing the transactional relationships.

Second analysis: relationship disruption and firm performance

For the second analysis on the effect of the disruption to the relationship on the firms' performance, we construct firm-level datasets and take the propensity score matching, difference-in-differences (PSM-DID) approach.[12] We expect that the disruption to the relationship worsens firms' performance because it is likely to be costly for firms to find alternative partners. To the extent that firms can easily find new partners, however, the negative effect of the disruption to the relationship on firms' performance should be smaller.[13]

For this purpose, we divide the sample used in the first analysis by the types of transaction partners (first to third suppliers and customers) and construct six firm-level samples. Each sample consists of the treatment firms whose transactional relationships with the relevant partners were disrupted by the disasters and the non-treatment firms whose transactional relationships continued.[14] To identify the control group firms from the non-treatment firms, we use the propensity score accounting for the estimated probability of the firms that experienced a disrupted relationship (i.e., one minus the estimated probability of continuing the relationship) obtained from the estimation of equation (1) using each of the six samples.

Then we proceed to calculating the DID effect for the change in the firms' performance between the responding firms in the treatment group and those in the control group. We match the control group based on the nearest-neighbor matching algorithm. Using this PSM-DID, we can estimate the causal effect of transaction disruption on firm performance measured by business conditions and credit scores. We report the average treatment effect on the treated firms with z- statistics based on Abadie-Imbens standard errors (Abadie and Imbens, 2012).

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[12] The PSM-DID approach identifies a causal relationship to the extent that the ex-ante characteristics is identical between the treated and control groups.
[13] Miyauchi (2018), for example, find that firms rematch with new suppliers at a faster rate in locations and industries where there are a larger number of potential alternative suppliers.
[14] As the treatment group, we choose the firms whose transactional relationships with the relevant partners were disrupted and not continued because more than 90 percent of our estimation sample continued relationships (Table 1). If we chose the firms whose relationships continued as the treatment group, we cannot choose the control group from the small number of firms whose relationships were disrupted.

5. Results

5.1 Descriptive statistics

Table 1 shows the descriptive statistics for the variables we use. The detour dummy, which takes the value of one if the detour time is positive, has a mean of 0.00979, which means that about 1.0% of the transactional relationships are subject to some detour. For the transactional relationships that involve a detour, the mean detour time is 13.55 minutes. The mean detour time ratio for such relationships is 6.41%. The continuation dummy has a mean of 0.911, which indicates that 91.1% of the transactional relationships continued while the remaining 8.9% were either temporarily suspended or permanently terminated during the two and a half years after the earthquake. The changes in business conditions and credit scores have a median of 0, which indicates that the typical firm does not experience substantial changes in their business conditions or credit scores subsequent to the earthquake.

One of the most important control variables is the damage dummy that takes the value of one if the responding firm suffered from damages due to the earthquake and zero otherwise. Table 1 shows that 72.5 % of the responding firms suffered from the damages. On the other hand, 39.7% of their partners incurred damages.

5.2 Simple comparison between transactions with and without detour

Before conducting formal analyses using regressions, in this subsection we compare the continuation and disruption ratios between the transactional relationships with and without a detour. Table 2 shows the results for the whole sample. It shows that while only 8.98% of the transactional relationships were disrupted when there is no detour, 17.22% of those were disrupted when there is a detour. The Chi-squared test rejects the null hypothesis that the continuation and disruption distributions are the same between the transactional relationships with and without a detour at a very low level of statistical significance.

Table 3 shows the results for the same analysis when we split the sample by the ranking of the responding firms' suppliers or customers. The disruption ratios of the transactional relationships with a detour are higher than those without a detour for all the subsamples, and the differences are statistically and economically significant for the transactional relationships with the third suppliers and the first and the third customers. For example, the disruption ratios with the third suppliers are 8.43% for the relationships without a detour, and 20.00% for those with a detour. The difference is even larger in the case of the third customers (11.52% versus 31.58%).

Table 4 shows the results when we split the sample by the responding firm's industry. As an example, for the industries of utilities, information and communication, and transportation that includes the business of road transportation of cargo, the disruption rate of the transactions with a detour is 36.84%, which is significantly higher than that without a detour (12.96%).

5.3 Estimation results for the continuation probability

Now we present the estimation results for equation (1). Table 5 reports the results by using the whole sample, where we show the marginal effect on the estimated probability at the mean value of each variable.[15] Column (1) shows the result when we use the detour time ratio as the only explanatory variable. The ratio has a negative and statistically significant marginal effect. Column (2) shows the result when we add the responding firm's damage variables, the industry dummies, and the transaction partner's damage variable to the explanatory variables. Again, the marginal effect for the detour time ratio is negative and is statistically different from zero. The marginal effects for the responding firm's and the transaction partner's damage variables are all negative and statistically significant, except the

[15] For the dummy variables, the marginal effects are the change in the estimated probability associated with the discrete change in the relevant dummies from zero to one.

marginal effect for the responding firm's severely damaged area dummy.

Column (3) shows the result when we use all control variables as explanatory variables. Although the number of observations decreases by almost 40% compared to that in column (1), the marginal effect of the detour time ratio is still negative and statistically different from zero. Among the newly added variables, the effect of log(distance) is negative and statistically significant as expected. The marginal effects for the score and age are both positive and statistically significant, which indicates that safer and older firms are more likely to continue their transactional relationships. Further, the third customer dummy has a negative and statistically significant effect when we use the first supplier as a reference group. This result shows that the transactions with customers with a relatively small share of sales are more likely to be disrupted regardless of the level of the detour time ratio.

Next, we present in Table 6 the estimation results for equation (1) using the subsamples divided by the ranking of suppliers or customers.[16] The detour time ratio has a negative and statistically significant effect when the relevant relationship is the one with the third supplier or the third customer. These findings mean that transactions with suppliers or customers that have a relatively small share of sales or purchases are more likely to be disrupted as the transit time increases. We should note that this result is obtained for a given ranking of suppliers or customers. Thus, while the transactions with customers with a relatively small share of sales are more likely to be disrupted regardless of the level of the detour time ratio as we mentioned in the previous paragraph (i.e., the unconditional effect), the relationships with the customers and suppliers with a relatively small share of transactions are more likely to be disrupted due to the disruption of transportation network (i.e., the conditional effect).

We also assess the economic significance of the effects of the transit time on the probability of

[16] As for the relationships with the second supplier, there is no observation for which the detour time ratio is positive and the relationship is disrupted.

continuing the relationship using the estimated coefficient and the standard deviation (SD) in *Detour*. For all transactions (whole sample), the marginal effect of the detour time ratio is -0.486 after controlling for all the variables (Column 3 of Table 5), and the SD in *Detour* for the transactions that involved a detour is 0.0507 (Table 1). These two figures indicate that an increase in the detour time ratio by one SD (5.07 percentage points) leads to a decrease in the probability of continuing a relationship by 2.46 percentage points. In the case of the third supplier, an increase in the detour time ratio by one SD (6.63 percentage points) results in a decrease in the probability of continuing the relationship by 4.28 percentage points (= -0.646×6.63). These effects are economically non-negligible but are small relative to the average probability of continuing transactions for all the relationships (91.0% for the whole sample and 91.4 % for the subsample of the third suppliers). However, if we focus on the third customer, the quantitative effect is more sizable. An increase in the detour time ratio by one SD (3.89 percentage points) leads to a decrease in the probability of continuing the relationship by 12.01 percentage points $(= -3.087 \times 3.89)$, which accounts for a significant fraction of the average probability of continuing the relationship with the third customer (88.3%).

In sum, our results show that an increase in transit time due to the disruption of the Jonbando Highway caused a higher probability of disrupted relationships, especially with customers with a relatively small sales share. Our results also show that the increase in the probability of disrupted relationships are economically non-negligible. Based on these results, we can confirm that an exogenous increase in transportation costs has a negative effect on the continuation of interfirm transactional relationships and that the effect varies over the importance of transaction partners.

5.4 Estimation results for the effect of disrupted relationships on firm performance

Next we turn to the results for the effect of disrupted relationships on firm performance using the PSM-DID approach. As explained in Section 4.3, the firms in the treatment group and those in the control group are selected based on the estimation results in Table 6.

Table 7 shows the results from the PSM-DID. We cannot estimate the DID for the sample of firms with the second suppliers because for all the firms in this sample, their transactional relationships continued when there is a detour.[17] Among the samples that we can estimate, the DID in business conditions is negative for the firms with all the partners and statistically significant for the firms with the third suppliers and the third customers. In addition, the DID in credit scores is negative and statistically significant for the sample of firms with the third suppliers. These results show that the disruption of relationships with these partners worsened the firms' business conditions and credit scores. On the other hand, the disruption of relationships with the first or second partners did not significantly affect firms' performance.[18]

As we saw in Table 6, the relationships with the third partners were significantly affected by the highway disruption, and the relationships with the third customer were more likely to be disrupted than the relationships with the third supplier. When we evaluate the economic significance, the disruption of the transactional relationships worsened the firms' business conditions by 0.282 and 0.241 respectively in the case of the third supplier and the third customer, which are non-negligible given that the average change in business conditions was 0.288 (see Table 1). The quantitative impact of the disruption of the third supplier to deteriorate credit score is also sizable (1.288) relative to the average change in credit scores (0.679).

5.5 Robustness check

In the sample that we used for the baseline analysis above, all of the responding firms'

[17] For the same reason, we drop the nuclear plant area dummy from the explanatory variables when we estimate the first stage of the PSM-DID in the credit scores for the sample of firms that had relationships with the second and third customers.

[18] Why the effects of the disruption to the transaction partners differ across the first to the third suppliers and customers is left for future work.

transaction partners are located in coastal Tohoku and Kanto prefectures. This approach might invite a concern that our estimation results are contaminated by the direct effects of damage that the partners suffered from. Although we already control for the partners' damage using a dummy variable, there might be some remaining effect of the partners' damage that we do not control for, and the impacts that we found of highway disruption on the firms' disrupted relationships, and thereby on their business conditions, might be overestimated. To mitigate this concern, we rerun the regression by restricting our sample to the transactional relationships with partners that were located in coastal Tohoku and Kanto prefectures but *not* damaged by the earthquake.

Table 8 shows the results using this sample.[19] The results show that the marginal effects for the detour time ratio are negative and statistically different from zero for the whole sample and for the subsamples of the relationships with the third suppliers and with the third customers. The absolute value of the marginal effect for the detour time ratio is the largest for the case of the third customers and is 1.677, although it is somewhat smaller than that for the unrestricted sample (3.087 in Column (6) in Table 6). We can at least conclude that our baseline results for the effect of a detour on the probability of continuing relationships is not solely due to the direct effect of damages to transaction partners.

Table 9 shows the results from the DID analysis using the restricted subsamples for firms transacted with undamaged suppliers or customers.[20] It shows that the DID in business conditions is

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[19] For the first and the second suppliers and the first customer, all the transactions with positive detour time ratios were continued, so that we cannot estimate the marginal effects for the detour time ratio. For the samples of the firms that have relationships with the first to the third suppliers or customers, we drop the nuclear plant dummy from the explanatory variables either because all the transactions where this dummy equals one were continued (in the cases of the third suppliers and the second customers) or because of collinearity with other variables (in the case of the third customer).

[20] Again, we cannot estimate the DID for the samples of firms that had relationships with the first and the second suppliers and the first customers because all these relationships when involving a detour were continued. We drop the nuclear plant dummy from the explanatory variables for all the samples and further drop industry dummy 6 (retails) for the sample of the firms that had relationships with the second customer.

negative and statistically significant for the subsamples of firms that had relationships with the second and the third customers, while it is not significant for the subsample of those that had relationships with the third supplier. In the case of firms that had relationships with the third customer, the magnitude of the DID for the restricted sample is rather larger than that for the unrestricted sample (-0.744 versus -0.241, respectively). The DID in credit scores in the case of the third suppliers is negative, although not significant. Thus, we can again conclude that the DID that we found is not an artifact of the direct damage to the partners.

6. Conclusion

We have estimated the impact of the Tohoku Earthquake in Japan on interfirm transactional relationships and firm performance through the exogenous increase it caused in transportation costs due to the disruption of a highway. We find that firms became less likely to continue transactional relationships for the two and a half years subsequent to the earthquake as the transit time to their partners increased due to the disruption. This effect was more pronounced when the partner was a customer with a relatively low sales share (the third customer). Quantitatively, an increase in the detour time as a proportion of the original transit time by one standard deviation leads to a decrease in the probability of continuing the relationship with the third customer by 12.0 percentage points. We also find that the disruption of the transactional relationships deteriorates the firms' ex-post business conditions and credit scores. Furthermore, our robustness check confirms that these results are not artifacts of the direct damage to partners.

Our results show that natural disasters have negative impacts on firms' transaction networks and thereby performance through the disruption of the transportation infrastructure. While anecdotal evidence on the disruption of supply chain networks immediately after the earthquake is abundant, to the best of our knowledge, this study is the first to show that the negative impacts of the disrupted transportation infrastructure on interfirm transactional relationships and firm performance last for a long period of time (two and a half years in our study).

Some interesting and important issues still remain. First, it is desirable to explore to what extent our quantitative results depend on the specificity of the disrupted highway (Jobando). In the case of the Tohoku Earthquake, it was relatively easy to take a detour because the inland highway (Tohokudo) runs parallel to, and about 60 kilometers west of, the Jonbando Highway. Without such an easily available alternative option, the quantitative impact of the disrupted highway could be much larger. It is thus desirable to generalize our analysis by collecting data on much broader cases and by taking into account a variety of damages to the transportation infrastructure with and without alternatives. Second, although we have focused on the negative effect of the disrupted highway on the disruption to existing transactional relationships, it is also interesting to examine whether such a relationship disruption affects the creation or establishment of new transactional relationships. This issue is important when we evaluate aggregate impacts of disasters on interfirm network dynamics. Finally, and relatedly, such an assessment of the aggregate impacts on firm performance might contribute to conducting cost-benefit analyses of building infrastructure. All these issues remain for future studies.

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Table 1. Descriptive statistics

Variables	N	mean	p50	sd	min	max
Transactional relationships						
Continuation dummy	14,907	0.911	1	0.284	0	1
Detour dummy	14,907	0.00979	0	0.0985	0	1
Detour time ratio	14,907	0.000631	0	0.00811	0	0.287
Distance (km)	14,907	37.27	15.02	55.55	0	544.2
Log(distance(km))	14,907	2.788	2.709	1.350	-6.908	6.299
Detour time (minitues)	14,907	0.133	0	1.569	0	35
Transactional relationships with detour						
Time through Jobando (minutes)	149	239.1	235	95.60	122	476
Detour time (minutes)	149	13.55	12	8.287	1	35
Detour time ratio	149	0.0641	0.0479	0.0507	0.00347	0.287
Responding firms						
Severely damaged area dummy	3,050	0.687	1	0.464	0	1
Flood area dummy	3,050	0.0970	0	0.296	0	1
Score prior to earthquake	3,049	50.53	50	4.863	33	70
Nuclear plant area dummy (within 20 km radius)	3,050	0.00393	0	0.0626	0	1
Business conditions prior to earthquake	3,005	3.273	3	0.829	1	5
Damage dummy	2,953	0.725	1	0.447	0	1
Debt-to-asset ratio, winsorized	2,031	0.812	0.707	0.700	0.000149	5.021
Age	2,910	32.49	32	15.32	3	114
Log (No. of employment)	3,050	2.337	2.303	1.139	0	6.405
Change in business conditions	2,984	0.288	0	1.254	-4	4
Change in score	2,443	0.679	0	2.807	-14	17
Industry dummy 1: Agriculture, fisheries, and mining	3,050	0.0177	0	0.132	0	1
Industry dummy 2: Construction	3,050	0.391	0	0.488	0	1
Industry dummy 3: Manufacturing	3,050	0.129	0	0.335	0	1
Industry dummy 4: Utilities, information and communication, and transportation	3,050	0.0652	0	0.247	0	1
Industry dummy 5: Wholesale	3,050	0.0856	0	0.280	0	1
Industry dummy 6: Retail	3,050	0.121	0	0.327	0	1
Industry dummy 7: Other services	3,050	0.190	0	0.392	0	1
Partners						
Partner damage dummy	14,376	0.397	0	0.489	0	1

Table 2. Transportation and transactional relationships: whole sample

	Transportation		
Relationships	No detour	Detour	Total
Disrupted	1,365	26	1,391
(%)	(8.98)	(17.22)	(9.07)
Continued	13,827	125	13,952
(%)	(91.02)	(82.78)	(90.93)
Total	15,192	151	15,343
(%)	(100.00)	(100.00)	(100.00)
Chi sq. (1)	12.2946		
Marginal Prob.	0		

Upper numbers indicate the number of transactions.
Numbers in the parentehses indicate the share of the transactions in the column total.

Table 3. Transportation and transactional relationships: by the ranking of suppliers/ customers

1st supplier

Relationships	Transportation No detour	Detour	Total
Disrupted	255	4	259
(%)	(8.25)	(9.76)	(8.27)
Continued	2,837	37	2,874
(%)	(91.75)	(90.24)	(91.73)
Total	3,092	41	3,133
(%)	(100)	(100)	(100)
Chi sq. (1)	0.1215		
Marginal Prob.	0.727		

2nd supplier

Relationships	Transportation No detour	Detour	Total
Disrupted	232	2	234
(%)	(8.08)	(10.00)	(8.09)
Continued	2,639	18	2,657
(%)	(91.92)	(90.00)	(91.91)
Total	2,871	20	2,891
(%)	(100)	(100)	(100)
Chi sq. (1)	0.0983		
Marginal Prob.	0.754		

3rd supplier

Relationships	Transportation No detour	Detour	Total
Disrupted	226	6	232
(%)	(8.43)	(20.00)	(8.56)
Continued	2,455	24	2,479
(%)	(91.57)	(80.00)	(91.44)
Total	2,681	30	2,711
(%)	(100)	(100)	(100)
Chi sq. (1)	5.0754		
Marginal Prob.	0.024		

1st customer

Relationships	Transportation No detour	Detour	Total
Disrupted	207	5	212
(%)	(8.87)	(20.83)	(8.99)
Continued	2,126	19	2,145
(%)	(91.13)	(79.17)	(91.01)
Total	2,333	24	2,357
(%)	(100)	(100)	(100)
Chi sq. (1)	4.1517		
Marginal Prob.	0.042		

2nd customer

Relationships	Transportation No detour	Detour	Total
Disrupted	213	3	216
(%)	(9.68)	(17.65)	(9.74)
Continued	1,988	14	2,002
(%)	(90.32)	(82.35)	(90.26)
Total	2,201	17	2,218
(%)	(100)	(100)	(100)
Chi sq. (1)	1.219		
Marginal Prob.	0.27		

3rd customer

Relationships	Transportation No detour	Detour	Total
Disrupted	232	6	238
(%)	(11.52)	(31.58)	(11.71)
Continued	1,782	13	1,795
(%)	(88.48)	(68.42)	(88.29)
Total	2,014	19	2,033
(%)	(100)	(100)	(100)
Chi sq. (1)	7.3274		
Marginal Prob.	0.007		

Upper numbers indicate the number of transactions.
Numbers in the parentehses indicate the share of the transactions in the column total.

Table 4. Transportation and transactional relationships: by industry

1. Agriculture, fisheries, and mining

	Transportation		
Relationships	No detour	Detour	Total
Disrupted	16	1	17
	(7.21)	(100.00)	(7.62)
Continued	206	0	206
	(92.79)	0.00	(92.38)
Total	222	1	223
	(100)	(100)	(100)
Chi sq. (1)	12.1722		
Marginal Prob.	0		

2. Construction

	Transportation		
Relationships	No detour	Detour	Total
Disrupted	354	1	355
	(6.23)	(4.00)	(6.22)
Continued	5,330	24	5,354
	(93.77)	(96.00)	(93.78)
Total	5,684	25	5,709
	(100)	(100)	(100)
Chi sq. (1)	0.2119		
Marginal Prob.	0.645		

3. Manufacturing

	Transportation		
Relationships	No detour	Detour	Total
Disrupted	220	8	228
	(11.12)	(20.00)	(11.30)
Continued	1,758	32	1,790
	(88.88)	(80.00)	(88.70)
Total	1,978	40	2,018
	(100)	(100)	(100)
Chi sq. (1)	3.0833		
Marginal Prob.	0.079		

4. Utilities, info. & comm., and transportation

	Transportation		
Relationships	No detour	Detour	Total
Disrupted	122	7	129
	(12.96)	(36.84)	(13.44)
Continued	819	12	831
	(87.04)	(63.16)	(86.56)
Total	941	19	960
	(100)	(100)	(100)
Chi sq. (1)	9.1283		
Marginal Prob.	0.003		

5. Wholesale

	Transportation		
Relationships	No detour	Detour	Total
Disrupted	213	4	217
	(11.81)	(12.90)	(11.83)
Continued	1,591	27	1,618
	(88.19)	(87.10)	(88.17)
Total	1,804	31	1,835
	(100)	(100)	(100)
Chi sq. (1)	0.0351		
Marginal Prob.	0.851		

6. Retail

	Transportation		
Relationships	No detour	Detour	Total
Disrupted	159	3	162
	(10.27)	(17.65)	(10.35)
Continued	1,389	14	1,403
	(89.73)	(82.35)	(89.65)
Total	1,548	17	1,565
	(100)	(100)	(100)
Chi sq. (1)	0.9858		
Marginal Prob.	0.321		

7. Other services

	Transportation		
Relationships	No detour	Detour	Total
Disrupted	214	1	215
	(8.28)	(7.69)	(8.28)
Continued	2,370	12	2,382
	(91.72)	(92.31)	(91.72)
Total	2,584	13	2,597
	(100)	(100)	(100)
Chi sq. (1)	0.0059		
Marginal Prob.	0.939		

Upper numbers indicate the number of transactions.
Numbers in the parentehses indicate the share of the transactions in the column total.

Table 5. Probability of transactional relationships continued: Probit estimates

Column number	(1)	(2)	(3)
Detour time ratio	-0.914***	-0.572**	-0.486*
	(-3.494)	(-2.414)	(-1.802)
Damage dummy		-0.0159**	-0.0136
		(-2.060)	(-1.429)
Severely damaged area dummy		-0.00711	-0.0108
		(-0.946)	(-1.209)
Flood area dummy		-0.0656***	-0.0406***
		(-5.037)	(-2.907)
Nuclear plant area dummy		-0.350***	-0.294***
		(-5.557)	(-3.576)
Partner damage dummy		-0.0954***	-0.0985***
		(-14.80)	(-12.75)
Debt-to-asset ratio			-0.000267
			(-0.0472)
Business conditions prior to earthquake			-0.00565
			(-1.162)
Score prior to earthquake			0.00242***
			(2.616)
Age			0.000588**
			(2.187)
Log (No. of employment)			0.00304
			(0.728)
Log (distance)			-0.00604**
			(-2.343)
2nd supplier dummy			0.00137
			(0.207)
3rd suppllier dummy			-0.00586
			(-0.867)
1st customer dummy			0.000661
			(0.0817)
2nd customer dummy			-0.0128
			(-1.481)
3rd customer dummy			-0.0266***
			(-2.951)
Observations	14,907	13,963	9,255
Industry dummy	no	yes	yes
Pseudo R2	0.00185	0.0869	0.0975

Robust z-statistics clustered at the firm level in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 6. Probability of transactional relationships continued: Probit estimates by the ranking of suppliers/ customers

Column number	(1)	(2)	(3)	(4)	(5)
Supplier / Customer	1st suppllier	3rd supplier	1st customer	2nd customer	3rd customer
Detour time ratio	-0.199	-0.646*	0.403	-0.291	-3.087***
	(-0.510)	(-1.807)	(0.571)	(-0.276)	(-2.668)
Damage dummy	-0.0310**	-0.00331	-0.0110	-0.0142	-0.00188
	(-2.201)	(-0.203)	(-0.665)	(-0.786)	(-0.0914)
Severely damaged area dummy	-0.0244*	-0.0312**	0.00334	0.00997	-0.0107
	(-1.935)	(-2.275)	(0.211)	(0.595)	(-0.557)
Flood area dummy	-0.0189	-0.0187	-0.0470**	-0.0713***	-0.0649**
	(-1.124)	(-1.034)	(-2.005)	(-2.727)	(-2.308)
Nuclear plant area dummy	-0.247**	-0.313*	-0.267	-0.632***	-0.537**
	(-1.963)	(-1.787)	(-1.486)	(-3.019)	(-2.545)
Partner damage dummy	-0.0928***	-0.114***	-0.0976***	-0.0947***	-0.106***
	(-7.634)	(-8.046)	(-6.802)	(-6.292)	(-6.218)
Debt-to-asset ratio	0.00188	0.0109	-5.60e-05	-0.00645	-0.00926
	(0.244)	(1.151)	(-0.00678)	(-0.620)	(-0.751)
Business conditions prior to earthquake	-0.00898	-0.00685	-0.00124	-0.00399	-0.00940
	(-1.412)	(-0.985)	(-0.154)	(-0.493)	(-0.955)
Score prior to earthquake	0.00385***	0.00233	0.000733	0.00304*	0.000837
	(2.971)	(1.605)	(0.438)	(1.745)	(0.441)
Age	0.000501	0.000431	0.000351	0.00105**	0.00132**
	(1.419)	(1.187)	(0.798)	(2.284)	(2.418)
Log (No. of employment)	-0.00723	-0.00201	0.0144*	0.00151	0.0173*
	(-1.341)	(-0.346)	(1.955)	(0.201)	(1.917)
Log (distance)	-0.00434	0.00144	-0.00525	-0.0193***	-0.0140*
	(-1.066)	(0.323)	(-0.985)	(-3.628)	(-1.925)
Observations	1,840	1,622	1,449	1,360	1,256
Industry dummy	yes	yes	yes	yes	yes
Pseudo R2	0.118	0.127	0.0879	0.122	0.117

Robust z-statistics clustered at the firm level in parenth

*** p<0.01, ** p<0.05, * p<0.1

Table 7. Difference-in-differences in firm performance

	(1)	(2)	(3)	(4)	(4)
Suppliers / Customers	1st customer	3rd supplier	1st customer	2nd customer	3rd customer
Business conditions	-0.0855	-0.282**	-0.164	-0.134	-0.241*
	(-0.578)	(-2.057)	(-1.120)	(-0.920)	(-1.679)
Observations	1,828	1,614	1,440	1,352	1,250
Score	-0.617	-1.228***	-0.550	-0.541	0.160
	(-1.605)	(-3.179)	(-1.536)	(-1.230)	(0.450)
Observations	1,494	1,313	1,191	1,121	1,029

*** p<0.01, ** p<0.05, * p<0.1

Table 8. Probability of transactional relationships continued:
sample being limited to relationships with undamaged transactional partners

Column number	(1)	(2)	(3)	(4)
Supplier / Customer	all	3rd supplier	2nd customer	3rd customer
Detour time ratio	-0.540***	-0.864*	-0.883	-1.677**
	(-3.057)	(-1.648)	(-1.272)	(-1.963)
Damage dummy	6.14e-05	0.00828	0.00927	0.0141
	(0.00889)	(0.762)	(0.649)	(0.811)
Severely damaged area dummy	-0.00539	-0.0216**	0.000603	0.0107
	(-0.775)	(-2.100)	(0.0430)	(0.639)
Flood area dummy	-0.0252*	0.00637	-0.0589*	-0.0624*
	(-1.873)	(0.368)	(-1.703)	(-1.684)
Nuclear plant area dummy	-0.327*			
	(-1.863)			
Debt-to-asset ratio	-0.00286	-0.00503	-0.00410	-0.00964
	(-0.682)	(-0.853)	(-0.462)	(-1.032)
Business conditions prior to earthquake	-0.0120***	-0.00987*	-0.00607	-0.00649
	(-3.078)	(-1.718)	(-0.740)	(-0.694)
Score prior to earthquake	0.00103	0.000315	3.54e-05	-0.000108
	(1.316)	(0.297)	(0.0227)	(-0.0611)
Age	0.000351	0.000119	0.000949**	0.000948*
	(1.505)	(0.371)	(2.013)	(1.747)
Log (No. of employment)	-5.18e-05	-0.00304	0.00260	0.00103
	(-0.0144)	(-0.617)	(0.363)	(0.114)
Log (distance)	-0.00396*	0.00218	-0.00940*	-0.0156**
	(-1.838)	(0.622)	(-1.894)	(-2.542)
2nd supplier dummy	-0.00151			
	(-0.226)			
3rd suppllier dummy	-0.00109			
	(-0.165)			
1st customer dummy	-0.000806			
	(-0.0941)			
2nd customer dummy	-0.0136			
	(-1.538)			
3rd customer dummy	-0.0281***			
	(-2.944)			
Observations	5,502	1,059	791	718
Industry dummy	yes	yes	yes	yes
Pseudo R2	0.0496	0.0651	0.0932	0.106

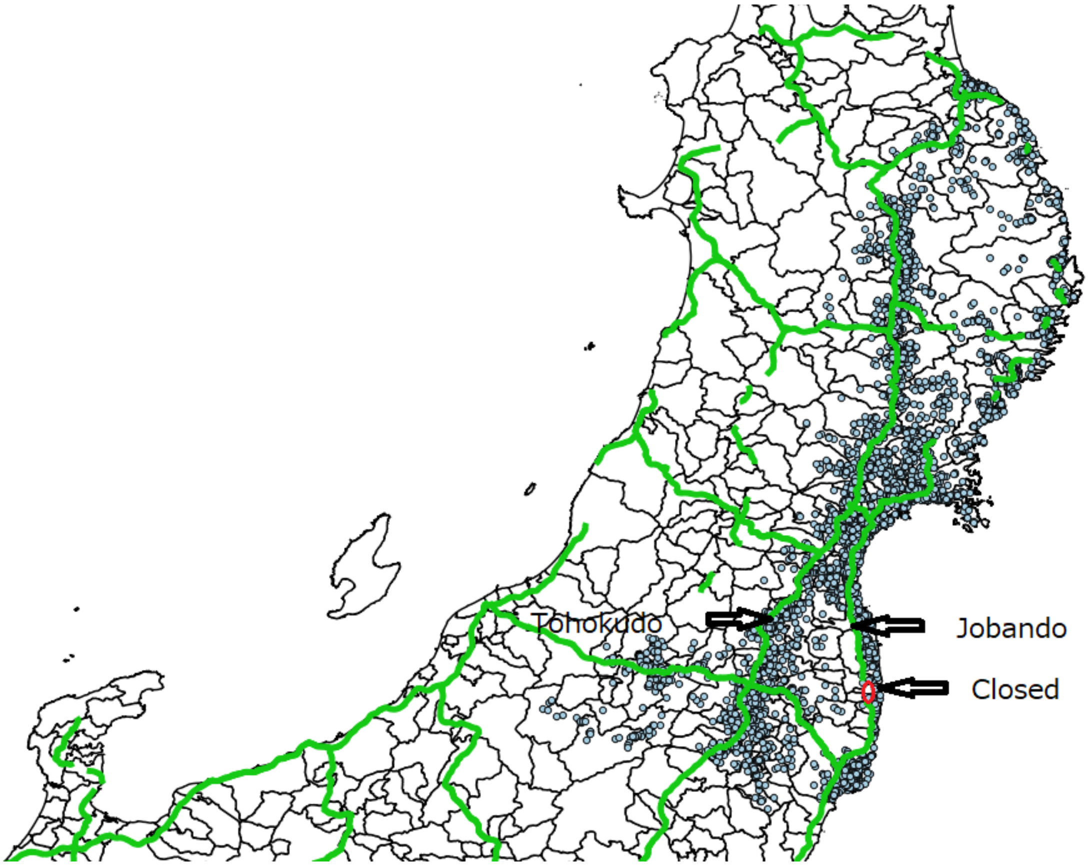
Robust z-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 9. Difference-in-differences in firm performance:
sample being limited to responding firms with undamaged transactional partners

	(1)	(2)	(3)
Suppliers / Customers	3rd supplier	2nd customer	3rd customer
Business conditions	0.0270	-0.568**	-0.744***
	(0.121)	(-2.112)	(-3.617)
Observations	1,054	786	715
Score	-0.778	0.444	0.333
	(-1.591)	(0.665)	(0.528)
Observations	861	664	607

Figure 1 Location of responding firms' headquarters



Notes. The circles indicate the location of the responding firms' headquarters. The lines show highways. The big circle indicates the disrupted zone of Jonbando Highway.