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Impact of supply chain network structure on FDI: Theory and evidence[*]

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Abstract: This study investigates how the structure of a supply chain network influences the FDI decisions of firms embedded in the network. We theoretically describe firms' FDI decisions through a coordination game of a fixed network with incomplete information. We show that the network effect in the equilibrium can be represented by Katz-Bonacich centrality. Firms with a larger Katz-Bonacich centrality than other firms are more likely to engage in FDI. We empirically test this prediction with disaggregated inter-firm transaction network data of 115,111 Japanese firms and confirm that the Katz-Bonacich centrality has a significantly positive, robust effect on firms' FDI engagements.

Keywords: *FDI, network game, supply chain, Katz-Bonacich centrality*

JEL Classification: D20, D85, F23.

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1. Introduction

A growing number of firms enjoy the benefit of extending their market or accessing cheap production resources from foreign direct investment (FDI). However, they also face difficulty procuring from local firms in the host country due to a mismatch in design and the quality of products and delivery systems.[1] Therefore, there is an incentive to replicate transaction partnerships in the domestic market, form supply links with home-country suppliers and maintain their sales in foreign countries (e.g., Martin, Mitchell and Swaminathan, 1995; Hackett and Srinivasan 1998). This type of FDI is called "follow-sourcing" (Humphrey 2003) and is observed in various industries, such as the automotive industry in India and Brazil (Humphrey 2003), supermarkets (Reardon et al 2007) and machinery sectors, which require numerous components that are supplied by subcontractors (Urata, 1994). Because of this "follow-sourcing" behavior, a firm's FDI decision heavily depends on the FDI decisions made by existing transaction partners in the home country.

[1] A substantial body of literature suggests the difficulty and impediments of procuring from local firms in the host country (e.g., Lim and Fong, 1982: Capannelli, 1997). Reid (1995) noted that the mismatch in the design and quality of products and their delivery systems are the crucial impediments to local procurement. Kelegama and Foley (1999) note the importance of the production quality of local firms, and Asanuma and Kikutani (1992) note the importance of long-term supply relationships for product quality.

As several papers have noted, the follow-sourcing incentive leads to the agglomeration of multi-national enterprise plants that belong to the same industry, to vertically related industries, or to the same firm-group (*keiretsu*; e.g., Smith and Florida, 1994; Head et al., 1995, 1999; Head and Ries, 1996; Belderbos and Carree, 2002). However, these measures, such as the same industry, industry-level vertical relationship, and firm group, are over-aggregated to capture the actual relationships across individual firms because two firms that belong to related industries or to the same firm group do not necessarily transact with each other. The structure of an entire supply chain network is large and complex, as several studies have noted (e.g., Saito et al., 2008; Atalay et al., 2011). Firms that belong to related industries or the same group are located differently in the supply chain network, and their follow-sourcing incentives are different depending on the location in the network. To precisely capture the follow-sourcing incentive, we need to shed more light on the disaggregated information of a supply chain network.

In this context, this study examines the effect of the follow-sourcing incentive on FDI decisions by focusing on the disaggregated information in a supply chain network. We show that if a firm’s FDI decision depends on its transaction partners' decisions, the decisions of all the firms embedded in the supply chain networks indirectly matter for the firm's decision. This is the issue that previous literature does not treat explicitly. To understand the indirect effect of the supply chain network, we consider the FDI decision of a firm, which depends on the decisions of direct transaction partners. This is the direct effect. Furthermore, the firm's direct partners also have their transaction partners, and their decisions also depend on their direct partners. Thus, the firm's decision indirectly depends on the partners' partners' decisions. Given this perspective, a firm's FDI decision also depends on all of the firms connected by the supply chain network, not only the firm's own direct transaction partners. Indeed, huge numbers of firms are indirectly linked via a supply chain network, and they exert both a direct and an indirect influence on each other.

Therefore, each firm is influenced by the entire network, and that influence differs by firm depending on its location in the network. Bearing these points in mind, this study investigates the effects of the complicated supply chain network on firms' FDI decisions. Our goal is to empirically estimate these network effects using fully disaggregated firm supply chain network data.[2]

[2] Yamashita et al. (2014) use actual transaction relationship data instead of keiretsu data,

In the theory section, we describe the decision making of firms embedded in a supply network regarding whether they should undertake FDI in a region in the incomplete information game. Our network game basically follows the one presented by Bloch and Quérou (2013) with minor differences in settings.[3] We assume a fixed network of firms, interpreted as transactions in the domestic market, that have incentives to replicate their domestic partnership in the destination market. Furthermore, part of the profit from FDI is assumed to be private information for each firm and unobservable to others. In such an incomplete information setting, the decisions of other firms are uncertain; thus, each firm has expectations about its decision or the probability to invest. Although the expected profit of each firm depends only on the FDI probability of its direct partners, to know the accurate probability of its direct partners, the firm must consider the probability of all indirectly linked partners via a network (i.e., partners of the direct partners and so on). When each firm takes the expectation for all firms over the entire network into account, its decision converges to a

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and they empirically show the influence of both direct and indirect transaction partners on the FDI location decision of firms. However, they study only a pair of firms whose distance is at most two links, not a whole network effect.

[3] Bloch and Quérou (2013) investigate whether each consumer embedded in the network purchases one unit of indivisible network good or not.

unique Bayesian Nash equilibrium, which is explicitly described by a measure of network called Katz-Bonacich centrality.[4] Katz-Bonacich centrality denotes how a node is accessible to all others through the network.[5] Some of our companion papers apply it to describe the Nash equilibrium of network games (e.g., Ballester, Calvó-Armengol, and Zenou 2006; hereafter BCZ).[6] From the equilibrium characteristics, we can induce the empirically testable theoretical implication that the incentive for the FDI of a firm increases with its Katz-Bonacich centrality.

In the empirical part, we test this theoretical implication with the actual data. We use the disaggregated inter-firm transaction data of 115,111 Japanese firms in the manufacturing sector. This network information enables us to calculate the Katz-Bonacich centrality that represents the detailed network structure of the whole Japanese manufacturing sector by capturing the inter-sectorial effects among the small sectors. Merging this firm-level data with

4 This measure was first proposed by Katz (1953) and generalized by Bonacich (1987); hence, Ballester and Calvó-Armengol (2011) call the index after their names.

5 This index is equivalent to a linear function of centralities of directly linked nodes.

6 The BCZ model and our model have similar mathematical forms: a quadratic (expected) payoff function and, hence, a linear best-response function. However, the issues of the two studies differ fundamentally. BCZ considers a continuous choice (e.g., the quantity of effort or money spent for education), whereas we consider a discrete choice (i.e., whether to invest).

the database of the Japanese foreign affiliates, we estimate the role of the supply chain network on the FDI decisions of firms by regressing the firms' FDI behavior on Katz-Bonacich centrality.

Our empirical results show significantly positive effects of Katz-Bonacich centrality on firms' FDI decisions. Even if we control for the various individual attributes of firms, including the industry fixed effects and headquarters' location fixed effects, the Katz-Bonacich centrality has a robust positive effect on FDI decisions. Quantitatively, the magnitude of positive effects of Katz-Bonacich centrality is large, as are the effects of productivity, which is noted as a main engine of FDI (Helpman et al. 2004). This suggests the importance of considering the supply chain network in the FDI decisions of firms.

Our baseline model is based on the incomplete information static game framework in which we focus only on the follow-sourcing incentive via expectations. In the past two decades, when the FDI of Japanese firms has rapidly increased due to the tidal wave of worldwide globalization, some firms have been forced to make snap decisions regarding FDI, and the expectations of trends of other firms are important. However, one may note that FDI decisions are made sequentially; hence, the observation of others' investment might also matter in addition to expectations. We conduct an extended theoretical analysis to consider this dynamic feature of FDI, and show the FDI of firms is influenced by the Katz-Bonacich accessibility to prior investors as well as their Katz-Bonacich centrality in the network. We also test this prediction based on the actual data and verify it. Katz-Bonacich centrality, interpreted as the influence of expectations, still has a significant effect on FDI even with such extension.

This paper investigates the issue of the network effect, for which there is a growing amount of empirical literature, particularly in the application to social interactions, starting with Manski (1993; e.g., De Giorgi, Pellizzari, and Redaelli, 2010; De Giorgi and Pellizzari, 2012; Blume, Brock, Durlauf, and Jayaraman, 2014). In the literature on social interactions, Calvó-Armengol et al. (2009) is a companion paper of this research. They use BCZ's model and show the network effects under the equilibrium of Katz-Bonacich centrality. Then, these authors structurally estimate the payoff functions of each individual and estimate the network effects by using data on the educational effort of households and their networks. We also propose that network effects under the equilibrium equal the

Katz-Bonacich centrality and estimate this by applying the FDI decisions of firms embedded in the network. Our model, however, has two differences from Calvó-Armengol et al.'s (2009) model. First, our model is based on the discrete choice model. Second, our model has incomplete information.[7] As Bernard and Jensen (1999) show, only some firms conduct FDI; in that case, a continuous outcome model such as Calvó-Armengol et al.'s (2009) model does not fit the situation. Therefore, we need discrete choice setup. Furthermore, in contrast to the peer effects in the classroom, we focus on firms' FDI decisions. In this case, there are many business secrets, and firms' private information cannot be observed exactly by the other competitor firms. Thus, incomplete information setup is more suitable for our topic. Our contribution is to show that the network effect on the equilibrium is also characterized by Katz-Bonacich centrality in the incomplete information discrete choice game on the network and to verify the theoretical implications using the large amount of firm-level transaction network data. Because this measure and estimation strategy are easily computable even for huge network data (we use network information for more than 100,000 firms), this information is broadly applicable for future empirical studies on firm

[7] Recently, literature on the estimation of games under incomplete information has also increased (e.g., Bajari et al., 2010; De Paula and Tang, 2012)

behaviors.

The remainder of this paper is structured as follows. Section 2 presents a static coordination game with a network and a theoretical examination of the game. Section 3 presents the data and framework used for our empirical analysis. Section 4 discusses our baseline empirical results obtained with eigenvalue centrality, and section 5 discusses the robustness of the baseline analysis by extending the model and empirical methods. Finally, section 6 concludes the paper.

2. Theory and testable prediction

2.1. Inter-firm transaction and profit of affiliates

Set $N = \{1,2, \dots, \mathrm{n}\}$ is a finite set of risk-neutral firms in the home country (i.e., Japan), and the n×n matrix $\boldsymbol{G}=\{\phi_{ij}\}$ denotes an exogenously given transaction relationship between the firms, that is, the supply chain network adjacency matrix in the home country in period t. Parameter ϕ_{ij} is equal to one if firms *i* and *j* are trading partners and zero otherwise. We assume that $\mathbf{G}$ is symmetric, that $\phi_{ij}=\phi_{ji}$ holds, and that $\phi_{ii}= 0$ holds for diagonal components.

We suppose an emerging foreign market *r* (e.g., Eastern Asia) with no prior investors,[8] and firms face a simultaneous decision of whether to establish an affiliate in that market; therefore, our model is interpreted as a greenfield investment. The (ex-post) operation profit of affiliate *i* in region *r* in period *t* can be given as follows:

$$\pi_i(\upsilon_r; z_{ir}, \tau_{ir}, \mathbf{G}) = \tau_{ir} \sum_{j=1}^{n} \upsilon_{jr}\, \phi_{ij} + z_{ir}, \quad (1)$$

where $\upsilon_{\mathrm{r}} = (\upsilon_{1r}, \ldots, \upsilon_{nr})$ is a vector of the investment status of domestic firms in region *r*. Suppose the set of firms investing in r is $\mathrm{N_r}$; variable υ_{jr} is one if firm *j* has an affiliate in region *r* or $j \in N_r$ and zero otherwise. Affiliates *i* and *j* can (and necessarily) gain a positive profit from trading if and only if $i, j \in \mathrm{N_r}$ and $\phi_{ij} > 0$ hold. Then, the total profit that firm *i* gains from all transactions is denoted by $\tau_{ir} \sum_{j=1}^{n} \upsilon_{jr} \phi_{ij}$. Furthermore, we normalize the profit of firms to be zero if they do not establish affiliates.

We assume that the replication of domestic transaction relationships in a foreign country yields an additive profit. Consider the case in which firm I, which transacts with firm j in the domestic market, undertakes FDI in country r. We assume that if firm j also undertakes FDI in country r, firm i obtains $\tau_{ir} > 0$

[8] This assumption is extended in section 5.

of additional profit by the local transaction with j.[9] That is, the local transaction with existing transaction partners is more profitable than international transactions with existing partners or searching for alternative transaction partners.

The second variable on the right-hand side, z_{ir}, is the stand-alone profit of affiliate *i* in region *r*. Stand-alone profits can be influenced by the attributes of firm i, the economic condition of region *r* such as labor, energy, and trade costs, and the demand for firm *i*'s products by the consumers and local firms in *r*. This study assumes that z_{ir} includes any variable cost and profit source independent of transactions with the domestic transaction partners. Thus, z_{ir} can be both positive and negative.

As Eq. (1) indicates, even if a firm considers investing simultaneously in multiple regions (e.g., North America and Eastern Asia), we suppose that the decision making of each investment is independent. We assume that an investment for a country does not influence the investment of the other countries. Therefore, without any special necessity, the remainder of this paper omits

[9] When the profit of transaction is determined by inter-firm negotiation such as Nash bargaining, τ_{ir} depends on the total profit of two firms yielded by the trading, profit of disagreement and bargaining power of each firm. However, we neglect the details of such bargaining processes and give τ_{ir} as a parameter.

subscripts r from all variables and parameters for simplicity of notation.

2.2. Decision making on FDI

Under the payoff function, we describe firms' decision making on whether to establish a foreign affiliate in region r in a simultaneous move game with incomplete information on others' profits. We assume that firm i observes only its own z_i and τ_i when it faces an investment decision; hence, the decision of each firm is uncertain to all others.[10]

Despite the incomplete information on other firms' τ_j and z_j, firms have accurate probabilistic information about these variables, which is common knowledge among all firms. We suppose that τ_j and z_j are independently distributed. Furthermore, we assume that the entire network structure $\mathbf{G}$ is public information for all firms; hence, the firms are aware of the relationships of all other firms.

We assume that all firms make their decisions simultaneously; hence, they make their decision with given τ_i and z_i and with probabilistic expectations for the decisions of other firms. We also suppose that firms are risk

[10] Whereas Bloch and Quérou (2013) also assume such private information on stand-alone profits, we further assume that the marginal transaction profit is also private information.

neutral and then maximize their expected value of total profit described by equation (1). Firm *i*'s expected total profit from its investment in region *r* can be denoted as

$$E(\pi_i \,|\mathbf{p}, \mathbf{G}, z_i, \tau_i) = \tau_i \sum_{j=1}^{n} p_j \phi_{ij} \; + z_i \; , \tag{2}$$

where $p_j = \Pr(v_j = 1)$ represents the expectations of *j*'s probability of investing, and $\mathbf{p} = (p_1, \ldots p_n)$ is their vector. Therefore, the first term of the RHS of equation (2) indicates the expected profit from trading with partners. Firm *i* establishes an affiliate only when $E(\pi_i \,|\mathbf{p}, \mathbf{G}, z_i, \tau_i) > 0$ holds because the firm would gain zero profit without an affiliate. Then, for a given expectation vector $\mathbf{p}$, each firm has the best-response threshold θ_i with which it decides to invest if and only if $\mathrm{z_i}/\tau_i > \theta_i(\mathbf{p}; \mathbf{G})$ holds. Hence, the best-response strategy of each firm is equivalent to the threshold. Here, θ_i is the best-response threshold of firm *i* with respect to z_i/τ_i, and θ_i can be described as follows from equation (2):

$$\theta_i(\mathbf{p}; \mathbf{G}) = -\sum_{j=1}^{n} p_j \, \phi_{ij}. \tag{3}$$

This equation implies that higher expectations for partners to invest decreases θ_i and hence increases the firm's probability to establish its affiliate. Because each firm compares θ_i and z_i/τ_i in deciding FDI, threshold θ_i

displays the firm's expected profit of trading per τ_i.

To derive a specific Bayesian-Nash equilibrium,[11] we assume that firms expect z_i to be uniformly distributed within $[-a+\bar{z}, a+\bar{z}]$, where $a > 0$. The expected value of z_i, denoted by $\bar{z}$, can be both positive and negative. We also assume that $\bar{z}-a < -(n-1)\tau^m$ and $\bar{z}+a > 0$, where τ^m is the upper bound of τ_i. These assumptions guarantee sufficiently wide support for z_i to ensure unique and interior equilibrium of the model.[12]

Probability of investment, p_j, of each firm is determined by threshold θ_j, and is linear function of θ_j due to the assumption of uniformly distributed z_i. Therefore, we can readily transform Eq. (3) into a system of linear equations of $\boldsymbol{\theta} = (\theta_1, \dots, \theta_n)$ to describe the best-response threshold θ_i to others' θ_j. By solving the linear system for $\boldsymbol{\theta}$, unique equilibrium threshold is derived as follows;

$$\boldsymbol{\theta}^* = -\boldsymbol{\rho}\gamma\boldsymbol{G}(\boldsymbol{I}-\gamma\boldsymbol{G})^{-\mathbf{1}} \quad (4)$$

where $\mathbf{1}$ denotes the column vector of one; we denote $\rho = (a+\bar{z})/\bar{\tau}$,

[11] Detailed derivation of the equilibrium is shown in Online Appendix.

[12] Due to that assumption, $\tau_i\theta_i$ is always within $[-a+\bar{z}, a+\bar{z}]$; thus, we can exclude any corner solution in which some firms make a choice (i.e., whether to invest) in probability one. These assumptions are sufficient to ensure a unique and interior equilibrium for the model.

$\gamma = \bar{\tau}/(2a)$ to simplify the notation.[13] In equation (4), each firm's equilibrium strategy is described as follows:

$$\theta_i^* = -\rho b_i(\mathbf{G})$$

$$\text{where } b_i(\mathbf{G}) = \sum_{j=1}^{n} \sum_{k=1}^{\infty} \gamma^k \phi_{ij}^{\{k\}} \; . \tag{5}$$

Note that $\phi_{ij}^{\{k\}}$ is the *ij* component of $\mathbf{G^k}$ but does not have the *k*-th power of ϕ_{ij}, which is well known to describe all *walks* (i.e., the routes on the network for which links can be traversed more than once) between *i* and *j* with distance *k*. The function $b_i(\mathbf{G})$ in equation (5) is identical to a Katz-Bonacich centrality network measure or alpha-centrality (Bonacich 1987, BCZ, Ballester and Calvo-Armengol 2011).

Remember that a lower threshold θ_i^* indicates a higher incentive (and then probability) for investments, and the coefficients of $b_i(\mathbf{G})$ are negative because $\rho > 0$ holds. Therefore, we can summarize the theoretical results as a testable theoretical implication as follows.

Testable theoretical implication 2.3.

[13] Although γ must be smaller than the inverse of the largest eigenvalue of $\mathbf{G}$ so that $\boldsymbol{I} - \gamma\boldsymbol{G}$ is invertible, the assumptions $\bar{z} - a < -(n-1)\tau_i^m$ and $\bar{z} + a > 0$ promise $\gamma < 1/(n-1)$; thus γ is smaller than the inverse of the largest eigenvalue.

The incentive for the foreign direct investment of firm i increases with its Katz-Bonacich centrality $b_i(\mathbf{G})$.

The important characteristic of Katz-Bonacich centrality is its consideration of the influence of both direct and indirect relationships (i.e., with one's partners' partners). Remember that thresholds of our game characterized by the Katz-Bonacich centrality describe the expected benefits of colocation according to equation (3). Therefore, our result shows that although the benefit of transaction itself is yielded by local relationships within the network, the entire network structure gives feedback on the expected profit and probability of investing of each firm.

This indirect effect is caused by the diffusion of expectations via an inter-firm network. Suppose that firm i has a partner (j) who has many direct trading partners. Firm *j* is expected to gain considerable profit from establishing an affiliate in transacting with direct partners because a number of partners are expected to establish affiliates. Then, firm *j*'s probability to establish a foreign affiliate increases. The increase in firm *j*'s probability to establish a foreign affiliate increases firm *i*'s probability to establish a foreign affiliate because firm *i* expects to continue transacting with firm *j* in a foreign country. This is a type of positive externality that mutually influences and spreads on the network. Thus, central firms gain considerably from the externality.

Finally, one may note that some trading firms promise to invest together in reality. However, considering no ex ante (i.e., before allocating z_i) communication and promise changes our result because we assume that firms accurately expect others' probability of FDI and equilibrium is unique. Therefore, even if a pair of trading firms promises to invest together, each firm considers that the partner might break this promise and give up the investment if its stand-alone profit is sufficiently low, due to, for example, worsening market conditions. In other words, firms believe in their expectations rather than the promise of cheap talk; thus, the unique equilibrium is unchanged.[14]

3. Data and Empirical Strategy

3.1 Data

We use the data compiled by a major credit research firm, Tokyo Shoko Research Incorporated (TSR), for 2006. The dataset includes information on

[14] If there are multiple equilibria and we consider how to select one of them, communication will be important.

826,169 large and small corporations in Japan and covers approximately half of all incorporated firms in Japan. The focus of this paper is on manufacturing firms, which reduces our sample size to 142,282 firms. The dataset includes information on the firms' name, address, industry classification code, establishment year, number of employees, sales, and credit score. Furthermore, this database includes information on the firms' suppliers and customers. There is an upper limit of 24 with regard to the number of customers or suppliers each firm can report. The upper bound of 24 may truncate the actual number of transaction partners. To mitigate this issue, we combine self-reported and other-reported transaction information.[15]

We also use the dataset of Japanese manufacturing firms with foreign investments compiled by another major research firm, Toyo Keizai Shimpo Sha (TKZ). This dataset contains information on the location (country and address), the year invested, employment, the name of the owners, and the ownership ratio of all foreign affiliations of Japanese firms. We use the database of all foreign subsidiaries with Japanese ownership of 10 % or higher operating in 2010.

[15] Consider a large assembler such as Toyota. The firm has many suppliers and cannot report all of them. However, each supplier is relatively small and may report Toyota as a buyer of the supplier. By using this other-reported information, we can mitigate the upper bound problem.

By combining the TSR dataset by the names of firms and the TKZ dataset by the ownership of firms, we build a database of Japanese firms' FDI activity and their transaction relationships in Japan. Table 1 presents the summary statistics of the dataset.

[Table 1 here]

Our dataset has a total of 115,111 observations after merging the reduced samples of the TSR and TKZ databases. For FDI behavior, a total of 2,278 manufacturing firms have at least one foreign affiliate in 2010, with 2,070 firms having affiliates in the Southeast Asian countries. This suggests that most FDI firms have affiliates in Southeast Asian countries.

3.2 Empirical strategy

To test our theoretical prediction, we estimate the following equation:

$$\mathrm{FDI}_{ir} = \alpha_r + \beta_r \ln(\mathrm{centrality}_i) + \boldsymbol{\delta}_\mathbf{r}\mathbf{X}'_\mathbf{ir} + \varepsilon_{ir}, \quad (6)$$

where FDI_{ir} is the FDI dummy that takes the value of one if firm i is conducting FDI in region r and zero otherwise, $\ln(\mathrm{centrality}_i)$ is the natural logarithm of Katz-Bonacich centrality, $\mathbf{X}'_\mathbf{ir}$ represents the other covariates, and

ε_{ir} is the error term. We estimate Eq. (6) by using logit and linear probability models.

To estimate this equation, we need to calculate Katz-Bonacich centrality. We consider the overall supply chain network in the manufacturing industry to capture the inter-sectorial effects. Because the supply chain network extends beyond the industry, the FDI decision of a firm depends on the whole manufacturing transaction network rather than on the industry network to which the firm belongs. For example, the FDI decision of a tire-producing firm classified under the rubber industry depends on the behavior of other firms that belong not only to the rubber industry but also to other industries, such as the motor vehicle industry.

Considering the supply chain network of overall manufacturing firms leads to computational difficulty in calculating Katz-Bonacich centrality. This is because, as shown in Eq. (4), we must calculate the inverse matrix of the adjacency matrix with 115,111×115,111 element if we consider the transaction network of all manufacturing firms. To avoid calculating an inverse matrix for such a large matrix, we consider the special case of Katz-Bonacich centrality called eigenvalue centrality. This measure is obtained by assuming the value of the decay parameter γ in Eq. (5) by the inverse of the largest eigenvalue of $\mathbf{G}$. Eigenvalue centrality is computable without calculating the inverse matrix of the adjacency matrix. Thus, we use eigenvalue centrality as a proxy for Katz-Bonacich centrality when we use full-size network data. Then, we check the validity of using eigenvalue centrality by using a subset of the supply chain network data.

For the other covariates, $\mathbf{X}'_{\mathbf{ir}}$, we first include firm productivity. As noted by Helpman et al. (2004), firm productivity is an important determinant of firms' FDI decisions. A firm's productivity may correlate to the firm's supply chain network. A highly productive firm may attract many customers and increase Katz-Bonacich centrality. To respond to this endogeneity concern, we introduce firm productivity. Unfortunately, our database does not include capital information and cannot estimate the Total Factor Productivity (TFP). Thus, instead of TFP, we introduce labor productivity, that is, sales divided by the number of workers, as a measure of firm productivity.

In addition to firm productivity, firm performance and firm credibility might also affect firms' FDI decisions and Katz-Bonacich centrality. We include firm age and the listed firm dummy, which takes the value of one if the firm is listed and zero otherwise. Furthermore, we include firm credibility as a measure of comprehensive firm performance. Firm credibility is a measure of the total evaluation of a firm that was originally created by TSR. This information is used for a firm that qualifies potential suppliers and buyers. This represents the total performance of a firm and is actually used by companies in their choice of transaction partners. The value of credibility ranges from zero to 100 and was originally generated by TSR using public sources of information and face-to-face interviews.

One may be concerned an endogeneity problem that the FDI decision of a firm itself may affect the structure of the transaction network. For example, two firms with no transaction relationships between them in a home country may establish foreign affiliates closely locate each other, and after the establishment, their geographical proximity may facilitate transactions between them. However, these new transaction relationships between foreign affiliates are not very frequent. In the Japanese firm context, Asanuma and Kikutani (1992) noted that long-term supply relationships are crucial for firms' performance in the Japanese automobile industry. Indeed, it is commonly observed that firms replicate their supply links with home-country suppliers and maintain their sales in foreign countries (e.g., Urata, 1994; Martin, Mitchell and Swaminathan, 1995; Hackett and Srinivasan 1998). Therefore, what matters for the FDI of firms is the supply chain network in the domestic market. These trunk relationships would be negligibly influenced by investments and would be stable at least in the short run.

4. Empirical Results

4.1 Baseline results

In this section, we present our estimation results. Table 1 shows that firms conducting FDI have a relatively higher Katz-Bonacich centrality value than that of non-FDI firms.

Now, we show the results of the baseline estimation using pooled FDI data regardless of the destination in Table 2. Column (1) presents the benchmark results, including all manufacturing firms in Japan, estimated by the logit model. The coefficient for Katz-Bonacich centrality is positively significant. This is consistent with our theoretical prediction that an increase in Katz-Bonacich centrality increases the probability of undertaking FDI. Furthermore, we obtain reasonable coefficient signs for the other covariates. The coefficients for worker productivity, credit score, listed firm dummy, and firm age are positively significant, suggesting the validity of the model specification.

The magnitude of the supply chain network effect would differ with the firm size. To check this point, we separately estimate Eq. (6) based on firm size. Column (2) gives the results of the sample with the number of workers restricted to less than 100 (smaller firms), and Column (3) gives the results of the sample with the number of workers more than 100 (larger firms). In both columns, the coefficients for Katz-Bonacich centrality are positively significant. However, note that the coefficient for Katz-Bonacich centrality is larger in larger firms than in smaller firms. Larger firms tend to be assemblers and need to procure many parts and ingredients. Thus, local procurement would be more crucial for operation than for smaller firms.

[Table 2 here]

The FDI decision of a firm depends on the products of the firm. To control for such industry heterogeneity, we include industry fixed effects in the estimation equation, the results of which are presented in Table 2, Columns (4) to (6). We use the four-digit industrial classification in the Japan Standard

Industrial Classification (JSIC) and conduct an ordinary least squares (OLS) estimation (linear probability model) to reduce computation time. Column (4) presents the results. Even after controlling for industry fixed effects, the coefficient for Katz-Bonacich centrality is positively significant, and the coefficients for all other covariates are also positively significant. Column (5) and (6) gives the results of small and large firms, respectively. Notably, the differences in coefficients for Katz-Bonacich centrality between larger and smaller firms becomes much larger. By controlling for industry fixed effects, the difference between the transaction networks' role in the FDI decisions of large and small firms becomes much sharper.

One may note that both the FDI decisions and centrality of firms in the supply chain network depend on the firms' domestic headquarter locations. Firms located in large metropolitan areas can find numerous transaction partners due to their locational proximity with other firms and can reduce transaction costs; furthermore, the concentration of firms may spill over the knowhow to conduct FDI, promote the entrance of mediating firms that support other firms' FDI, and facilitate the FDI decision of firms. To respond to this concern, we include prefectural-level location fixed effects of firms' domestic headquarters.

The results are shown in Table 2, Columns (7) to (9). These results suggest that even if we control for firm location, Katz-Bonacich centrality positively affects the FDI decision of firms.

Finally, from a quantitative point of view, we compare the magnitudes of Katz-Bonacich centrality and worker productivity based on their standardized coefficients, which means how many standard deviation of predicted FDI probability will increase per standard deviation increase in a variable. For example, the results presented in Column (7) imply that the standardized coefficient of worker productivity is 0.410, whereas that of Katz-Bonacich centrality is 0.318. This result indicates that the role of the supply chain network in FDI is significant and has a magnitude similar to that of worker productivity, as has been emphasized (e.g., Helpman et al. 2004). In that sense, considering the supply chain network is necessary to consider firms' FDI decisions.

4.2 Heterogeneity in destination countries

In the above analysis, we include every FDI regardless of destination. However, Japanese firms have been conducting FDI in various countries, and, as Baldwin and Okubo (2012) suggested, the purpose and structure of their FDI differ by destination. Thus, the role of the supply chain network in FDI decisions may also be different across host countries. To capture the difference in the role of supply chain networks in FDI decisions across host countries, we also conduct a separate analysis that focuses on the Japanese FDI behavior by region. Table 3 presents the results.

[Table 3 here]

Column (1) gives the results of FDI in Southeast Asian countries. In the estimation, the dependent variable is the dummy of FDI in Southeast Asian countries; this takes the value of one if the firm conducts FDI in Asian countries and zero otherwise. We estimate the dummy using a linear probability model that includes industry and prefectural fixed effects. The coefficient for Katz-Bonacich centrality is significantly positive; the coefficients for all the other covariates are also significantly positive. Column (2) gives the small firm results, and Column (3) gives the large firm results. In both estimations, the coefficients for Katz-Bonacich centrality and other variables are still positively significant. Furthermore, the magnitude of Katz-Bonacich centrality is still larger in the results for large firms than for small firms.

Columns (4) to (6) give the same estimation results for FDI in North America. In the estimation, the dependent variable is the FDI dummy in North America. Similar to the results for Southeast Asian countries, the coefficients for Katz-Bonacich centrality is significantly positive. However, the magnitude of Katz-Bonacich centrality is much smaller in North America than that for FDI in Southeast Asian countries in every estimation (baseline, small firms, and large firms). The effect of transaction networks on FDI decisions is much larger in Asian countries than in North America. As Baldwin and Okubo (2012) noted, Japanese firms form a regional value chain across Asian countries, and the role of local sourcing and selling in Asian countries is crucial for their profits. The difference in the magnitude of Katz-Bonacich centrality between North America and Southeast Asia represents this fact.

We specifically focus on FDI in China among Asian countries because Japanese firms have recently been conducting vast FDIs in that country. Columns (7) to (9) in Table 2 give the results of Japanese FDI in China. In every result, the coefficient for Katz-Bonacich centrality is positively significant, and the magnitude is still larger for large firms than for small firms. Furthermore, the magnitude of Katz-Bonacich centrality is intermediate between the results of

FDI in Asian and North American countries.

4.3 Industry heterogeneity

To examine industry heterogeneity in FDI decisions, we estimate the equation for each two-digit industry classification in JSIC. Because separating the samples by industry would reduce the sample size, we exclude prefectural fixed effects in this analysis. The results are shown in Table 4.

[Table 4 here]

The coefficient for Katz-Bonacich centrality is significantly positive in every industry other than lumber and wood, which may not need an intense network for production. Although much of the related literature has focused on follow-sourcing FDI in assembly industries, as mentioned by Urata (1994) and Humphry (2003), the positive coefficient for Katz-Bonacich centrality is actually the case in most industries. This paper suggests that firms in most industries actually require intense production networks; the location of a firm in the interfirm network significantly affects the firm’s FDI behavior.

4.4 Validity of using eigenvalue centrality

We have conducted an analysis using a special case of Katz-Bonacich centrality (eigenvalue centrality) by specifying the Katz-Bonacich centrality decay parameter γ with the inverse of the largest eigenvalue of the adjacency matrix of the whole supply chain network $\mathbf{G}$. We now check the robustness of the results by estimating γ.

To implement our estimation, we need to reduce the size of the adjacency matrix of the whole supply chain network. For that purpose, we extract the largest 10,000 firms based on number of employees from the sample,[16] and we conduct our estimation by non-linear least squares.[17]

The results are shown in Table 5. First, the coefficient for the log of Katz-Bonacich centrality is positively significant at the 1 % level. Katz-Bonacich centrality has a positive effect on FDI even without exogenously specifying the decay parameter. Furthermore, the point estimate of γ is 0.020 and is positively

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[16] The reason for sampling large firms instead of random sampling is to preserve the original network forms. Because large firms tend to be hubs in the network, omitting large firms makes the sampled network structure totally disconnected and significantly changes the relationship across sampled firms.

[17] Specifically, first, we fix γ and calculate the Katz-Bonacich centrality with the given γ. Next, we estimate equation (6) using the OLS and using the calculated Katz-Bonacich centrality to obtain the point estimates of β, δ and the sum of the squared residual, SSR. We find the value of γ that minimizes SSR and the minimizers of SSR to be the point estimates of γ, β, and δ. The standard errors for the estimated parameters are obtained through 100 bootstrap iterations.

significant. This implies that network length has a statistically significant decay effect on FDI decisions. We cannot reject the null hypothesis that our point estimate of γ is equal to the inverse of the largest eigenvalue of adjacency matrix (0.023) that is used to calculate eigenvalue centrality at the 10 % level. This suggests the validity of using a decay parameter based on the inverse of the adjacency matrix eigenvalue and the results of the previous section that used this eigenvalue centrality.

[Table 5 here]

5. Influence of prior investors

We confirm the importance of expectations to the other firms' decisions by the static incomplete information game framework. However, FDI decisions are made sequentially; hence, the observation of others' investment might also matter in addition to expectations. To capture the dynamic features of FDI, this section extends our theory and empirical analysis.

5.1 Extension of the theoretical prediction

In each period, we consider the two types of firms, prior investors and others. Prior investors already have an affiliate in the head of the period. Based on the prior investors' investing information, firms decide on FDI to maximize their static profit. All firms play this game. That is, prior investors decide whether to maintain existing affiliations, and other firms that have no foreign affiliates decide whether to establish affiliates in the country. In each period ("t"), all firms, including prior investors, play a simultaneous move game with incomplete information on τ_{it} and z_{it}, as shown in the baseline model presented in section 2. However, the critical difference is that there are prior investors, and each firm knows who they are.

Whereas new entrants to the foreign market must pay investment cost $W > 0$ to establish a new affiliate, prior investors can maintain their affiliates without a cost. Therefore, new entrants invest if and only if their expected static profit outweighs W, whereas prior investors remain in the market only if their expected profit is non-negative. However, we should note that prior investors should exit the market if the profit is negative.

By extending Eq. (2), the expected profit of firm i in a period is now described as follows:

$$E\left(\pi_i \mid \mathbf{p}, \mathbf{G}, \upsilon_{i,-1}, z_i, \tau_i\right) - W\left(1 - \upsilon_{i,-1}\right)$$
$$= \tau_i \sum_{j=1}^{n} p_j \phi_{ij} + z_i - W\left(1 - \upsilon_{i,-1}\right). \tag{7}$$

We omit subscript t from all variables for simplicity of notation; thus, $\upsilon_{i,-1}$ is one if firm i has an affiliate in the previous period and zero otherwise. Therefore, firm i establishes (or maintains, if it is a prior investor) an affiliate only when $E\left(\pi_i \mid \mathbf{p}, \mathbf{G}, \upsilon_{i,-1}, z_i, \tau_i\right) > W(1 - \upsilon_{i,-1})$ holds. For a given expectation vector $\mathbf{p}$, each firm has the best-response threshold θ_i with which it decides to invest if and only if $\{z_i - W(1 - \upsilon_{i,-1})\}/\tau_i > -\sum_{j=1}^{n} p_j \phi_{ij} \equiv \theta_i(\mathbf{p}; \mathbf{G})$ holds. Note that this threshold is never influenced by its own investment in the previous period; hence, it describes the profit of the firm in the foreign market in each period.

Because each firm has the information of prior investors, denoted as $\boldsymbol{\upsilon}_{-1} = \left(\upsilon_{1,-1}, \dots, \upsilon_{n,-1}\right)$, the other firms' expectations of firm i's probability to invest are described as $p_i(\theta_i \mid \boldsymbol{\upsilon}_{-1}, \boldsymbol{G})$. The equilibrium threshold is described as $\theta_i(\boldsymbol{\theta}; \boldsymbol{\upsilon}_{-1}, \boldsymbol{G})$. When we suppose that z_i follows an uniform distribution within $[-a + \bar{z}, a + \bar{z}]$ and assume $\bar{z} - a - W < -(n-1)\tau^m$ and $\bar{z} + a > W$ for τ_i and z_i to ensure interior equilibrium of $\boldsymbol{\theta}$,[18] solving the model in

[18] These variables represent idiosyncratic shock; thus, there is no inter-temporal correlation

the same way as section 2 yields the following equilibrium:

$$\theta_i^* = -(\rho - \omega)b_i(\mathbf{G}) - \omega AC_i(\mathbf{G}, \boldsymbol{\upsilon}_{-1})$$
$$\text{where } \omega = \frac{W}{2a} > 0, \; AC_i(\mathbf{G}, \boldsymbol{\upsilon}_{-1}) = \sum_j \sum_{k=0}^{\infty} \gamma^k \phi_{ij}^{\{k\}} \upsilon_{j,-1}. \tag{8}$$

We call $AC_i(\mathbf{G}, \boldsymbol{\upsilon}_{-1})$ "Katz-Bonacich accessibility to prior investors." Katz-Bonacich accessibility between node i and j is calculated by summing all walks of the network from i to j decaying by their length by decaying parameter γ, described as $\sum_{k=0}^{\infty} \gamma^k \phi_{ij}^{\{k\}} \upsilon_{j,-1}$. With this accessibility, we define Katz-Bonacich accessibility to prior investors as the total accessibility only to all prior investors.

From Eq. (8), the extended testable prediction is presented as follows.

Testable theoretical implication 5.1

The incentive for the foreign direct investment of firm i increases with its Katz-Bonacich centrality $b_i(\mathbf{G})$ *and Katz-Bonacich accessibility to prior investors* $AC_i(\mathbf{G}, \boldsymbol{\upsilon}_{-1})$.

This is because the prior investor is expected to remain in the market

for them.

with high probability due to sunk cost W, and this expectation diffuses player to player via the network. For example, suppose that a direct transaction partner (*j*) of firm *i* is trading with a prior investor in a foreign market (and that firm *i* and *j* have no affiliates). The prior investor maintains its affiliate with a higher probability than starting a new investment with a positive initial cost. At this time, firm *i* expects that firm *j* will invest in high probability; thus, *i* also considers investing if it faces a chance (i.e., relatively low z_i).

5.2 Empirical investigation

We investigate the theoretical prediction in the extended model. Similar to the analysis in section 4.4, to reduce the computational burden in calculating the inverse matrix of the adjacency matrix, we restrict the samples to the largest 10,000 firms based on the number of employees. Then, we split the sample into three groups: prior investors, post-investors and others. The prior investors are the firms that already have foreign affiliates in the threshold year. The post-investors are the firms that do not have any foreign affiliates in the threshold year but that conduct investments after the threshold year. The others are firms that have any foreign affiliates through the whole period.

We focus on Japanese FDI in China and Southeast Asia, and we set the threshold year as 2000. In fact, Japanese FDI in China and Southeast Asia increases over the decade from 2000, particularly in China. Thus, prior investors are firms that undertook FDI in 2000, and we investigate the FDI decisions of firms that did not undertake FDI in 2000. Under this definition, 470 firms are defined as prior investors, and 576 firms are post-investors in China. In Southeast Asia, 1,056 firms are defined as prior investors, and 307 firms are post-investors. In both markets, there are enough post-investors.

From the theoretical prediction, we estimate the following equation:

$$\mathrm{FDI}_{ir} = \alpha_r + \beta_r \ln(\mathrm{centrality}_i) + \beta_r \ln(\mathrm{accessibility}_i) + \boldsymbol{\delta}_\mathbf{r}\mathbf{X}'_\mathbf{ir} + \varepsilon_{ir}, \qquad (9)$$

where $\ln(\mathrm{accessibility}_i)$ is Katz-Bonacich accessibility, which is the distance to the prior investors, defined as Eq. (9). The estimated variable $\mathrm{FDI_{ir}}$ is one if firm i is a post-investor in the threshold year and zero if the firm is neither a post- nor a prior investor.[19]

[Table 6]

[19] We omit prior investors from the estimation and only use them for calculating network measures.

Table 6 shows the results. Column (1) shows the results of FDI in China. The coefficient for the log of accessibility is positively significant. This suggests that network proximity to the prior investors affects firms’ FDI decisions. Furthermore, the coefficient for Katz-Bonacich centrality is still positively significant. Column (2) shows the results of FDI in Southeast Asia. The results are very similar to FDI in China. The coefficients of accessibility and Katz-Bonacich centrality are positively significant.

From these results, our extended theoretical prediction is verified from the data. The FDI of firms is actually stimulated by observing others’ FDI. However, even if we consider such sequential dynamic features in our estimation, Katz-Bonacich centrality still positively affects firms’ FDI decision significantly. In other words, although firms observe prior investors’ investment information, the relationships between domestic transaction partners that do not undertake FDI are nonetheless important for FDI decisions.

6. Concluding remarks

This paper investigated how the structure of a domestic market’s supply chain network influences the FDI of firms embedded in the network. We first described firms' choices regarding whether to invest using a coordination game on a network with incomplete information on firms' stand-alone profits. We show that the model has a unique equilibrium represented by the Katz-Bonacich centrality measure, which captures the diffusion of expectations for FDI via direct and indirect relationships of the network.

Then, we empirically tested the theoretical implication with large disaggregated data on Japanese firms and their supply chain network. We verified that the Katz-Bonacich centrality of each firm has a significantly positive effect on FDI, as our theory anticipated. The magnitude of Katz-Bonacich centrality is similar to that of worker productivity, which has long been emphasized in the FDI literature. This result is robust even when we consider FDI by destination, industry-specific effects and headquarters' locations. We note that most of our estimations employ eigenvalue centrality, the special case of Katz-Bonacich centrality with a given decay parameter, to escape the computational burden in treating large amounts of network data. We then estimate the decay parameter in the smaller sample and confirm the validity of using eigenvalue centrality as a proxy for Katz-Bonacich centrality. Finally, even supposing sequential dynamics of investment to control the effect of observation on others' investment and controlling Katz-Bonacich accessibility to prior investors, Katz-Bonacich centrality still matters for FDI decisions. These results conclusively show the inevitable importance of the influence of the entire structure of the supply network when discussing FDI, and Katz-Bonacich centrality provides a good sketch of the equilibrium outcome of the interaction among firms.

Our empirical results also provide an implication of the policy of host countries in terms of how to attract FDI to increase tax revenue. Because we consider mutual interactions among firms, Katz-Bonacich centrality also implies the influence from each firm to others and to others from others. Therefore, attracting the investment of several key-player firms with high Katz-Bonacich centrality will strongly stimulate others' investment. Itoh (2014) focuses on the strong influence of key-player firms and theoretically shows that the host country can effectively increase its total revenue of corporate tax by giving special tax incentives to these firms. By providing basic empirical support for the influence of the network on firms' decisions, we can also show the availability of such a policy in the host country. On the contrary, Itoh (2014) addresses international tax competition and shows that more central firms enjoy lower tax rates in equilibrium. Therefore, an empirical study that focuses on the strategic tax differentiation of countries considering network effects will be an important future thesis.

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Table 1 Summary statistics

		Katz-Bonacich centrality	Labor productivity	Listed firm dummy	Firm age	Credit score
All	Obs.	115111	115111	115111	115111	115111
	Mean	0.0025876	30296.03	0.0089305	43.60812	51.29483
	SD	0.0096307	219833.3	0.0940789	22.69696	6.457229
All FDIs						
FDI firms	Obs.	2278	2278	2278	2278	2278
	Mean	0.0174771	58830.89	0.3446005	60.97147	62.89728
	SD	0.052036	60254.76	0.4753422	25.53022	8.021161
Non-FDI firms	Obs.	112833	112833	112833	112833	112833
	Mean	0.002287	29719.94	0.0021536	43.25757	51.06059
	SD	0.0059508	221838.5	0.0463574	22.49865	6.202139
FDI to South East Asia						
FDI firms	Obs.	2070	2070	2070	2070	2070
	Mean	0.0184025	59414.82	0.3531401	61.14493	63.04928
	SD	0.0543769	60716.73	0.4780613	25.51585	8.060938
Non-FDI firms	Obs.	113041	113041	113041	113041	113041
	Mean	0.002298	29762.81	0.0026274	43.28698	51.07958
	SD	0.0059719	221649.2	0.0511907	22.5152	6.220415
FDI to North America						
FDI firms	Obs.	953	953	953	953	953
	Mean	0.0280559	64754.13	0.5613851	66.18258	66.26863
	SD	0.0776739	48930.1	0.4964781	25.5777	7.871422
Non-FDI firms	Obs.	114158	114158	114158	114158	114158
	Mean	0.002375	30008.37	0.0043186	43.41966	51.16983
	SD	0.0061441	220681.2	0.0655741	22.57669	6.296013
FDI to China						
FDI firms	Obs.	1440	1440	1440	1440	1440
	Mean	0.021614	60488.77	0.4111111	62.9625	64.08542
	SD	0.0637736	48011.6	0.4922063	25.60465	7.974965
Non-FDI firms	Obs.	113671	113671	113671	113671	113671
	Mean	0.0023466	29913.55	0.0038356	43.36293	51.1328
	SD	0.0061476	221129	0.0618139	22.55156	6.270575

Table 2 Baseline results

Dependent: FDI dummy	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ln (Katz-Bonacich centrality)	0.375***	0.220***	0.296***	0.000797***	0.000216***	0.0125***	0.000789***	0.000215***	0.0120***
	(0.0177)	(0.0327)	(0.0200)	(0.0000404)	(0.0000267)	(0.00140)	(0.0000406)	(0.0000268)	(0.00140)
	[0.00089]	[0.00032]	[0.03023]						
ln (Labor productivity)	0.603***	0.515***	0.573***	0.00775***	0.00243***	0.0604***	0.00698***	0.00223***	0.0534***
	(0.0335)	(0.0663)	(0.0443)	(0.000487)	(0.000337)	(0.00456)	(0.000497)	(0.000347)	(0.00467)
	[0.00143]	[0.00074]	[0.05846]						
ln (Credit score)	7.212***	6.572***	2.996***	0.123***	0.0269***	0.298***	0.128***	0.0280***	0.327***
	(0.233)	(0.477)	(0.287)	(0.00441)	(0.00230)	(0.0286)	(0.00456)	(0.00240)	(0.0294)
	[0.01708]	[0.00943]	[0.30586]						
Listed firm dummy	3.046***	3.639***	2.373***	0.695***	0.323***	0.538***	0.692***	0.323***	0.526***
	(0.102)	(0.640)	(0.0908)	(0.0132)	(0.0912)	(0.0149)	(0.0132)	(0.0912)	(0.0152)
	[0.04411]	[0.05044]	[0.43260]						
ln (Age)	0.495***	0.216*	0.353***	0.00717***	0.000916***	0.0323***	0.00667***	0.000807**	0.0291***
	(0.0659)	(0.111)	(0.0664)	(0.000650)	(0.000347)	(0.00546)	(0.000658)	(0.000353)	(0.00552)
	[0.00117]	[0.00031]	[0.03603]						
Constant	-38.57***	-35.95***	-19.89***	-0.581***	-0.132***	-1.820***	-0.595***	-0.136***	-1.885***
	(0.891)	(1.754)	(1.191)	(0.0186)	(0.00953)	(0.123)	(0.0190)	(0.00984)	(0.127)
Industry FEs	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Pref FEs	No	No	No	No	No	No	Yes	Yes	Yes
Estimation	Logit	Logit	Logit	Linear Prob.	Linear Prob.	Linear Prob.	Linear Prob.	Linear Prob.	Linear Prob.
Sample	All	Small firms	Large firms	All	Small firms	Large firms	All	Small firms	Large firms
Observations	114765	103914	10335	114765	103914	10335	114765	103914	10335
Adjusted R-squared				0.288	0.019	0.322	0.289	0.019	0.324

Note: Robust standard errors are in parentheses. ***: 1% level; *: 10% level. Marginal effects are in brackets.

Table 3 Results by FDI destinations

Dependent	(1) FDI to South East Asia	(2) FDI to South East Asia	(3) FDI to South East Asia	(4) FDI to North America	(5) FDI to North America	(6) FDI to North America	(7) FDI to China	(8) FDI to China	(9) FDI to China
ln (Katz-Bonacich centrality)	0.000726***	0.000188***	0.0123***	0.000189***	0.0000284***	0.00628***	0.000498***	0.000114***	0.0113***
	(0.0000392)	(0.0000258)	(0.00138)	(0.0000198)	(0.00000708)	(0.000916)	(0.0000322)	(0.0000208)	(0.00122)
ln (Labor productivity)	0.00652***	0.00194***	0.0517***	0.00193***	0.000378***	0.0189***	0.00430***	0.00131***	0.0362***
	(0.000478)	(0.000328)	(0.00461)	(0.000272)	(0.000113)	(0.00318)	(0.000410)	(0.000286)	(0.00398)
ln (Credit score)	0.117***	0.0236***	0.325***	0.0568***	0.00501***	0.272***	0.0842***	0.0157***	0.287***
	(0.00436)	(0.00219)	(0.0288)	(0.00306)	(0.000996)	(0.0234)	(0.00374)	(0.00179)	(0.0262)
Listed firm dummy	0.647***	0.251***	0.493***	0.493***	0.111*	0.418***	0.532***	0.144**	0.421***
	(0.0141)	(0.0855)	(0.0158)	(0.0154)	(0.0610)	(0.0162)	(0.0153)	(0.0694)	(0.0165)
ln (Age)	0.00598***	0.000885***	0.0228***	0.00221***	-0.000197	0.0155***	0.00402***	0.000494*	0.0164***
	(0.000633)	(0.000322)	(0.00537)	(0.000398)	(0.000168)	(0.00366)	(0.000518)	(0.000253)	(0.00447)
Constant	-0.548***	-0.116***	-1.862***	-0.252***	-0.0232***	-1.295***	-0.388***	-0.0769***	-1.499***
	(0.0181)	(0.00909)	(0.123)	(0.0127)	(0.00407)	(0.0964)	(0.0156)	(0.00741)	(0.112)
Industry FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pref FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	Linear Prob.	Linear Prob.	Linear Prob.	Linear Prob.	Linear Prob.	Linear Prob.	Linear Prob.	Linear Prob.	Linear Prob.
Sample	All	Small firms	Large firms	All	Small firms	Large firms	All	Small firms	Large firms
Observations	114765	103914	10335	114765	103914	10335	114765	103914	10335
Adjusted R-squared	0.275	0.016	0.308	0.303	0.012	0.318	0.254	0.013	0.281

Note: Robust standard errors are in parentheses. ***: 1% level.

Table 4 Results by industry

	Industry	ln(centrality)		ln(labor productivity)		ln(firm credibility)		listed firm		ln(age)		Constant		Observations
(1)	Food	0.349***	(0.0668)	0.854***	(0.151)	6.817***	(1.199)	2.840***	(0.333)	0.297	(0.242)	-39.77***	(5.156)	10527
(2)	Beverages,tobacco and feed	0.588***	(0.137)	0.426	(0.275)	4.421*	(2.546)	2.160***	(0.657)	0.0607	(0.578)	-22.91**	(8.908)	2189
(3)	Textile mill products	0.279***	(0.0712)	0.416*	(0.219)	6.389***	(1.586)	3.795***	(0.593)	0.162	(0.372)	-31.86***	(5.988)	3229
(4)	Apparel	0.0786*	(0.0434)	0.730***	(0.177)	5.545***	(1.246)	3.594***	(0.826)	0.977***	(0.354)	-36.66***	(5.460)	4129
(5)	Lumber and wood products	0.174	(0.117)	0.294	(0.279)	11.38***	(2.680)	3.028***	(0.802)	0.922	(0.577)	-56.14***	(9.016)	3179
(6)	Furniture and fixtures	0.389**	(0.172)	1.212**	(0.509)	9.678*	(5.461)	2.548**	(1.067)	0.995**	(0.506)	-57.62***	(18.70)	2478
(7)	Pulp, paper and paper products	0.383***	(0.125)	0.728**	(0.291)	5.616***	(1.389)	2.327***	(0.596)	1.603***	(0.501)	-38.59***	(6.321)	3865
(8)	Printing	0.710***	(0.193)	1.337***	(0.323)	7.854***	(2.385)	1.916**	(0.885)	-0.127	(0.628)	-45.89***	(8.651)	6846
(9)	Chemical	0.251***	(0.0845)	0.319***	(0.0927)	6.641***	(0.828)	3.080***	(0.286)	-0.0209	(0.203)	-31.71***	(3.521)	3892
(10)	Plastic products	0.597***	(0.217)	0.571*	(0.299)	-1.883	(2.463)	2.019**	(0.925)	1.873*	(0.967)	-5.168	(10.81)	273
(11)	Petroleum and Coal	0.567***	(0.0903)	0.609***	(0.129)	6.064***	(0.928)	2.906***	(0.561)	0.811**	(0.340)	-34.07***	(3.982)	6599
(12)	Rubber products	0.296**	(0.119)	0.969***	(0.228)	9.683***	(1.560)	2.806***	(0.720)	0.210	(0.647)	-51.14***	(7.165)	1409
(13)	Leather tanning, products and fur skins	0.437***	(0.139)	0.562	(0.733)	14.71***	(4.627)	.	.	3.130***	(1.193)	-77.98***	(16.67)	708
(14)	Ceramic, stone and clay products	0.575***	(0.0805)	0.649***	(0.230)	7.693***	(1.251)	3.412***	(0.521)	1.137***	(0.337)	-42.60***	(5.341)	5114
(15)	Iron and steel	0.431***	(0.0798)	0.855***	(0.145)	4.904***	(1.148)	1.984***	(0.448)	1.109**	(0.516)	-34.02***	(4.984)	2420
(16)	Non-ferrous metals and products	0.375***	(0.101)	0.699***	(0.122)	7.689***	(1.201)	2.716***	(0.525)	0.104	(0.326)	-39.82***	(4.933)	1826
(17)	Fabricated metal products	0.475***	(0.0515)	0.745***	(0.133)	7.416***	(0.745)	2.164***	(0.453)	1.113***	(0.283)	-42.91***	(2.994)	15395
(18)	General machinery	0.397***	(0.0376)	0.654***	(0.0820)	7.944***	(0.518)	3.257***	(0.276)	0.644***	(0.158)	-42.43***	(2.014)	17832
(19)	Electrical machinery	0.466***	(0.0679)	0.791***	(0.124)	6.879***	(0.847)	3.444***	(0.413)	0.597**	(0.250)	-39.09***	(3.146)	6560
(20)	Information and communicaion electronics	0.397***	(0.111)	0.613***	(0.151)	6.406***	(1.644)	2.617***	(0.542)	1.090***	(0.360)	-37.16***	(6.335)	1461
(21)	Electronic parts and devices	0.438***	(0.0777)	0.401***	(0.106)	5.434***	(1.057)	4.642***	(0.774)	0.780***	(0.274)	-29.86***	(4.308)	3270
(22)	Trasportation equipment	0.437***	(0.0976)	0.720***	(0.134)	8.898***	(1.086)	3.548***	(0.484)	0.393*	(0.223)	-45.78***	(4.478)	4038
(23)	Precision instruments and machinery	0.229***	(0.0605)	0.260	(0.549)	9.083***	(1.496)	3.827***	(0.736)	0.126	(0.348)	-41.79***	(5.560)	2489
(24)	Miscellaneous	0.149**	(0.0658)	0.459**	(0.196)	10.78***	(1.477)	5.227***	(0.968)	-0.0487	(0.349)	-51.20***	(5.452)	5036

Note: Robust standard errors are in parentheses. ***: 1% level; **: 5% level; *: 10% level.

Table 5: Results in full specification

ln(centrality)	ln(labor productivity)	ln(firm credibility)	listed firm	ln(age)	Gamma	Industry & Pref Fes	Observations
0.032	0.044	0.251	-0.071	0.019	0.020	yes	10000
(0.008)	(0.003)	(0.005)	(0.001)	(0.001)	(0.005)		

Note: Standard errors are calculated by 100 bootstrap iterations. Bootstrapped standard errors are in square parentheses. ***: 1% level; **: 5% level; *: 10% level.

Table 6: Results in sequential analysis

	(1)	(2)
Dependent	FDI to China	FDI to South East Asia
ln (Katz-Bonacich centrality)	0.585**	0.237**
	(0.250)	(0.123)
ln (Accessibility)	0.003*	0.004**
	(0.002)	(0.001)
ln (Labor productivity)	0.014**	0.008**
	(0.004)	(0.003)
ln (Credit score)	0.143**	0.116**
	(0.021)	(0.022)
Listed firm dummy	-0.04**	-0.037**
	(0.002)	(0.003)
ln (Age)	0.003	-0.005
	(0.003)	(0.004)
Gamma	0.004	0.005
	(0.004)	(0.004)
Industry FEs	yes	yes
Pref FEs	yes	yes
Observations	10000	10000

Online appendix: Derivation of Bayesian-Nash equilibrium

When firm *i* is expected to decide according to equation (3), the other firms' expectations of firm *i*'s probability to invest, $p(\theta_i|G)$, can be denoted as

$$p(\theta_i|G) = \text{Prob}(\upsilon_i = 1|\theta_i) = \text{Prob}\left[\frac{z_i}{\tau_i} \geq \theta_i\right] = \int_{-\infty}^{+\infty} l(\tau_i)[1 - F(\tau_i\theta_i)]d\tau_i, \quad \text{(A1)}$$

where $F(\cdot)$ represents the cumulative distribution function of z_i, and $l(\cdot)$ is the density function of τ_i. All firms have common knowledge of these distribution functions and know that they are independent.

Now, we denote a vector of thresholds as $\boldsymbol{\theta} = (\theta_1, \ldots, \theta_n)$ and denote a vector of probability of holding an affiliate for given set of thresholds as $\mathbf{p}(\boldsymbol{\theta}) = (p(\theta_1), \ldots, p(\theta_n))$. We then define $\theta_i(\boldsymbol{\theta}; \boldsymbol{G}) = \theta_i(\mathbf{p}(\boldsymbol{\theta}); \mathbf{G})$ as a function of *i*'s best response threshold for given others' threshold, described as follows by using equations (3) and (A1):

$$\theta_i(\boldsymbol{\theta}; \boldsymbol{G}) = -\sum_{j=1}^{n}\left[\int_{-\infty}^{+\infty} l(\tau_j)\left[1 - F(\tau_j\theta_j)\right]d\tau_j\right]\phi_{ij}. \quad \text{(A2)}$$

We describe a vector of the best-response threshold as $\boldsymbol{\theta}(\boldsymbol{\theta};\, \boldsymbol{G}) = \left(\theta_1(\boldsymbol{\theta}; \boldsymbol{G}), \ldots, \theta_n(\boldsymbol{\theta}; \boldsymbol{G})\right)^{\boldsymbol{T}}$. At this time, the Bayesian-Nash equilibrium of this incomplete information game is a state where the threshold of any firm satisfies the best response to others' thresholds; that is, $\boldsymbol{\theta} = \boldsymbol{\theta}(\boldsymbol{\theta}; \boldsymbol{G})$ holds.

Now, we stipulate the distribution of z_i to derive a specific equilibrium. Assuming that firms expect z_i to be uniformly distributed within $[-a + \bar{z}, a + \bar{z}]$, the distribution function can be denoted as

$$F(z) = \begin{cases} 0 & \text{if} \quad z < -a + \bar{z} \\ \dfrac{a - \bar{z} + z}{2a} & \text{if} \quad -a + \bar{z} \leq z \leq a + \bar{z}\,, \\ 1 & \text{if} \quad z > a + \bar{z} \end{cases} \qquad \text{(A3)}$$

where $a > 0$. The expected value of z_i, denoted by $\bar{z}$, can be both positive and negative. We also assume that $\bar{z} - a < -(n-1)\tau^m$ and $\bar{z} + a > 0$, where τ^m is the upper bound of τ_i. Due to that assumption, it is readily seen that $\tau_i \theta_i(\boldsymbol{\theta}; \boldsymbol{G})$ is always within $(-a + \bar{z}, a + \bar{z})$ because $\tau_i \theta_i(\boldsymbol{\theta}; \boldsymbol{G}) \in [(n-1)\tau^m, 0]$ holds from Eq. (3), and then we must consider interior equilibrium in which $\mathrm{p}(\theta_i(\boldsymbol{\theta}; \boldsymbol{G})) \in (0,1)$ holds. Therefore, $F\big(\tau_i \theta_i(\boldsymbol{\theta}; \boldsymbol{G})\big) \in (0,1)$ always holds, and hence, by equation (A3), equation (A2) can be rewritten as follows:

$$\theta_i(\boldsymbol{\theta}; \boldsymbol{G}) = -\sum_{j=1}^{n} \frac{a + \bar{z} - \bar{\tau}\theta_j}{2a} \phi_{ij}, \qquad \text{(A4)}$$

where $\bar{\tau}$ is the expected value of τ_i. We can denote the simultaneous equation system of equation (A4) by a vector as follows:

$$\boldsymbol{\theta}(\boldsymbol{\theta};\ \boldsymbol{G}) = -\rho\gamma \boldsymbol{G}\mathbf{1} + \gamma \boldsymbol{G}\boldsymbol{\theta}, \qquad \text{(A5)}$$

where **1** denotes the column vector of one; we denote $\rho = (\mathrm{a} + \bar{z})/\bar{\tau}$,

$\gamma = \bar{\tau}/(2a)$ to simplify the notation.

We derive the equilibrium of the model denoted as $\boldsymbol{\theta}^* = (\theta_1^*, \ldots, \theta_n^r)$ by solving equation (A5) by $\boldsymbol{\theta}$. The system of linear equations shown in equation (A5) has a single interior solution if and only if γ is positive and smaller than the inverse of the largest eigenvalue of $\mathbf{G}$. The assumptions $\bar{z} - a < -(n-1)\tau_i^m$ and $\bar{z} + a > 0$ promise $\gamma < 1/(\mathrm{n} - 1)$, and then γ is smaller than the inverse of the largest eigenvalue. Therefore, the firms' strategies necessarily converge to a unique interior equilibrium because any corner solution (where p_i =1 or 0 for any i) can be omitted based on the assumption of sufficiently wide support for z_i. The equilibrium of the model which is equivalent to Eq. (4) can be derived as follows:

$$\begin{aligned} \boldsymbol{\theta}^* &= -\boldsymbol{\rho}\gamma\boldsymbol{G}(\boldsymbol{I} - \gamma\boldsymbol{G})^{-\mathbf{1}} \\ &= -\rho \textstyle\sum_{k=1}^{\infty} \gamma^k \boldsymbol{G}^{\boldsymbol{k}} \mathbf{1}. \end{aligned} \qquad \text{(A6)}$$