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Role of Hub Firms in Geographical Transaction Network

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Abstract

In this study, we investigate the role of geographical proximity in an inter-firm transaction network and the role of hub firms on geographical spread of regional impact. By using inter-firm micro transaction data of over 800 thousands firms, we found that indirect transaction is geographically dispersed mainly due to a few hub firms, although firm's direct transactions mostly occur within geographically narrow areas. More precisely, median distance between indirect transaction partners (partners' partners) is 255km, which is much larger than that between direct transaction partners (29km). In a counterfactual transaction network without hub firms, whose transaction relations are no less than 100, median distance between indirect transaction partners is reduced to 70km, thereby suggesting the important role of hub firms in a geographical transaction network. We confirm this suggestion through an analysis of regional impact of the Great East Japan Earthquake.

Keywords: Inter-firm network; Geographical proximity; Earthquake
JEL codes: R11

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1. Introduction

It is well known that economic activities are highly localized and inter-firm transaction is theoretically pointed out as one of the important factors that cause industry agglomeration. Borukhov and Hochman (1977) O'Hara (1977), and Fujita and Ogawa (1982) theoretically describe the agglomeration of economic activities in the urban metropolitan areas. In order to reduce transaction cost, firms tend to locate in close proximity to their transaction partners. Nakajima, Saito and Uesugi (2012) found that inter-firm transactions occur within geographically narrow areas, statistically. Calculating geographical distances between transaction partners of manufacturing firms, they found that half of these relations occur within a distance of 40km; only a few firms have transaction partners that are located far away.

After experiencing the unprecedented and devastating Great East Japan Earthquake, many Japanese firms re-evaluated importance of understanding their supply chain network structure, even though they are located in non-affected areas. It was reported that many firms in non-affected areas suffered the consequences of the earthquake though the supply chain. Saito (2012) examined geographical spread of the Great East Japan Earthquake through inter-firm transaction network and found that 5060% firms in non-affected areas have indirect transaction partners (partners' partners) in the affected areas, whereas only a few firms, i.e. less than 3% firms, have direct transaction partners.

Many socioeconomic networks, including inter-firm networks, possess characteristics of a small world network structure, where many entities are very closely connected.[1] Ohnishi, Takayasu and Takayasu (2010) found the small-world network structure in Japanese inter-firm transaction network, where the average shortest path length for pairs of firms in the network was extremely short. In the context of earthquake impact, a small-world network structure suggests that many firms in non-affected areas are closely connected to firms in affected areas through inter-firm transaction network, whereas geographical proximity of firm's direct transaction relation suggests that damage of the earthquake doesn't spread geographically.

In this study, we examined the geographical proximity of direct and indirect transactions, for general case other than earthquake. We calculated geographical distance distribution between direct and indirect transaction partners, which has never done in previous studies. In previous studied, the geographical aspect is rarely considered in the field of network and the indirect links are scarcely considered in the special economics. We found that the median distance between indirect partners is much larger than that between direct partners. We also found the important role of hub firms on geographical spread of transaction network, by considering a counterfactual network without hub firm whose transaction relations are no less

[1] The phenomenon of many socioeconomic networks with common structures is well known and considered as self-organization. Many networks are found to possess both scale-free and small-world characteristics, which are explained in detail in the work of A.-L. Barabási (2002). See Appendix A.

than 100. We confirm the important role of hub firms through the analysis of regional impact of the Great East Japan Earthquake.

This paper is constituted as follows. In the next section, we explain the data used in this analysis. In section3, we discuss the geographical proximity of indirect transaction partners. In section 4, we present the role of hub firms in a geographical transaction network, and in section 5, we discuss the impact of the Japanese earthquake in a geographical transaction network. In section 6, we present the conclusion.

2. Data

The data used in this study are from a database created by Tokyo Shoko Research (TSR), including approximately 800,000 firms, including small- and medium-sized firms. This database encompasses approximately half of the registered firms in Japan, thereby, making it a very comprehensive dataset.

The survey was conducted in 2006. The data obtained includes firm's information, such as industrial classification, establishment year, sales and profits of preceding three years, number of employee, address, and transaction partners (suppliers, customers, and major shareholders). Transaction partners are identified by identification code, and therefore can be combined with firm's information data. The database contains approximately four million transaction relationships in total.

By using an address matching service provided by the Center for Spatial Information Science, University of Tokyo, the firms' addresses in the TSR data were geo-coded to longitude and latitude data. This enables us to visualize geographical distribution of firms and to calculate geographical distances between transaction partners.

An upper limit of 24 was set for the number of firms listed as transaction partners for each firm; thus, not all transaction relationships are included in the data. However, when counting the number of times each firm is listed by other firms as transaction partners, it is possible to identify some hub firms, e.g. firms with more than 10,000 relations, as in Saito and Watanabe (2007). By doing so, Saito and Watanabe (2007) showed that inter-firm network is a scale-free network, while Ohnishi, Takayasu and Takayasu (2010) showed that it is a small-world network.

In this study, we focus on is supply chains; thus, links were created between firms using supplier and customer relations. The links representing transaction relationship reveal the direction of the flow of goods and the corresponding graph can be "directed graph" (i.e. graph with directed links). In order to simplify the problems, the graph is evaluated without considering the direction of links in this analysis.[2]

[2] Some results considering direction about the flow of goods will be shown in footnotes. The main properties of the results remain the same as simplified case without direction.

3. Geographical Proximity of Indirect Transactions

In this section, we examine a geographical proximity of indirect transactions. The most interesting feature presented in Saito (2012) regarding the geographical spread of the Japanese earthquake is that the population of Tier 2 firms that is, firms in non-affected areas whose transaction partners' partners are located in the affected areas is strikingly larger than that of direct transaction partners (Tier 1 firms). Here Tier 0 firms are defined as firms in the affected areas and the transaction partners of Tier n firms are defined as Tier n+1 firms.[3] In order to clarify the mechanism underlying this, we compare geographical proximity of direct and indirect transaction in general context other than the Japanese earthquake. Using inter-firm transaction data with firm's micro location, i.e. longitude and latitude, we calculate geographical distances between indirect transaction partners (partners' partners) and compare with those between direct transaction partners.

Nakajima, Saito, and Uesugi (2012) have already shown the localization of direct transaction. They found that half of direct transactions for manufacturing firms are within 40km and Table 1 shows that those for firms of all industries are within 29km. The direct transactions for non-manufacturing firms are found to be more localized than that for manufacturing firms. Table 1 also shows the distances between indirect transaction partners, that is, partners' partners. We find that the median distance between indirect partners is 255km, which is much larger than that between direct partners (29km).

Furthermore, we compare the distance between indirect partners with that between randomly chosen counterfactual partners, in order to determine the broad distribution of indirect transaction partners. Keeping the number of transactions of each firm as actual one and exchanging partners with others, the median distance between randomly chosen counterfactual partners is found to be 426km. The median distance between indirect partners, which is approximately nine times larger than that between direct partners, is relatively closer to (more than half of) that between randomly chosen counterfactual partners.

The fact that the percentage of Tier 1 firms in non-affected areas is extremely small in Saito (2012) is consistent with the localization of direct transaction. On the other hand, the fact that the percentage of Tier 2 firms in non-affected areas is much larger is consistent with dispersion of indirect transaction.

	N	mean	sd	p50	p25	p75
direct	3461510	169.64	271.73	28.84	6.74	231.67
indirect	17500000	341.83	340.19	255.44	40.83	504.74
random	17500000	481.68	378.26	416.37	186.24	717.41

Table 1. Geographical Proximity of Direct and Indirect Transaction

[3] The more detailed definition of firm's Tier is provided in Appendix A.

4. Role of Hub Firms in the Geographical Transaction Network

In this section, we examine relation between geographical proximity and inter-firm transaction network structure. First, we examine number of transaction partners, that is, number of suppliers and number of customers. As is explained in Section 2, not all transaction relationships are included within the data due to an upper limit of 24 set for the number of firms listed as transaction partners by each firm. In order to include more relationships for each firm, we use both relationships that are reported by each firm and those reported by the other firms.

Figure 1 depicts the distribution of the number of transaction partners. The distribution is straight line for the most part, which means that transaction network is scale free network. I such a network, a few hub firms have many transaction partners in a scale free network. The percentage of hub firms with no less than 1000 relations is 0.06%, that with no less than 500 relations is 0.53%, and that with no less than 100 relations is 1.34%, while median number is 4 and the average is 8.8.

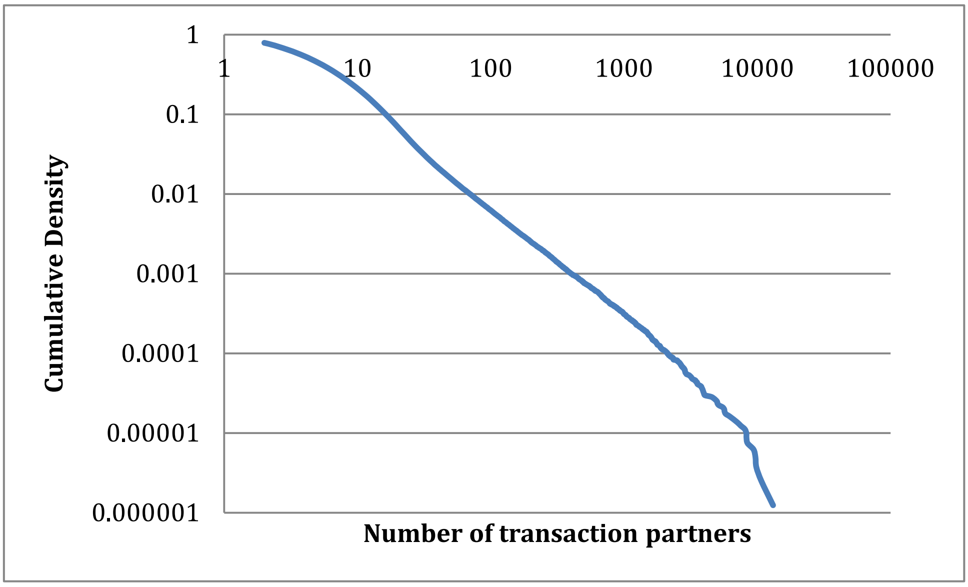

Figure 1. Distribution of Number of Transaction Partners

Next, we examine relationships between geographical proximity and firm's transaction network. Table 2 depicts geographical distances between direct transaction partners of the transaction relationships that involve hub firms and compare them with all relationships. Here, we define hub firms in three different ways, i.e. as firms with no less than 1000 relations (def_100), those with no less than 500 relations (def_500), and those with no less than 100 relations (def_1000). We found that geographical distances are much longer when transaction relation is involved by larger hub firms. This result suggests that hub firms play an important role in the geographical spread of transaction network.

	N	mean	sd	p50	p25	p75
all	3461510	169.64	271.73	28.84	6.74	231.67
def_100	2902788	259.50	310.41	118.61	15.82	456.17
def_500	1402642	310.53	324.23	207.27	25.43	486.45
def_1000	938824	329.38	328.93	257.24	28.98	490.85

Table 2. Geographical Distances between Direct Transaction Partners

In order to examine the role of hub firms in geographical spread of indirect transaction, we consider a counterfactual network. First, we define hub firms as firms with no less than 100 relations. Next, we exclude hub firms from transaction network. Then, we calculate geographical distances between indirect transaction partners in the counterfactual network. Table 3 shows that the median distance between indirect partners is reduced to 70km, although the population of hub firms is 1.34%. We found that indirect transaction is dispersed mainly due to a few hub firms.

	N	mean	sd	p50	p25	p75
all	17500000	341.83	340.19	255.44	40.83	504.74
without hub	3752601	218.78	301.52	70.13	13.75	321.76

Table 3. Geographical Distances between Indirect Transaction Partners

5. Geographical Spread in the Transaction Network without Hub Firms

In this section, we consider the case of the Japanese earthquake as an example of regional impact. We utilize the counterfactual transaction network without hub firms that was introduced in previous section and examine the geographical spread of the earthquake in the network. We defined the affected areas as done in TSR's survey entitled "Related Research on Great East Japan Earthquake,"[4] in which the affected areas are defined as 44 municipalities throughout Aomori, Iwate, Miyagi, and Fukushima Prefectures, along the Pacific coast.[5]

As is explained in Section 3, Tier 0 firms are defined as firms in the affected areas, Tier 1 firms are defined as Tier 0 firms' partners, and Tier 2 firms are defined as Tier 1 firms' partners. Saito (2012) examined

[4] TSR has conducted a survey entitled "Related Research on Great East Japan Earthquake." They defined the affected areas and analyzed the population and properties of firms in the affected areas in order to estimate the impact of the damage. According to their analysis, 32,341 firms were in the affected area, with a total of 363,796 employees.

[5] By using firms' addresses which are transformed to longitude and latitude data, we mapped the firms in the affected areas in Figure B1.

geographical spread of the Great East Japan Earthquake spreads, by counting the number of firms in each tier and each region. The percentage of Tier 2 indirect transaction partners (partners' partners) is 50-60% even in non-affected areas, which is much larger than that of Tier 1, that is, less than 3%.

Table 4 presents the cumulative percentage of firms in each tier and each region in a counterfactual network without hub firms, where hub firms are defined as firms with no less than 100 transaction partners.[6] The percentage of Tier 1 firms is also small for the counterfactual case, just as in the actual network. In non-affected areas, the percentage is less than 3% in the actual network and less than 2% in the counterfactual network. On the other hand, the percentage of up to Tier 2 firms in the counterfactual network is much less than that in the actual network: 50-60% in the actual network and 10-20% in the counterfactual network. Thus, the results reveal the important role of a few hub firms in geographical spread of transaction network by examining the case of the Japanese earthquake.[7]

	Tier 0	Tier 1	Tier 2	Tier 3
Total	1.8%	4.0%	20.3%	55.9%
Hokkaido	0.0%	1.3%	19.8%	65.2%
Tohoku	16.6%	27.3%	56.6%	81.2%
Kanto	0.0%	1.9%	19.8%	55.2%
Chubu	0.0%	0.6%	13.8%	54.4%
Kinki	0.0%	0.8%	14.0%	49.5%
Chugoku/Shikoku	0.0%	0.4%	11.5%	48.9%
Kyushu	0.0%	0.3%	9.8%	44.9%

Table 4. Cumulative Percentage of Firms in Counterfactual Network without Hub Firm

Finally, we examine how Tier 1 firms and Tier 2 firms are connected geographically in order to clarify the path of indirect transactions. Table 5 depicts that how the Tier 1 firms are connected to Tier 2 firms by region. For all Tier 2 firms in each region, we identify the region of Tier 1 firms that connect them to Tier 0

[6] Another alternative counterfactual network can be a network excluding some links (relations) of hub firms, instead of excluding hub firms themselves. We exclude links of hub firms, where geographical distances between nodes (firms) are no less than 300km. The percentage of Tier 2 firm is 34% in such a counterfactual network, which is much smaller than that in the actual network.

[7] These are the results in the simplified network where the directions of flow of goods are not considered. The main results do not change after considering a flow of goods, in the following way. We consider directed inter-firm network. Then, we calculate the corresponding values presented in Table 4 and Table B1 in the directed network. We define Tier 1 firms as those which have suppliers in affected areas and Tier n firms as those with supplier of Tier n-1 firm. Then, the percentage of Tier 2 firm is found to be 29% in the actual directed network, while the corresponding value is 8% in the counterfactual directed network. We found substantial decrease from actual network to counterfactual network in directed network, just as in the undirected network.

firms, and calculate the percentage of firms. It is evident that percentage is larger in the diagonal of the matrix, which means that Tier 2 firms are frequently connected to Tier 0 firms through Tier 1 firms in the same region. For example, 75% of Tier 2 firms in Hokkaido are connected to Tier 0 firms through Tier 1 firms in the same region (Hokkaido).

Figure B2 in Appendix B depicts the geographical distribution of Tier 1 firms, and reveals that Tier 1 firms are broadly distributed throughout the country, although the proportion of Tier 1 firms is extremely small. Considering the fact that the number of Tier 1 firms is much smaller than that of Tier 2 firms in non-affected areas and hub firms disperse the geographical transaction distance, it is evident that hub firms in each region play an important role in geographical spread of the impact of the earthquake in each region.

		Tier 2						
		Hokkaido	Tohoku	Kanto	Chubu	Kinki	Chugoku/ Shikoku	Kyushu
Tier 1	Hokkaido	75%	1%	5%	4%	3%	2%	1%
	Tohoku	8%	80%	10%	8%	7%	7%	4%
	Kanto	11%	14%	50%	24%	29%	20%	15%
	Chubu	1%	1%	8%	40%	10%	5%	3%
	Kinki	3%	3%	13%	13%	33%	11%	8%
	Chugoku/Shikoku	1%	1%	7%	5%	10%	45%	6%
	Kyushu	1%	0%	7%	5%	8%	9%	63%

Table 5. Geographical Relation between Tier 1 and Tier 2

To sum up, numerous Tier 2 firms in the non-affected areas are connected to Tier 0 firms in following way. First, regional hub firms in non-affected areas are related to Tier 0 firms. Because hub firms can construct transactions with firms which are located away from the region, they are likely to be connected to firms in the affected areas. Next, many firms in the same region have transaction with the regional hub firms which are located closely. In this case, there are a larger proportion of Tier 2 firms in non-affected area, despites the small proportion of Tier 1 firms. Figure 4 depicts the connecting path in geographical network. In the figure, the circles represent firms and the color of circle represent firms' region, that is, grey circles represent firms in the affected areas and white circles represent firms in non-affected areas. The lines represent transaction relations and the length of each line represents geographical distances between the firms.

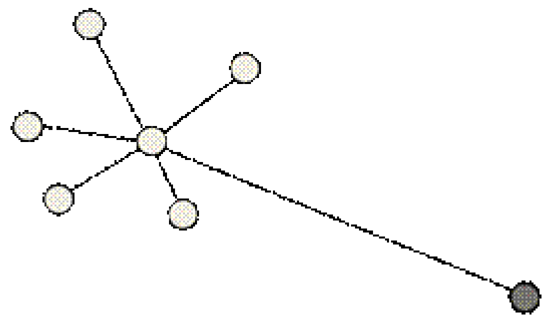

Figure 4. Connecting Path in Geographical Network

6. Concluding Remarks

In this study, we examine the role of hub firms in geographical spreads of inter-firm transaction networks. The main purpose of our study was to answer the conflicting implications on the geographical impact of the Great East Japan Earthquake from previous studies of inter-firm networks, that is, small world structure and geographical proximity. Small world structure of the inter-firm network suggests that the impact of the earthquake spreads broadly, whereas geographical proximity suggests differently. In previous studies, regional impacts of earthquakes on firms, for example, were found to spread broadly through the transaction network, although firm's direct transaction occurred within geographically narrow areas.

Using inter-firm transaction data of approximately 800,000 firms, we examined how firms in non-affected areas have relationships with those in the affected area. The percentage of direct transaction partners is very small, accounting for less than 3% of total firms in the non-affected areas. We also found that the figure increases to 50% to 60% if indirect transaction partners, i.e. partners' partners, are included. We examined the geographical proximity of indirect transactions for a general case other than that of the Japanese earthquake and found that the median distance between indirect partners is 255km. This is much larger than that between direct partners (29km) and relatively close to that between randomly chosen partners (429km).

The fact that the proportion of direct transaction partners in non-affected areas is very small in our analysis is consistent with implication from the geographical proximity of direct transaction. In addition, the fact that indirect transactions are not localized is consistent with implication from the small world network structure.

Thus, by examining the connecting path between indirect transaction partners, we found the differences between direct and indirect transaction in terms of geographical proximity is due to regional hub firms, which can construct transaction with firms located at a distance.

These results suggest that regional government have to pay attention to regional hub firms in order to protect many firms in the region when regional impact occurs in different area.

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Appendix A: Network Analyses

Network analysis has been developed in the field of natural sciences, but employed to sociology, management studies, and other areas. In graph theory, "graphs" are described by sets of "nodes" and "edges" (or "links"). In Figure 1, circles represent nodes and lines represent edges. Each node is connected by edges, and various combination patterns of nodes and edges produce various characteristics.

In natural science, analyses of various network structures have been conducted and networks are categorized according to certain patterns in graph theory. For example, universal structures have been observed in networks such as ecosystems (e.g., protein interactions and metabolic pathways) and the Internet. These universal structures, called "self-organizing phenomena" are often captured by distribution of number of links and shortest path length. For example, numbers of links for nodes (A, B, C, and D) are 3, 2, 5, and 1, respectively. Shortest path length between A and B is 1, that between A and C is 2, and that between A and D is 3.

A scale-free network is one type of network structure. Scale-free networks have a power-law distribution for the number of links. Power-law distributions are frequently observed for phenomenon in sociology. Wealth distribution is a popular example; it is commonly stated that "20% of the population holds 80% of the wealth." The fact that the number of links in an inter-firm network follows a power-law distribution means that there exist hub firms with an extremely high number of relationships. Gabaix (2009) reviewed the "power law" observed in economics and finance.

Further, another universal network structure is the small-world structure. It has been confirmed that the path length of any combination of two nodes in a network is extremely small. It is often said that “there are only six degrees of separation from any two people in the world.”

In management studies, network analysis is often used as relationship visualization methods. It is possible to visualize specific firms’ transaction partners and partners’ partners in order to predict transmission paths of shocks such as deteriorating corporate performance or bankruptcy.

As an example, we can consider the impact of an earthquake through inter-firm transaction networks. In Figure 1, grey circles represent firms in the affected areas and white circles represent firms in the non-affected areas. In this analysis, Tier 0 firms are firms in the affected areas and Tier 1 firms are transaction partners of Tier 0 firms. Then, the transaction partner of Tier n firm is defined as Tier n+1 firm. In Figure 1, firms (A, B, C, and D) are Tier 0, Tier 1, Tier 2, and Tier 3, respectively. In defining these firms, there can be no overlap with firms in other tiers; thus, Tier n firm cannot be in Tier n+1 or lower-level tiers.

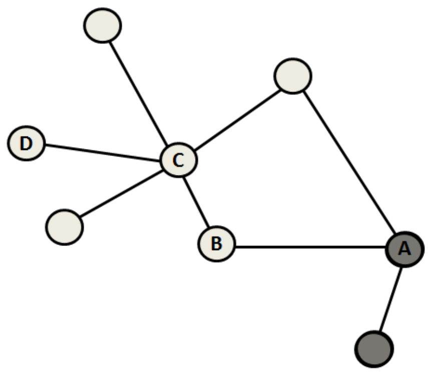

Figure A. Example of Graph

Appendix B. Geographical Spread of the Earthquake

Tokyo Shoko Research has conducted a survey entitled "Related Research on Great East Japan Earthquake." They defined the affected areas and analyzed the population and properties of firms in the affected areas in order to estimate the impact of the damage. According to their analysis, 32,341 firms were in the affected area, with a total of 363,796 employees. However, we already know that much more firms were impacted by the earthquake through supply chain.

Using TSR data for 2006, we plotted firms in the affected areas (Tier 0 firms) in Figure B1 and Tier 0 firms' transaction partners (Tier 1 firms) in Figure B2. It is evident that Tier 1 firms are broadly distributed, while Tier 0 firms are located in geographically narrow areas.

Thereafter, we counted the number of direct and indirect transaction partner and calculate the percentage of firms for each tier and for each region. Table B shows the cumulative percentage of firms. In this table, the vales mean cumulative percentage, that is, the value in the Tier 0 column indicates percentage of Tier 0 firms and the value in the Tier 1 column indicates percentage of firms up to Tier 1 (Tier 0 firms plus Tier 1 firms).

Since the affected areas are in Tohoku region, Tier 0 firms can be observed in only Tohoku region. The percentage of Tier 0 firms in the Tohoku region is 17%, and the value goes up to 34% when including transaction partners (Tier 1 firms), and 82% when including partners' partners (Tier 2 firms), thereby indicating the involvement of many firms. Next, we focus on the Kanto region that has largest population of firms. We see that transaction partners are less than 3% of the total, but including partner's partner brings the percentage up to 58%, thus more than half of the firms are impacted. Even outside the Kanto region, in areas at a distance from the affected areas, almost half of firms are impacted when partners' partners are included. Figure B3 depicts the cumulative percentage of firms by prefecture. The geographical spread of the impact can be seen visually.

With regard to Tier 3 firms (i.e. partners' partners' partners), the cumulative percentage of firms in all regions increases to almost 90%. This implies that there are almost no firms without any transaction relationships in the affected area. Thus, it is evident that inter-firm transactional network is truly a small world, and we were able to confirm by the analyzing spread of earthquake damage as well.

Figure B1. Geographical Distribution of Tier 0 Firms

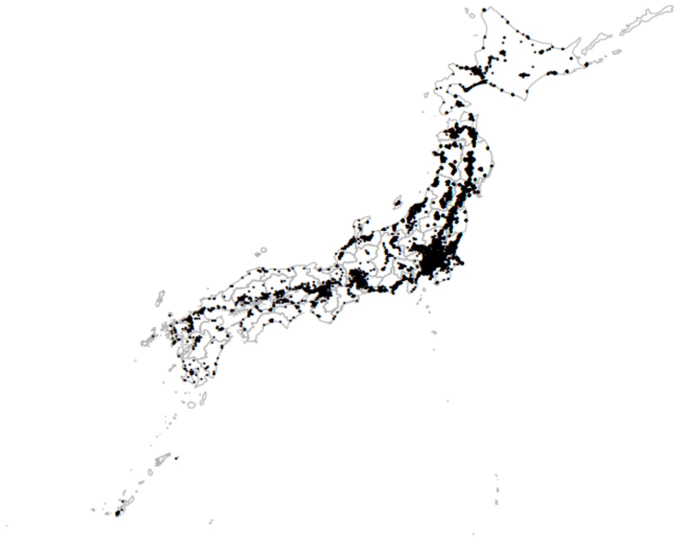

Figure B2. Geographical Distribution of Tier 1 Firms

	Tier 0	Tier 1	Tier 2	Tier 3
Total	1.8%	5.1%	56.7%	90.5%
Hokkaido	0.0%	2.3%	60.2%	95.8%
Tohoku	16.6%	33.6%	82.0%	96.7%
Kanto	0.0%	2.7%	58.2%	89.5%
Chubu	0.0%	0.8%	51.6%	90.6%
Kinki	0.0%	1.2%	54.2%	88.0%
Chugoku/Shikoku	0.0%	0.5%	47.2%	90.1%
Kyushu	0.0%	0.3%	42.8%	88.3%

Table B1. Cumulative Percentage of Firms by Region

Figure B3. Cumulative Percentage of Firms by Prefecture