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The Strength of Long Ties and the Weakness of Strong Ties: Knowledge diffusion through supply chain networks[*]

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Abstract

This paper examines the effect of the structure of supply chain networks on productivity and innovation capability through knowledge diffusion, using large firm-level panel data for Japan. We find that ties with distant suppliers improve productivity, as measured by sales per worker, possibly attributed to intermediates from distant firms embodying more diversified knowledge than from neighboring firms. Ties with neighboring clients also improve productivity, which may be a result of diffusion of disembodied knowledge from neighboring clients being more effective than from distant clients. By contrast, ties with distant suppliers and clients improve innovative capability, as measured by the number of patent applications, suggesting the importance of a diversity of knowledge from distant firms for innovation. In addition, the density of a firm's ego network, which is measured by how densely its supply chain partners transact with each other, is found to have a negative effect on productivity and innovative capability, implying knowledge redundancy in dense networks. Overall, our results emphasize the importance of diversified partners in knowledge diffusion through supply chain networks.

Keywords: Knowledge diffusion, Supply chain networks, Geography, Network density

JEL classification: O33; R11; L14

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1. Introduction

Growth in productivity and innovation capability of firms is largely affected by diffusion of knowledge, technology, and information from other firms (Bloom et al., 2013; Romer, 1990). Possible channels of such knowledge diffusion include buyer-supplier relations between firms, because buyers often provide new knowledge to their suppliers to procure high-quality products (Dyer and Nobeoka, 2002). In addition, buyers can benefit from knowledge diffusion from their suppliers, because the productivity of assemblers is higher when they employ a larger variety of parts, components, and materials from different suppliers (Dixit and Stiglitz, 1977).

Knowledge diffusion through buyer-supplier relations has been tested extensively in the empirical literature, in which an improvement in measures of productivity and innovation capability associated with such relations is considered to reflect knowledge diffusion. For example, when firms improve their productivity through exporting, it is assumed that firms learn new knowledge by exporting. Knowledge diffusion through international trade is examined by Crespi et al. (2008a), Kimura and Kiyota (2006), Lööf and Andersson (2010), Piermartini and Rubínová (2014), and Van Biesebroeck (2005), among many others. Javorcik (2004) shows evidence of knowledge spillovers from foreign-owned firms to their upstream suppliers.

Other studies pay attention to supply chain networks as a channel of knowledge diffusion more explicitly. For example, Crespi et al. (2008b) show that the number of registered patents and growth in total factor productivity (TFP) are higher when firms report that they obtain knowledge from their suppliers, using firm-level data for the United Kingdom. Isaksson et al. (2014) find evidence of a positive effect of buyers’ innovation on their suppliers’ innovation, using patent data for the US firms in the high technology sectors. In the literature on supply chain management, Flynn et al. (2010) find a positive effect of the strength of relations with customers, which is subjectively measured by firms, on firm performance but an insignificant effect of relations with suppliers. Bozarth et al. (2009) find that the number of suppliers or clients did not affect subjectively measured firm performance. Using a firm-level dataset for Japan similar to the one in this study, Bernard et al. (2014) and Belderbos et al. (2015) examine how firms' productivity is affected by their buyers and suppliers.

One shortcoming of the literature on knowledge diffusion through supply chain relations is that it has not paid attention to how a firm's direct suppliers and clients are connected with other firms. Knowledge diffusion to a particular firm from its supply chain partners may be influenced by whether the partners are connected with each other and with whom they are connected. For example, how much knowledge diffuses to a firm from its suppliers may vary depending on whether the suppliers are in the same closed firm group or are connected with different types of firms. However, the existing studies ignore such in-depth characteristics of the whole supply chain networks in the economy. Instead, they identify supply chain relations only by using firms' engagement in trade (Kimura and Kiyota, 2006; Lööf and Andersson, 2010; Van Biesebroeck, 2005), firms' subjective perception (Crespi et al., 2008a; Flynn et al., 2010), input-output tables at the industry level (Javorcik, 2004; Piermartini and Rubínová, 2014), or, at best, firms' direct supply chain partners (Belderbos et al., 2015; Bernard et al., 2014; Isaksson et al., 2014).

The importance of looking at the overall structure of networks has been emphasized in the literature on social networks (Granovetter, 2005). Burt (1992), for example, finds that actors who create bridging links between otherwise disconnected groups of actors, or structural holes, have superior access to diverse information. This is related to the argument of Granovetter (1973) that weak ties to relatively less frequently-met partners are instrumental for accessing new information because such links often reach outside of the immediate circle of densely-interconnected strong ties among similar partners with similar shared information. In other words, density of networks may prevent active knowledge diffusion, because it leads to overlaps and redundancy of knowledge among partners. However, structural holes and weak ties may not always be the key to knowledge diffusion, as some other studies found that dense networks within an organization in which actors are closely connected with each other but not so with outsiders can promote knowledge diffusion. The positive effect of dense networks emerges probably because actors in these networks know each other well and thus trust new knowledge from each other (Ahuja, 2000; Phelps, 2010).

Adopting methods in social network analysis, this study examines how the structure of the whole supply chain networks affects knowledge diffusion, using a large firm-level panel dataset for the Japanese manufacturing sector that covers most firms within the country and major buyer-supplier relations. Following the literature, we test the presence of knowledge diffusion by estimating whether the structure of supply chain networks positively affect productivity, measured by sales per worker, and innovation capability, measured by the number of registered patents.

More specifically, the contributions of this study are threefold. First, we investigate how the density of a firm's ego network, i.e., how densely its supply chain partners transact with each other, affects its performance for the first time in the literature on knowledge diffusion through supply chain networks. The effect of ego network density has been studied in the case of research collaboration networks in Ahuja (2000) and Phelps (2010) but not in the case of supply chain networks. Ego network density may have both positive and negative effects on knowledge diffusion, as we argued above. Therefore, the net effect of the network density should be empirically examined.

Second, we examine how ties with neighboring and distant supply chain partners affect firm performance differently, following the literature that has found negative effects of geographic distance on the degree of knowledge and information diffusion (Jaffe and Trajtenberg, 1993; Jaffe et al., 1999). Knowledge diffusion from neighboring partners may be easier than from distant partners because of smaller costs of transportation (Marshall, 1890). However, neighboring partners are more likely to be similar to the firm and to each other and thus to be equipped with similar knowledge and products. In other words, more knowledge and intermediate products new to the firm are available from its distant partners than from its neighbors. Therefore, the net effect of distance with network partners on firm performance is not very clear.

Finally, our empirical estimation employs a dynamic panel model, assuming that supply chain ties and firm performance interact with each other over time. In this framework, we can incorporate causality between firm performance and characteristics of supply chain networks in both directions and hence can alleviate possible biases in estimations of the effect of networks on performance due to reverse causality.

Our findings suggest that geographic proximity of supply chain partners and density of supply chain networks tend to reduce benefits from knowledge diffusion, probably because of redundancy of knowledge in such networks. Therefore, this study emphasizes the importance of diversification of network partners in knowledge diffusion.

2. Conceptual Framework

2.1. Channels of knowledge diffusion through supply chain networks

Supply chain ties can improve firm performance through diffusion of knowledge in the following two ways. First, clients often provide new knowledge and technology for production and market information to their suppliers to improve the quality of goods they purchase and reduce the price of the goods. For example, Dyer and Nobeoka (2002) show that Toyota often organizes associations of its suppliers in which it provides valuable technical and managerial assistance to suppliers. Egan and Mody (1992) show that a US shoe importer sent Italian skilled artisans to Taiwanese shoe manufacturers for technical assistance. Through such technical assistance, knowledge of clients diffuses to their suppliers. Second, production of clients is larger when they utilize a larger variety of inputs from their suppliers, as typically described by the production function assuming a constant elasticity of substitution among inputs developed by Dixit and Stiglitz (1977). In other words, knowledge of suppliers is embodied in their products and diffuses (or is "lent" according to Baldwin and Lopez-Gonzalez, 2014) to their clients.

2.2. Density of networks and strength of ties

The effect of supply chain ties may vary, depending on the structure of networks and characteristics of ties. In particular, density of networks, i.e., how densely actors in a network are connected with each other, and strength of ties, i.e., how closely an actor is connected to another, may positively or negatively promote knowledge diffusion. On the one hand, one may expect that dense networks and strong ties facilitate knowledge diffusion because these network characteristics can foster shared norms and explicit knowledge-sharing institutions (Ahuja, 2000). Using data from leading chemical firms in the United States, Ahuja (2000) finds that when a firm's research collaboration network is dense, the firm generates more patents. Centola (2010) also shows from his social experiment on the Internet that members of an online health forum are more likely to adopt new healthy behavior informed by a member when more members in the forum know each other. Centola (2010) interprets this evidence as showing that reinforcement from multiple informants promotes knowledge diffusion and adoption.

On the other hand, network density and strong ties may lower benefits from knowledge diffusion through networks, because these characteristics translate into redundant ties (Burt, 1992). When a firm is connected to only partners with which it already shares the same knowledge, the firm cannot learn much from the partners (Berliant and Fujita, 2011). Therefore, benefits from networks can be maximized when firms are connected with different types of partners, so that technology, knowledge, and information of partners are well diversified. The importance of diversified networks in knowledge creation and diffusion has been emphasized in the social network literature. Burt (2004), for example, finds that a measure of diversity of workers' networks in a firm is positively related to their salary and the probability of promotion, arguing that structural holes connecting different groups facilitate knowledge diffusion. Granovetter (1973) finds that for job seekers, more important information sources are persons who they meet less often, emphasizing the strength of weak ties. The importance of network diversity is also confirmed by Beugelsdijk and Smulders (2004), McFadyen and Cannella (2004), and Perry-Smith (2006) who find strong ties with trustworthy partners or dense networks within the community or organization may not enhance economic performance without links to other communities.

Thus, whether network density and strength of ties positively or negatively affect knowledge diffusion may depends on the situation (Phelps et al., 2012). Therefore, this study focuses on supply chain networks and empirically examines how network density affects its productivity and innovative capability through knowledge diffusion.

2.3. Geographic diversity

The argument in the previous subsection emphasizes the importance of diversity among network partners in knowledge diffusion. One factor which generates knowledge diversity is geographic locations of network partners. We presume that neighboring firms share more knowledge and information with each other than with distant firms. Therefore, we expect that more new knowledge and information diffuse from distant supply chain partners than from neighboring partners. The underlying idea is similar to the "learning-by-exporting" hypothesis that exporters can improve their productivity by learning new knowledge and technology from foreign countries, which is widely tested in the literature (Clerides et al., 1998; Kimura and Kiyota, 2006; Van Biesebroeck, 2005 among many others).

However, creating and maintaining ties with distant partners are more costly than those with neighboring partners because of transportation costs. In fact, low transportation costs of transaction with neighboring suppliers are one of the major factors of industrial agglomeration (Fujita and Thisse, 2013; Marshall, 1890). Jaffe et al. (1993) and Jaffe and Trajtenberg (1999) find evidence that geographic distance negatively affects the degree of knowledge diffusion, using data on patent citations.

Therefore, it is not clear whether ties with neighboring or distant partners are more beneficial to firm performance through knowledge diffusion. Bell and Zaheer (2007) in fact find that proximity can have a positive or negative effect on knowledge flows, using data from Canadian mutual fund companies. Therefore, this paper examines how neighboring and distant supply chain partners affect productivity and innovative capability of firms differently, distinguishing between partners within the same prefecture and outside of the prefecture.

2.4. Interaction between strong ties and weak ties

Finally, there may be complementarity between strong ties within the community and weak ties with outsiders, as found in Phelps (2010), Rost (2011), and Tiwana (2008). For example, Rost (2011) examines networks among inventors in the German automobile industry and finds that strong ties with regular collaborators promote innovation and moreover, that weak ties with unfamiliar researchers leverage the effect of strong ties. This evidence implies that new knowledge obtained from outsiders can disseminate effectively within the community when community members are densely connected, confirming the importance of knowledge diversity in diffusion. This study also tests this complementarity between strong ties within the community and weak ties with outsiders, particularly assuming that network density is associated with the strength of ties and that distant partners are outsiders equipped with new knowledge.

3. Data

3.1. Data sources

The dataset used in this study were mostly based on data collected by Tokyo Shoko Research (TSR), one of the two major corporate research companies in Japan. The TSR data contain corporate information, such as firms' location, sales, and the number of employees, and information on up to 24 suppliers of material and intermediates and up to 24 clients of products for each firm. The information on suppliers and clients can be merged with the corporate information data to establish the characteristics of each supplier and client. Although the upper limit of the number of suppliers and clients, 24, is clearly too small for many large firms, it still allows most of the supply chain networks to be captured by looking at the supplier–client relations from both directions.

This study utilizes data licensed from TSR to Research Institute of Economy, Trade and Industry (RIETI) in 2006 and 2012 to construct a panel data set. The number of firms in the TSR data licensed in 2006 and 2012 is 803,531 and 1,109,549, respectively. The number of supplier-client ties in 2006 and 2012 is 3,783,623 and 5,106,081, respectively.

TSR has been collecting information from all firms in Japan recognized by TSR throughout the year to sell the information to other firms, and hence the time of data collection varies across firms. Therefore, in the data licensed in 2006 (the 2006 data), information on 67 percent of firms was collected in 2005, 28 percent in 2004, and five percent in other years. In the data licensed in 2012 (the 2012 data), information on 12 percent of firms was collected in 2012, 69 percent in 2011, and 18 percent in earlier years. Among the 2006 data, we utilize only data collected in 2004 or 2005 to avoid old information. Among the 2012 data, we utilize only data collected after April 2011, because the Great East Japan earthquake in March 11, 2011 resulted in changes in suppliers and clients of many firms including those outside of the directly impacted areas.

Using the TSR data, we identify suppliers and clients of each firm as well as their locations and characteristics. Then, we count the number of suppliers and clients within the same prefecture and outside of the prefecture for each firm. It should be noted that because the TSR data are at the firm level, supplier-client relationships at the establishment level cannot be identified. Therefore, the sample in our estimations includes only single-establishment firms to clarify the geographic characteristics of supplier-client relationships, although transaction ties are identified using all firms including single- and multiple-establishment firms. In other words, we drop multiple-establishment firms from the sample for our analysis, but we utilize supply chain ties of single-establishment firms with multiple-establishment firms in the analysis.

Even so, one problem still remains. Consider, for example, single-establishment firm A in prefecture X has a transaction with a branch of firm B in the same prefecture whose headquarter is in prefecture Y. Then, our data identify the transaction of firm A with B as that with a firm outside of the prefecture, although it is indeed a tie with a firm within the same prefecture. However, this is acceptable, because we distinguish between transactions within the same prefecture and those across prefectures to examine the role of knowledge diversity. The transaction of firm A with a branch in the same prefecture of firm B whose headquarter is in a different prefecture may be regarded as that across prefectures, because the branch of firm B may share the knowledge of its headquarter.

The TSR data include both manufacturing and non-manufacturing firms. However, because the relation between supply chain networks and firm performance may be different across sectors, this study particularly focuses on firms in the manufacturing sector to highlight the effect of supply chains of parts and components on firm performance. We further restrict to firms whose information are available in both 2006 and 2012 data, and thus the number of firms in our sample for estimations is 36,814.

We merged the TSR data with data for the number of registered patents for each firm taken from the Institute of Intellectual Property Patent Database (Goto and Motohashi, 2007). This database covers all patents registered by the Japan Patent Office from 1963 to 2013. We merge the two datasets by names and addresses of firms. Addresses in the two datasets cannot be straightforwardly matched using their linguistic characters because the same address may be expressed in different characters due to abbreviations or different mixture of Japanese, Chinese, and Roman characters. Therefore, we utilize the CSV Address Matching Service of the Center for Spatial Information Science, the University of Tokyo to unify expressions of addresses. Using the unified addresses at the township level, we match addresses between the TSR and patent data.

3.2. Key variables for estimation

We examine whether knowledge diffuses through supply chain networks by estimating effects of variables for characteristics of networks on measures of productivity and innovative capability. To measure the diversity of knowledge of network partners, we use the number of suppliers and clients, which varies substantially across firms. Figure 1 shows the cumulative distribution function for the number of suppliers (the left figure) and clients (right) for single-establishment firms in the manufacturing sector in the 2006 data. Both figures show that the median of the number of suppliers and clients is small (two), while it is extremely large for some firms. This power-law nature has been found in existing studies such as Bernard et al. (2014).

We further distinguish between neighboring partners, i.e., those within the same prefecture, and distant partners, i.e., those outside of the prefecture, assuming that knowledge of distant partners are more diversified. Although our dataset includes the detailed address of each firm, we do not utilize the distance between supply chain partners to examine effects of distance to partners but simply distinguish between partners within and outside of the same prefecture to simplify the analysis.[1] However, this simplification may be justifiable because different prefectures reflect differences in industrial, social, and cultural backgrounds, in addition to geographic distance, which lead to knowledge diversity. Such border effects are also found in the literature of international knowledge diffusion (Griffith et al., 2011). Figure 2 demonstrates the relationship between the numbers of suppliers in and outside of the same prefecture. There is a weak positive relation between the two variables, as the correlation coefficient between the two is 0.20. However, it should also be emphasized that many firms are confined with a regionally closed network in that they have no suppliers outside of the prefecture. By contrast, there are many others whose suppliers are mostly in other provinces.

Firms occasionally change their suppliers and clients, and thus the number of suppliers and clients can change over time. Figure 3 shows the distribution of the change in the number of suppliers in total (the top figure), in the same prefecture (middle), and outside of the prefecture (bottom). Approximately one third of firms did not change the number of suppliers from 2006 to 2012, while

[1] Belderbos et al. (2015) utilize the full information of the distance by estimating a non-linear model in which the effect of knowledge diffusion decays exponentially with distance.

some others increased it and fewer others decreased it. As a result, the mean of the change in the total number of suppliers is 0.99. When we pay attention to the number of clients, rather than suppliers, we find a very similar characteristics.

Another key variable for the network structure is the density of each firm's ego network, measured by the ratio of the number of actual ties among each firm's supply chain partners (both suppliers and clients) to the number of all possible ties among them. For example, when a firm has three supply chain partners among which two also transact with each other, the density measure is 1/3 = 0.333. When a firm has only one supply chain partner, we define the density as zero. If the density measure is large, we assume that the diversity of knowledge among supply chain partners is low but that the strength of ties is high. As shown in Table 1, the mean of the network density is 0.26.

Our productivity measure is sales per worker. Obviously, value added per worker and TFP are better measures of productivity, but because the TSR data do not include value added, costs of intermediate goods, or the amount of capital stocks, we should rely on sales per worker. The mean of sales per worker and sales is 24 million yen and 462 million yen, respectively (Table 1). As we have explained above, we focus on firms with only one establishment, the mean of sales per worker and sales is smaller than their mean for all manufacturing firms (36 million yen and 1,458 million yen, respectively).

One major problem of using sales per worker as a productivity measure is that it overvalues productivity for firms which purchase intermediate goods from other firms. In the context of this study, this implies that sales per worker are likely to be higher when firms are connected with more suppliers and thus procure more intermediate goods from suppliers. Then, regardless of the presence of knowledge diffusion through supply chain networks, a positive correlation between the number of suppliers and our productivity measure may be realized. However, this problem does not arise in this study, because we employ a dynamic panel estimation method, as explained later in detail, essentially estimating effects of past network characteristics on the change in sales per capita, rather than the contemporaneous relation between our network variables and productivity measure.

Our measure of innovative capability is the number of registered patents. Because the minimum length between the two data periods for the TSR data is five years, we define as the number of registered patents for year *t* the summation of patents applied in years from *t* - 4 to *t* and registered by 2013.[2] The mean of the number of registered patents is quite small and 0.06, as it is zero for 97.7 percent of firm-year observations.

4. Empirical Strategy

The conceptual framework in Section 2 shows that firms' supply chain networks affect productivity and innovative capability through diffusion of embodied and disembodied knowledge. However, estimations of effects of supply chain networks can be biased because of endogeneity of covariates. For example, higher productivity may lead to larger supply chain networks, generating reverse causality, because more productive firms can find and can be found by suppliers and clients more easily. To alleviate the possible biases due to endogeneity, we employ the following estimation methods.

4.1. Effects on productivity

As we just argued, firm performance including productivity and supply chain networks are interlinked with each other. In addition, firms' performance and networks are affected by their own dynamics, as the recent literature on social networks suggests (Snijders and Doreian, 2010; 2012). To investigate the interlinked dynamics of firms' performance and networks, we employ a dynamic panel simultaneous equation model where outcome variables are assumed to be functions of their lags and other control variables, as follows:

$$\mathbf{Y}_{it} = \boldsymbol{\alpha} + \boldsymbol{\beta}\mathbf{Y}_{1t-1} + \boldsymbol{\delta}\mathbf{X}_{it} + \boldsymbol{\varepsilon}_{it} \,. \tag{1}$$

[2] The average length from application to registration is 11 months in the fiscal year of 2013 (Japan Patent Office, 2014). Therefore, the patent data up to 2013 used in this study should cover most registered patents applied in 2011 and 2012, the second period of the TSR data.

$\mathbf{Y}_{it}$ is a vector of five variables that represent firm *i*'s supply-chain networks and performance: the number of suppliers or clients in the same prefecture plus one in logs, the number of suppliers or clients outside of the prefecture plus one in logs, the density of firm *i*'s ego network, sales per worker in logs, and sales in logs. Total sales are included in the set of outcome variables to represents firm size. $\mathbf{X}_{it}$ is a vector of control variables including firm age, firm age squared, and dummies for industries, prefectures, and years of data collection, and $\boldsymbol{\varepsilon}_{it}$ is the vector of error terms. Industries are defined at the two-digit level of the Japan Standard Industrial Classification. We allow for correlation between error terms. In this framework, $\boldsymbol{\beta}$ can be considered as a Markov matrix. We estimate equation (1) separately for ties with suppliers and clients because the number of suppliers and clients is closely correlated with each other and hence incorporating both suppliers and buyers in one estimation may cause multicollinearity.

Given the estimates of $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, and $\boldsymbol{\delta}$, we simulate the model to examine what would happen if the number of suppliers within or outside of the same prefecture or the network density would increase. This computational exercise could provide deeper insights on the dynamics of firms' performance and networks interlinked with each other than estimation coefficients. In this computational analysis, we assume a hypothetical firm for which industry and prefecture dummies take their mean values and all other variables take their median values.

One shortcoming of this empirical strategy is worth noting. Although the number of supply chain partners is always a non-negative integer, equation (1) implicitly assumes that the log of the number of partners plus one is continuous. However, incorporating this limited-dependent-variable nature into the simultaneous equation framework requires additional assumptions in the distribution of error terms. Therefore, we assume the log of the number of suppliers plus one is continuous.

4.2. Effects on innovation capability

When we focus on effects of supply chain networks on innovative capability, we cannot employ the approach above, because the measure of innovative capability, the number of registered patents, is zero for 98 percent of firms. Therefore, we estimate a Tobit model in which the dependent variable is the log of the number of registered patents plus one. To alleviate endogeneity biases due to reverse causality from innovative capability to networks, we employ the minimum chi-squared estimator of Newey (1987) using lagged network variables to instrument current network variables. We do not employ the full information maximum likelihood estimation of the Tobit model, because it does not converge possibly due to many dummy variables for industries and prefectures.

5. Results

5.1. Effects on sales per worker and total sales

The results from the estimation of dynamic panel equation (1) focusing on ties with suppliers for the manufacturing firms are shown in Table 2, pointing to the following five notable findings. First, the results in columns (4) and (5) highlight differences in effects on firm performance between suppliers in the same prefecture and those outside of the prefecture. The effect of the number of suppliers within the same prefecture on productivity measured by sales per worker or firm size measured by total sales is not statistically significant at the 5-percent level. On the contrary, the effect of the number of suppliers outside of the same prefecture on sales per worker and sales is positive and significant at the 1-percent level. The results imply that ties with neighboring suppliers are less likely to improve productivity through knowledge diffusion, while ties with distant suppliers are more likely to do so.

Second, the density of a firm's ego network, defined as the ratio of the number of actual ties among the firm's supply chain partners to the number of all possible ties among them, has a negative and significant effect on both productivity and firm size. The negative effect of the ego-network density implies that benefits from closely related partners are smaller than those from unrelated ones, possibly because knowledge among dense networks is overlapped to a large extent and not well diversified.

Third, the number of suppliers in the same prefecture negatively affects the number of suppliers outside of the same prefecture, and vice versa. This finding suggests that ties within and beyond the region are substitutes probably due to costs of creating and maintaining supply chain ties.

Fourth, the effect of the ego-network density on the number of suppliers within and outside of the same province is negative and significant. This implies that when suppliers of a firm transact with each other, the firm is likely to lose some of its suppliers over time possibly to avoid redundant ties.

Finally, we find that the effect of the number of suppliers in the same prefecture in the previous year on the same variable in the current year is positive and significant but less than one. This is also the case for the number of suppliers outside of the prefecture and the ego-network density. This evidence implies that shocks to the network structure, such as the number of suppliers, diminish over time.

Next, we focus on ties with clients, rather than suppliers, and repeat the same analysis, showing the results in Table 3. The five major findings from the analysis focusing on suppliers apply to the analysis using clients, except for one. The number of neighboring clients in the same prefecture has a positive effect on sales per worker, while the number of neighboring suppliers has no significant effect. By contrast, the number of distant clients has a positive effect on total sales, as does the number of distant suppliers. The difference in effects on productivity between ties with suppliers and clients suggests knowledge diffusion from suppliers and clients is different in nature, as we will argue later in detail.

To illustrate how changes in supply chain networks affect firm performance and the structure of networks over time, we simulate equation (1) using the results in Tables 2 and 3. In the simulation, we first assume that a hypothetical median firm that has median characteristics in terms of all independent variables increases the number of suppliers or clients within or outside of the prefecture by 50 percent. The median value of the number of suppliers or clients within or outside of the prefecture is 1, and we add one to the number of suppliers before taking a log. Therefore, a 50-percent increase in the variable implies an additional one supplier or client within or outside of the prefecture.

Figure 4 illustrates the simulation results when the number of neighboring suppliers or clients increases. On the one hand, the left figure indicates that when the number of suppliers within the prefecture increases by a shock, the number of suppliers outside of the prefecture declines due to substitutability between the two types of suppliers. Then, because ties with neighboring suppliers do not contribute to firm performance while ties with distant suppliers do (Table 2), sales per worker slightly decline and sales do not change substantially over time. On the other hand, the right panel of Figure 4 shows that when the number of neighboring clients increases, sales per worker improves over time due to the positive effect of neighboring clients on productivity.

Now we repeat the same simulation, assuming an increase in the number of distant suppliers or clients by 50 percent, and show the results in Figure 5. Unlike the effect of neighboring suppliers, the effect of distant suppliers on sales per worker and total sales is positive and significant. As a result, in the left figure of Figure 5, both sales per worker and total sales improve substantially over time due to the expansion of ties with distant suppliers. The effect of the number of distant clients on total sales is also positive and significant, while its effect on sales per capita is insignificant. Therefore, in the right figure of Figure 5 in which ties with distant clients expand, total sales improve to a great extent whereas sales per worker improve only slightly associated with the increase in firm size.

In addition, we conduct the same simulation for an increase in the density of the hypothetical median firm’s ego network. Figure 6 shows that denser ego networks clearly lead to smaller productivity, firm size, and networks.

We further incorporate the interaction term between the density of the ego network and the number of distant suppliers or clients as a control variable to test complementarity between strong ties and ties with outsiders, as discussed in Section 2. The results in column (4) of Tables 4 and 5 show that the coefficient on the interaction term between the density measure and the number of distant partners is positive and significant. This implies that the negative effect of network density can be alleviated when firms are connected with distant partners and hence are exposed to diversified knowledge. Judging from the values of the coefficients of density and the interaction term, the net effect of the network density is positive if the log of the number of distant suppliers or clients plus one is approximately great than one, or the number of suppliers or clients is approximately greater than two.

To check the robustness of these results, we run two-stage least squares (2SLS) estimations of the log of sales per worker or the log of total sales on the current number of neighboring and distant suppliers or clients and other controls, using the lagged number of suppliers or clients as instruments. The results shown in Table 6 are virtually similar to the benchmark results in columns (4) and (5) of Tables 4 and 5.

We also check possible differences across industries by dividing the sample into two, one for machinery and equipment industries including the general machinery, electrical machinery, electronics, transportation equipment, and precision equipment industry and the other for other industries. Because supply chain networks in the machinery and equipment industries in Japan are often characterized as *keiretsu* where suppliers and clients are closely connected with each other (Aoki, 1989), effects of supply chain networks in these industries may be different from those in other industries. However, the main results from the two sub-samples, which are not shown here for brevity of presentation but available upon request, are similar to the benchmark results from the whole sample.

5.2. Effects on the number of registered patents

The estimation results of effects of suppliers and clients on registered patents from the two-step Tobit estimation of Newey (1987) are shown in columns (1)-(2) and (3)-(4) of Table 7, respectively. Columns (1) and (3) indicate that the effect of the number of distant suppliers and clients on innovative capability is positive and significant, while the effect of neighboring suppliers and clients is either insignificant or negative and weakly significant. The result implies that ties with distant partners is important to innovative activities more than to productivity improvement in production activities, possibly because the former requires more diversified knowledge than the latter.

When the interaction term between the ego-network density and the number of distant suppliers is incorporated (columns [2] and [4] of Table 7), the coefficient on the interaction term is positive while the coefficient on the density is negative and significant at the 10-percent level. Although the significance level of the result is quite low, it is similar to the result on the effect on sales per worker. We interpret this evidence as weakly showing that dense networks are harmful to knowledge diffusion for innovation although the negative effect can be alleviated by ties with distant suppliers.

5.3. Discussion

A notable finding from the results above is that sales per worker, a measure of productivity, increases as the number of distant suppliers increases, whereas neighboring suppliers do not affect productivity. This contrasting effect of neighboring and distant suppliers may be explained by the positive effect of input varieties on productivity argued by Dixit and Stiglitz (1977). Because parts, components, and materials from distant suppliers may be more diversified than those from neighboring suppliers, ties with distant suppliers enhance productivity more.

However, results focusing on clients are completely different: productivity is positively affected by neighboring clients but not by distant clients. Ties with clients enhance productivity, when clients provide new information or knowledge to their suppliers. In Japan, such knowledge transfer from clients to suppliers is often channeled through explicit knowledge sharing institutions, as Dyer and Nobeoka (2002) illustrate in the case of Toyota. Our result implies that such knowledge transfer is easier when suppliers and clients are geographically closer to each other.

The stark contrast between suppliers and clients indicates different roles of distance in knowledge diffusion from suppliers and clients. Because knowledge from suppliers is embodied in their intermediate products, clients can benefit from distant suppliers simply by using their products which are likely to be different from products of neighboring suppliers. However, because transfer of disembodied knowledge from clients to suppliers requires direct communication between them, for example, technical assistance by suppliers, suppliers can learn more from neighboring suppliers than from distant suppliers.

The results on the effect on the number of registered patents, a measure of innovative capability, are different from those on productivity, because we find a positive effect of distant suppliers and clients but no significantly positive effect of neighboring suppliers or clients. Because knowledge for innovation is more likely to be disembodied and require face-to-face communication for its diffusion, the result, which is different from the positive effect of neighboring clients on productivity through disembodied knowledge diffusion, is surprising at the first look. However, this result can be convincingly understood because it implies that diversity of knowledge associated with distant partners is more important to knowledge for innovation than for production.

Another important finding from our results is that the density of a firm's ego network, which represents how much the firm's supply chain partners are connected with each other, has a negative effect on all key variables, i.e., sales per worker, total sales, the number of registered patents, and ties with suppliers and clients. The negative effect of the density of networks on productivity and innovation capability, although it is weak for the latter, implies that firms in dense networks already share the same knowledge and thus cannot learn substantially from each other. However, this negative effect of density can be alleviated when the firm is connected with distant firms, because distant partners can bring new knowledge unavailable in dense networks.

These results above are contradicting with those of some existing studies. For example, Bernard et al. (2014) and Belderbos et al. (2015) found a negative effect of distance to supply chain partners on productivity, using the TSR data for 2006. This contradiction is probably because the two studies did not focus on single-establishment firms as we do. In fact, when we included multi-establishment firms in our analysis, we found a positive and negative effect of the number of suppliers within and outside of the same prefecture, respectively, on sales per worker. As we discussed in Section 3.1, distance to supply chain partners cannot be identified clearly when they have multiple establishments, because our data for supply chain partners are at the firm level, rather than at the establishment level. Therefore, our focus on single-establishment firms can be justified. In addition, Bernard et al. (2014) and Belderbos et al. (2015) did not distinguish between ties with supplier and clients or incorporate network density, as we do in this study.

The negative role of network density in knowledge diffusion found in this study contrasts with Ahuja (2000) and Centola (2010) who found its positive role. However, our finding is consistent with many other existing studies that found the "strength of weak ties" (Granovetter, 1973), or the importance of ties with outsiders in information diffusion. Burt (1992, 2004) also argues that structural holes, or actors who connect groups with complementary resources or information, can promote their performance. Using data from university laboratories, Perry-Smith (2006) found the number of strong ties for each member of laboratories, measured by subjective closeness, duration, and frequency of his/her relationship, has a negative effect on the creativity of laboratories, while the number of weak ties has a positive effect. Furthermore, our finding that the negative effect of network density can be alleviated by ties with distant firms is consistent with Phelps (2010), Rost (2011), and Tiwana (2008) who found complementarity between strong ties within the community and weak ties with outsiders.

In summary, our results emphasize the importance of diversity of networks in knowledge diffusion. Therefore, we suggest that to maximize benefits from knowledge diffusion through supply chain networks, firms should be connected with outsiders including distant firms and firms unrelated to current suppliers and clients.

However, the results should be viewed with caution for the following two reasons. First, the results do not necessarily mean that having any additional supply chain partner outside of the prefecture stimulates productivity and innovative capability, because firms usually choose high-productivity partners carefully. Our results may suggest that distant partners promote knowledge diffusion when they are carefully, rather than randomly, chosen.

Second, geographic diversification of supply chain partners is costly, as we find that a larger number of ties with distant supply chain partners is associated with a smaller number of ties with neighboring partners. This substitution between neighboring and distant partners is probably due to costs of maintaining supply-chain ties, which are also found in, for example, Phelps et al. (2012). Therefore, the net benefit of geographic diversification of supply chain partners, i.e., its benefits from knowledge diffusion less its creation and maintenance costs, is still unclear.

However, these needs for cautious interpretation do not change our main conclusion. Distant firms enjoy more diversified knowledge, which can improve partner firms' productivity and innovative capability, than neighboring firms, although it may be costly to find such valuable partners outside of the prefecture.

6. Conclusion

This paper examines the effect of the structure of supply chain networks on productivity and innovation capability through knowledge diffusion, using firm-level panel data for Japan. The dataset is large, including 800 thousand to one million firms per period and four to five million buyer-supplier ties, although we eventually focus on a sub-sample of single-establishment manufacturing firms. This study is the first to examine the effect of the structure of the whole supply chain networks in a large economy, most notably the density of each firm's ego network, on knowledge diffusion. We find that ties with distant suppliers improve productivity, measured by sales per worker, probably because intermediates from distant firms embody diversified knowledge. Ties with neighboring clients also improve productivity, probably because diffusion of disembodied knowledge from neighboring clients is more effective than from distant clients. By contrast, ties with distant suppliers and clients improve innovative capability, measured by the number of registered patents, more than neighboring suppliers and clients, suggesting particular importance of diversity of knowledge for innovation. In addition, density of a firm's ego network, which is measured by how densely its supply chain partners transact with each other, is found to have a negative effect on productivity and innovative capability, implying knowledge overlaps and redundancy in densely-connected firms. Overall, our results emphasize the importance of diversified partners in knowledge diffusion through supply chain networks, although the net benefit from diversified networks should be evaluated with caution because of higher costs of creating ties with diversified partners than with geographic or relational neighbors.

Some shortcomings and suggestions for future works are worth noting. First, when we examine the effect of geographic distance to supply chain partners, we simply distinguish between partners within and outside of the same prefecture to simplify the estimation. Non-linear estimation methods, as used in Belderbos et al. (2015), may lead to more accurate estimates of the effect of geography. Second, we utilize sales per worker as a measure of productivity, due to data limitations. Although our use of a dynamic panel simultaneous equation model can alleviate the problem arising from this, as we argued in Section 3.2, using labor productivity or TFP is clearly preferable. One could overcome this problem by merging the TSR data with other data in which value added and the amount of capital are available.

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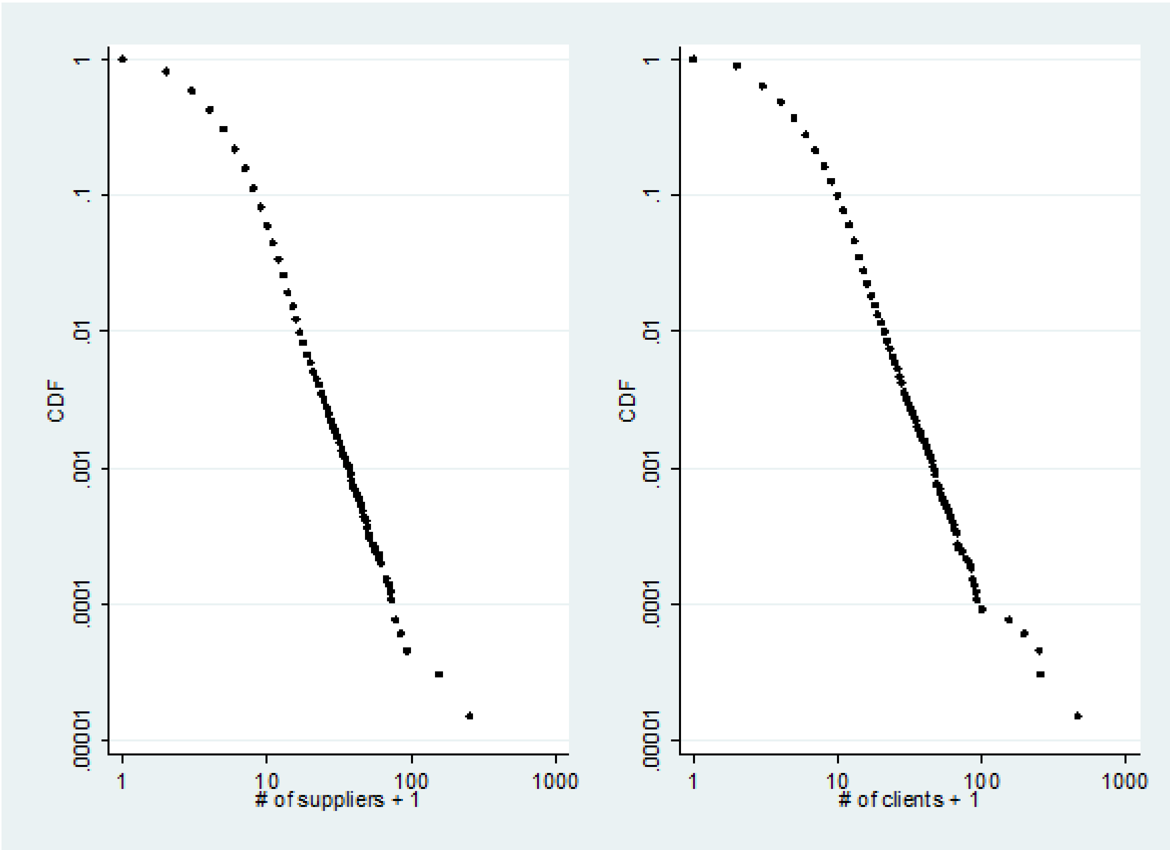
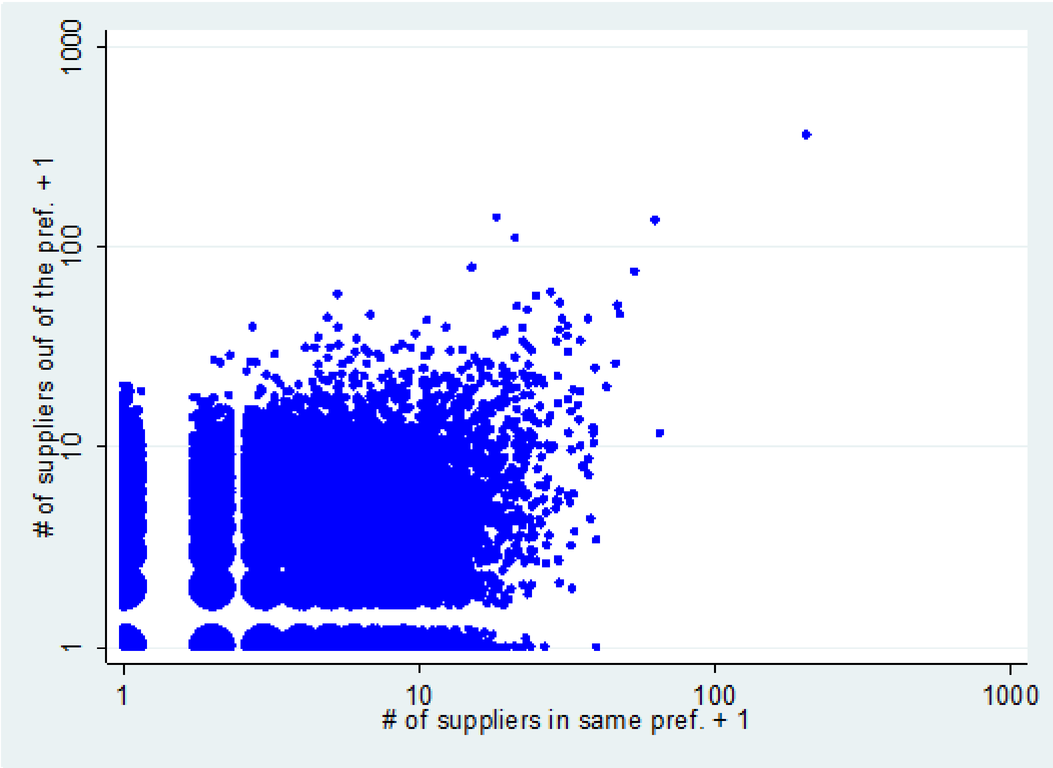
Figure 1: Distribution of the Number of Suppliers and Clients



Mean	Min	10%	Med	90%	Max			Mean	Min	10%	Med	90%	Max
4.0	1	1	3	8	257			4.7	1	1	3	9	462

Notes: This figure is based on all possible observations in the manufacturing sector in the data licensed in 2006.

Figure 2: Suppliers within the Prefecture and outside of the Prefecture



Notes: This figure is based on all possible observations in the manufacturing sector in the data licensed in 2006.

Figure 3: Changes in the Number of Suppliers from 2006 to 2012

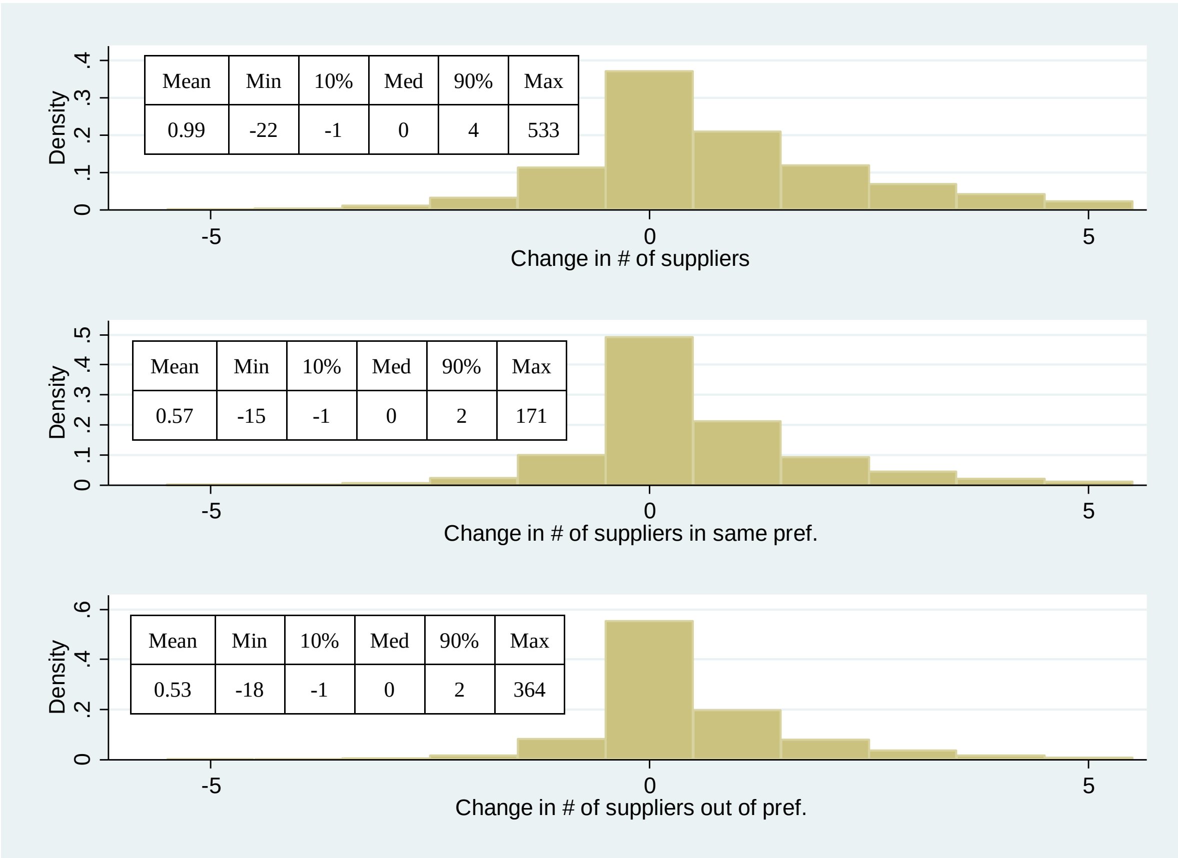
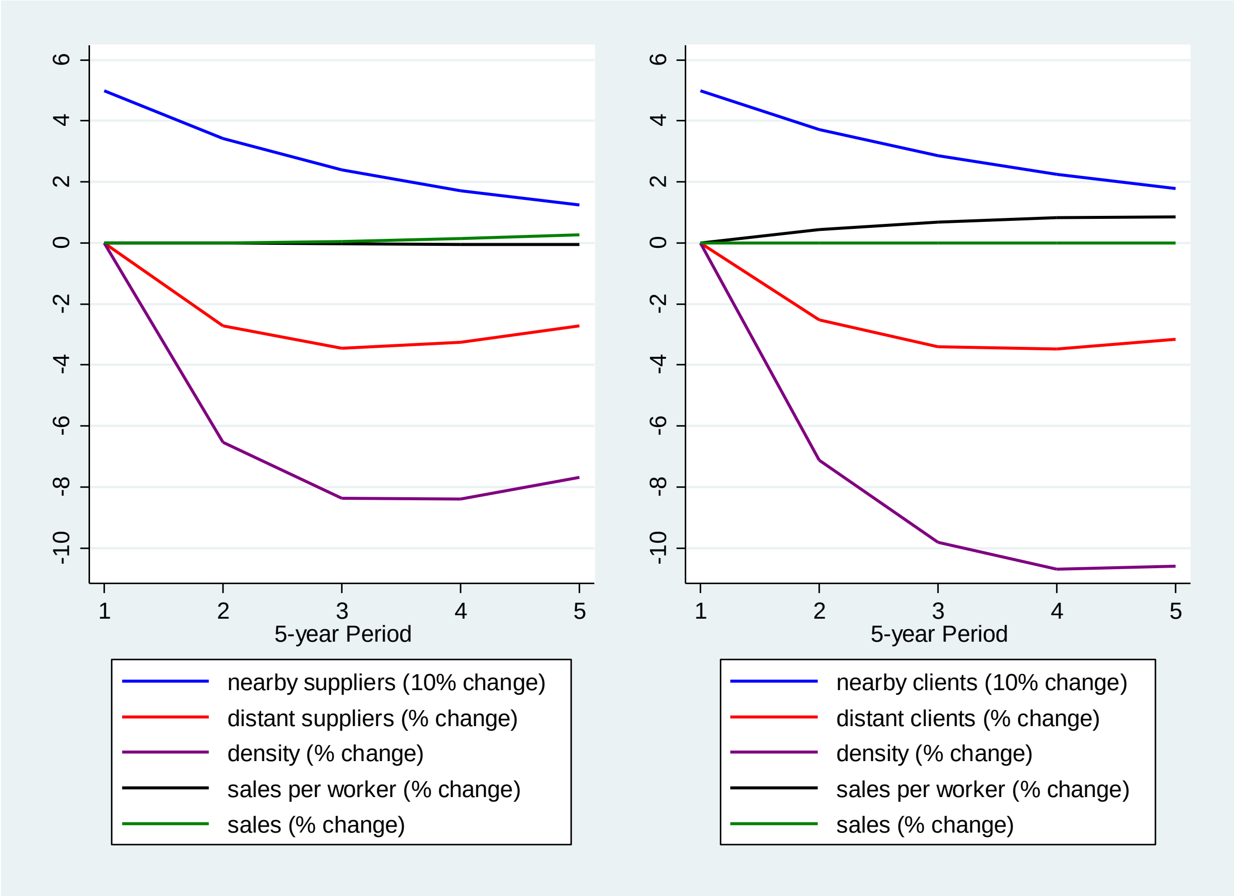
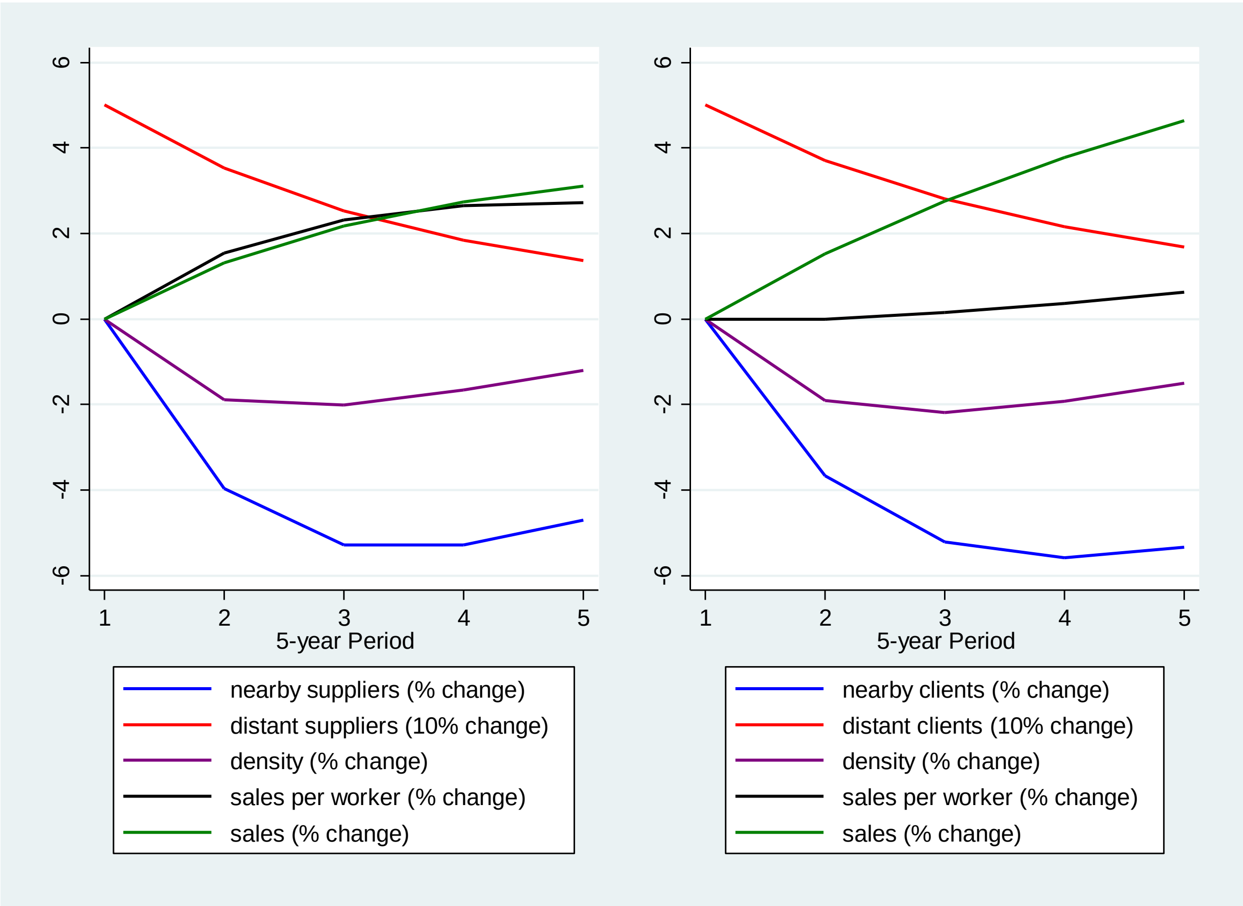


Figure 4: Long-run effect of an increase in the number of suppliers (left) and clients (right) within the same prefecture



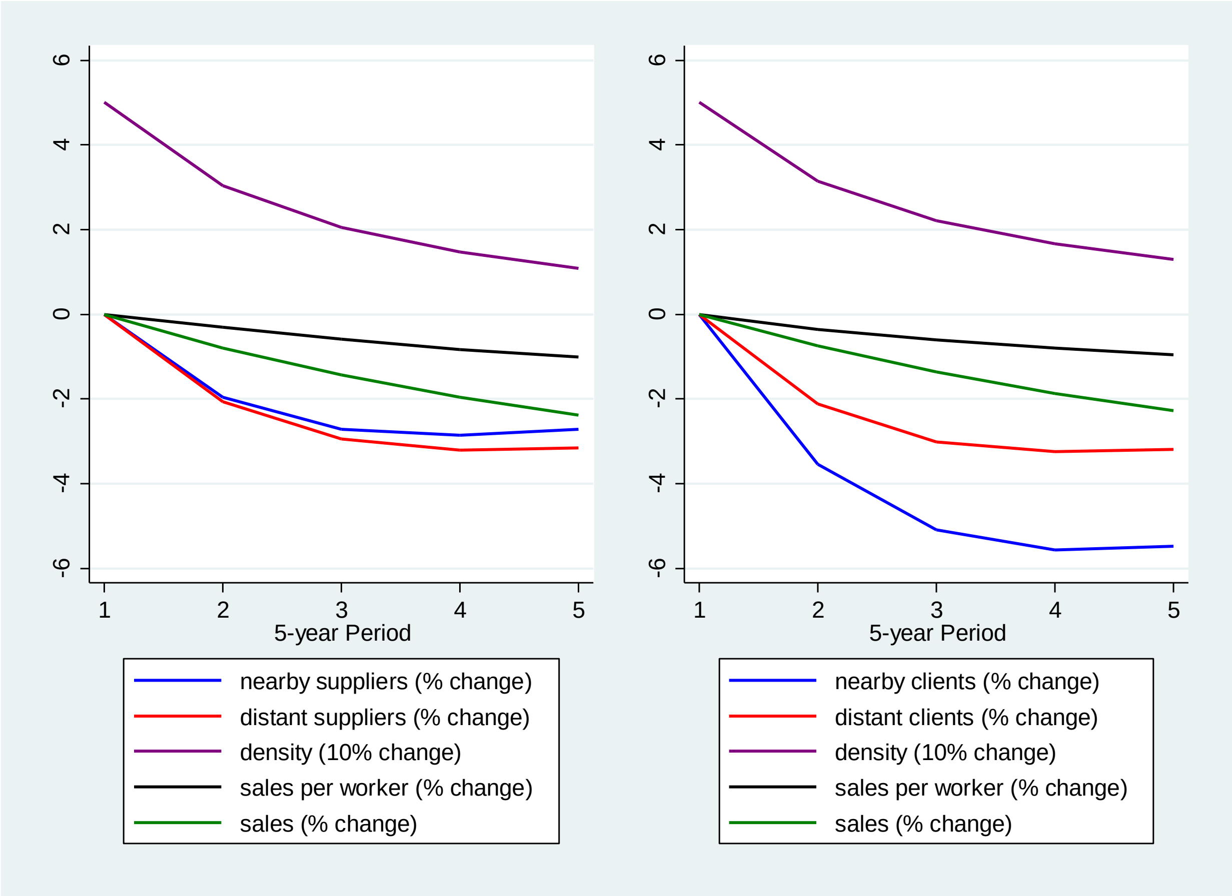
Notes: These figures are drawn from simulation of the five variables, the log of the number of nearby suppliers (right) or clients (left) within the same prefecture plus one, the log of the number of distant suppliers (right) or clients (left) outside of the same prefecture plus one, the density of each firm's ego network (measured by the ratio of actual ties among supply chain partners to all possible ties), the log of sales per worker, and the log of sales, of the hypothetical median firm. An increase in the log of the number of nearby suppliers or clients within the same prefecture by 50 percent is assumed. Each line indicates the percentage change (or 10 percentage change, if indicated so) in the variable assuming the change in the number of suppliers or clients compared with the variable without the change.

Figure 5: Long-run effect of an increase in the number of suppliers (left) and clients (right) outside of the prefecture



Notes: These figures are drawn from simulation of the five variables, the log of the number of nearby suppliers (right) or clients (left) within the same prefecture plus one, the log of the number of distant suppliers (right) or clients (left) outside of the prefecture plus one, the density of each firm's ego network (measured by the ratio of actual ties among supply chain partners to all possible ties), the log of sales per worker, and the log of sales, of the hypothetical median firm. An increase in the log of the number of distant suppliers or clients outside of the prefecture by 50 percent is assumed. Each line indicates the percentage change (or 10 percentage change, if indicated so) in the variable assuming the change in the number of suppliers or clients compared with the variable without the change.

Figure 6: Long-run effect of an increase in the density of ego network



Notes: These figures are drawn from simulation of the five variables, the log of the number of nearby suppliers (right) or clients (left) within the same prefecture plus one, the log of the number of distant suppliers (right) or clients (left) outside of the same prefecture plus one, the density of each firm's ego network (measured by the ratio of actual ties among supply chain partners to all possible ties), the log of sales per worker, and the log of sales, of the hypothetical median firm. An increase in the density of the firm's ego network by 50 percent is assumed. Each line indicates the percentage change (or 10 percentage change, if indicated so) in the variable assuming the change in the number of suppliers or clients compared with the variable without the change.

Table 1: Summary Statistics

Variables	Mean	S.D.	Min.	Max.
Number of suppliers in the same prefecture	1.92	2.58	0	204
Added one and logged	0.82	0.68	0	5.32
Number of suppliers outside of the prefecture	1.57	2.72	0	406
Added one and logged	0.69	0.67	0	6.01
Number of clients in the same prefecture	2.34	3.52	0	111
Added one and logged	0.91	0.73	0	4.72
Number of clients outside of the prefecture	2.06	3.44	0	426
Added one and logged	0.81	0.75	0	6.06
Density of ego network	0.26	0.20	0	1
Sales per worker (thousand yen)	24,278	60,871	21	5,155,000
Logged	9.73	0.77	3.06	15.46
Sales (thousand yen)	462,435	4,148,635	64	633,799,000
Logged	11.96	1.31	4.17	20.27
Number of registered patents	0.06	1.18	0	144
Firm age	41	21	0	138

Note: The number of observations is 73,628 (observations for two years for each of 36,814 firms). The density of a firm's ego network is defined as the ratio of the actual number of ties between the firm's supply chain partners to the number of all possible ties between them.

Table 2: Ties with Suppliers, Network Density, and Firm Performance

	(1)	(2)	(3)	(4)	(5)
Dependent variable	# of suppliers in the same prefecture	# of suppliers outside of the same prefecture	Density of networks among direct partners	Sales per worker	Sales
# of suppliers in the same prefecture (t-1)	0.684**	-0.0542**	-0.0366**	-0.00630	0.00256
	(0.00394)	(0.00389)	(0.00112)	(0.00470)	(0.00499)
# of suppliers outside of the same prefecture (t-1)	-0.0792**	0.705**	-0.0105**	0.0310**	0.0263**
	(0.00394)	(0.00389)	(0.00112)	(0.00469)	(0.00499)
Density of ego network (t-1)	-0.169**	-0.177**	0.729**	-0.0270*	-0.0681**
	(0.0113)	(0.0111)	(0.00319)	(0.0134)	(0.0143)
Sales per worker (t-1)	-0.0256**	-0.00582	-0.00218	0.699**	-0.113**
	(0.00393)	(0.00388)	(0.00111)	(0.00468)	(0.00498)
Sales (t-1)	0.128**	0.112**	-0.00414**	0.104**	1.056**
	(0.00260)	(0.00256)	(0.000737)	(0.00310)	(0.00329)
Observations	36,814	36,814	36,814	36,814	36,814
R-squared	0.619	0.637	0.619	0.610	0.850

Notes: Standard errors are in parentheses. * and ** signify statistical significance at the 5- and 1-percent level, respectively. The number of suppliers of any kind is added one and logged. Sales per worker and sales are also logged. The density of a firm's ego network is defined as the ratio of the actual number of ties between the firm's supply chain partners to the number of all possible ties between them. Age, age squared, industry dummies, prefecture dummies, and survey year dummies are included, but the results are not shown for brevity.

Table 3: Ties with Clients, Network Density, and Firm Performance

	(1)	(2)	(3)	(4)	(5)
Dependent variable	# of clients in the same prefecture	# of clients outside of the same prefecture	Density of networks among direct partners	Sales per worker	Sales
# of clients in the same prefecture (t-1)	0.746**	-0.0503**	-0.0383**	0.00877*	0.00718
	(0.00368)	(0.00366)	(0.000974)	(0.00412)	(0.00437)
# of clients outside of the same prefecture (t-1)	-0.0735**	0.743**	-0.0102**	0.00639	0.0304**
	(0.00383)	(0.00380)	(0.00101)	(0.00428)	(0.00454)
Density of ego network (t-1)	-0.304**	-0.182**	0.723**	-0.0301*	-0.0646**
	(0.0120)	(0.0119)	(0.00318)	(0.0134)	(0.0143)
Sales per worker (t-1)	-0.00697	-0.0179**	-0.000801	0.699**	-0.112**
	(0.00419)	(0.00417)	(0.00111)	(0.00469)	(0.00498)
Sales (t-1)	0.0649**	0.106**	-0.00645**	0.106**	1.054**
	(0.00270)	(0.00269)	(0.000715)	(0.00302)	(0.00321)
Observations	36,814	36,814	36,814	36,814	36,814
R-squared	0.632	0.663	0.623	0.610	0.850

Notes: Standard errors are in parentheses. * and ** signify statistical significance at the 5- and 1-percent level, respectively. The number of clients of any kind is added one and logged. Sales per worker and sales are also logged. The density of a firm's ego network is defined as the ratio of the actual number of ties between the firm's supply chain partners to the number of all possible ties between them. Age, age squared, industry dummies, prefecture dummies, and survey year dummies are included, but the results are not shown for brevity.

Table 4: Interaction between Ties with Suppliers and Network Density

	(1)	(2)	(3)	(4)	(5)
Dependent variable	# of suppliers in the same prefecture	# of suppliers outside of the same prefecture	Density of networks among direct partners	Sales per worker	Sales
# of suppliers in the same prefecture (t-1)	0.684**	-0.0538**	-0.0365**	-0.00574	0.00240
	(0.00395)	(0.00390)	(0.00112)	(0.00471)	(0.00500)
# of suppliers outside of the same prefecture (t-1)	-0.0774**	0.695**	-0.0114**	0.0202**	0.0295**
	(0.00578)	(0.00571)	(0.00164)	(0.00689)	(0.00732)
Density of ego network (t-1)	-0.165**	-0.198**	0.727**	-0.0506**	-0.0610**
	(0.0146)	(0.0144)	(0.00413)	(0.0174)	(0.0185)
# of suppliers outside of the same prefecture	-0.00748	0.0411*	0.00378	0.0464*	-0.0139
* Density of ego network (t-1)	(0.0182)	(0.0179)	(0.00515)	(0.0217)	(0.0230)
Sales per worker (t-1)	-0.0256**	-0.00584	-0.00218	0.699**	-0.113**
	(0.00393)	(0.00388)	(0.00111)	(0.00468)	(0.00498)
Sales (t-1)	0.128**	0.112**	-0.00415**	0.104**	1.056**
	(0.00260)	(0.00256)	(0.000737)	(0.00310)	(0.00329)
Observations	36,814	36,814	36,814	36,814	36,814
R-squared	0.619	0.637	0.619	0.610	0.850

Notes: Standard errors are in parentheses. * and ** signify statistical significance at the 5- and 1-percent level, respectively. The number of suppliers of any kind is added one and logged. Sales per worker and sales are also logged. The density of a firm's ego network is defined as the ratio of the actual number of ties between the firm's supply chain partners to the number of all possible ties between them. Age, age squared, industry dummies, prefecture dummies, and survey year dummies are included, but the results are not shown for brevity.

Table 5: Interaction between Ties with Clients and Network Density

	(1)	(2)	(3)	(4)	(5)
Dependent variable	# of clients in the same prefecture	# of clients outside of the same prefecture	Density of networks among direct partners	Sales per worker	Sales
# of clients in the same prefecture (t-1)	0.746**	-0.0499**	-0.0385**	0.00928*	0.00718
	(0.00369)	(0.00366)	(0.000974)	(0.00412)	(0.00438)
# of clients outside of the same prefecture (t-1)	-0.0843**	0.731**	-0.00329*	-0.0104	0.0302**
	(0.00574)	(0.00570)	(0.00152)	(0.00642)	(0.00682)
Density of ego network (t-1)	-0.330**	-0.212**	0.740**	-0.0715**	-0.0650**
	(0.0160)	(0.0159)	(0.00423)	(0.0179)	(0.0190)
# of clients outside of the same prefecture	0.0449*	0.0499**	-0.0289**	0.0700**	0.000529
* Density of ego network (t-1)	(0.0179)	(0.0178)	(0.00472)	(0.0200)	(0.0212)
Sales per worker (t-1)	-0.00718	-0.0181**	-0.000666	0.699**	-0.112**
	(0.00420)	(0.00417)	(0.00111)	(0.00469)	(0.00498)
Sales (t-1)	0.0650**	0.106**	-0.00649**	0.106**	1.054**
	(0.00270)	(0.00269)	(0.000715)	(0.00302)	(0.00321)
Observations	36,814	36,814	36,814	36,814	36,814
R-squared	0.632	0.663	0.624	0.610	0.850

Notes: Standard errors are in parentheses. * and ** signify statistical significance at the 5- and 1-percent level, respectively. The number of clients of any kind is added one and logged. Sales per worker and sales are also logged. The density of a firm's ego network is defined as the ratio of the actual number of ties between the firm's supply chain partners to the number of all possible ties between them. Age, age squared, industry dummies, prefecture dummies, and survey year dummies are included, but the results are not shown for brevity.

Table 6: Ties with Supply Chain Partners and Firm Performance: Results from IV Estimations

	(1)	(2)	(3)	(4)
Dependent variable	Sales per worker	Sales	Sales per worker	Sales
# of suppliers in the same prefecture (t)	-0.00538	0.00147		
	(0.00714)	(0.00757)		
# of suppliers outside of the same prefecture (t)	0.0254*	0.0421**		
	(0.0108)	(0.0115)		
# of clients in the same prefecture (t)			0.0124*	0.00838
			(0.00586)	(0.00620)
# of clients outside of the same prefecture (t)			-0.0160	0.0422**
			(0.00951)	(0.0101)
Density of ego network (t)	-0.0741*	-0.0687*	-0.107**	-0.0712*
	(0.0292)	(0.0310)	(0.0286)	(0.0303)
# of suppliers outside of the same prefecture (t)	0.0734*	-0.0247		
* density of ego network (t)	(0.0355)	(0.0377)		
# of clients outside of the same prefecture (t)			0.106**	-0.00632
* density of ego network (t)			(0.0310)	(0.0329)
Sales per worker (t-1)	0.698**	-0.113**	0.699**	-0.111**
	(0.00469)	(0.00497)	(0.00470)	(0.00497)
Sales (t-1)	0.0994**	1.051**	0.104**	1.048**
	(0.00381)	(0.00404)	(0.00340)	(0.00360)
Observations	36,814	36,814	36,814	36,814
R-squared	0.611	0.851	0.611	0.852

Notes: Standard errors are in parentheses. * and ** signify statistical significance at the 5- and 1-percent level, respectively. The number of suppliers or clients of any kind is added one and logged. Sales per worker and sales are logged. The density of a firm's ego network is defined as the ratio of the actual number of ties between the firm's supply chain partners to the number of all possible ties between them. Age, age squared, industry dummies, prefecture dummies, and survey year dummies are included, but the results are not shown for brevity.

Table 7: Ties with Suppliers and Clients and Innovation

Dependent variable: log of the number of patents plus one

	(1)	(2)	(3)	(4)
# of suppliers in the same prefecture (t-1)	0.120	0.146+		
	(0.0781)	(0.0791)		
# of suppliers outside of the same prefecture (t-1)	0.214**	0.0734		
	(0.0724)	(0.114)		
# of clients in the same prefecture (t-1)			-0.118+	-0.104
			(0.0658)	(0.0661)
# of clients outside of the same prefecture (t-1)			0.295**	0.228*
			(0.0616)	(0.0995)
Density of ego network (t-1)	-0.116	-0.747+	-0.225	-0.721+
	(0.245)	(0.424)	(0.250)	(0.436)
# of suppliers outside of the same prefecture (t-1)		0.666+		
* density of ego network (t-1)		(0.398)		
# of clients outside of the same prefecture (t-1)				0.338
* density of ego network (t-1)				(0.344)
Sales (t-1)	0.233**	0.227**	0.264**	0.269**
	(0.0608)	(0.0612)	(0.0578)	(0.0581)
# of workers (t-1)	0.195*	0.201*	0.214**	0.211**
	(0.0789)	(0.0794)	(0.0787)	(0.0794)
# of patents (t-1)	1.667**	1.673**	1.650**	1.648**
	(0.0751)	(0.0754)	(0.0741)	(0.0741)
Observations	36,839	36,839	36,839	36,839

Notes: Standard errors are in parentheses. +, *, and ** signify statistical significance at the 10-, 5-, and 1-percent level, respectively. The number of clients of any kind is added one and logged. Sales per worker and sales are also logged. The density of a firm's ego network is defined as the ratio of the actual number of ties between the firm's supply chain partners to the number of all possible ties between them. Age, age squared, industry dummies, prefecture dummies, and survey year dummies are included, but the results are not shown for brevity.