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Impact of Supply Chain Network Structure on FDI: Theory and evidence

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Impact of Supply Chain Network Structure on FDI: Theory and evidence[1]

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Abstract

This study investigates how the structure of a supply chain network in the domestic market influences the foreign direct investment (FDI) decisions of firms embedded in the network. We first describe the binary choice of firms on whether to invest through a coordination game of a fixed network with incomplete information of the firms' profits, and we show that the unique equilibrium of the game is represented by the Katz-Bonacich centrality measure, which captures both direct and indirect effects of the network. Then, we also conduct empirical tests to verify our theoretical hypothesis with large disaggregated data of Japanese firms and confirm that the Katz-Bonacich centrality of each firm has a significantly positive effect on its FDI even when sector-specific fixed effects and other attributes are controlled for, as our theory predicted.

Keywords: FDI, Network game, Supply chain, Katz-Bonacich centrality
JEL classification: D20, D85, F23

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1. Introduction

Foreign Direct Investment (FDI) has been growing during the last two decades. For companies wanting to establish affiliates in a foreign market, finding good procurement channels for materials and sales channels for products is a big issue. Companies starting new transactions with local firms sometimes suffer from various kinds of frictions such as mismatch in design and quality of products and their delivery systems (see Reid 1995); adjusting such frictions is also difficult because of miscommunications between firms that have different commercial customs and technical bases. Some firms therefore trade with their affiliates in the same home country and replicate transaction partnerships in the domestic market (Hackett and Srinivasan 1998). Such transactions yield profits to both sides of the transactions not only by smoothing the trade of products but also by exchanging various useful information on the markets and the government.

As a result, we believe that the FDI of a firm, including its expected future investments as well as completed ones, stimulates the investment of other firms in the same market through a supply chain network, which is a set of whole trades in the domestic market. Actually, a string of studies on country-of-origin FDI show that the agglomeration of investment from a particular home country attracts further investment from that country (e.g., Head et al. 1995, Chang and Park 2005, Chung and Song 2004). Specifically, Belderbos and Carree (2002) study the FDI influence of a group of Japanese companies (*keiretsu*) and show some kind of a supply chain network effect. Further, Yamashita et al. (2013) examine the actual transaction relationship data, instead of keiretsu data, and show the influence of both direct and indirect transaction partners on the FDI location decision of firms.

The purpose of this study is to empirically investigate the effect of the domestic market's supply chain network structure on firms' FDI decisions with a micro-founded model by using detailed data of a supply chain network. We employ a network game framework to describe the FDI decision of firms embedded in the supply chain network. Our model describes that the FDI decision of every firm mutually influences every other firm's decision via network, and shows how entire structure of the network feedbacks to the behavior of each firm. Although previous studies simply regress the FDI decision/location of a firm by the FDI decision/location of other firms, our theoretical model suggests that such estimation will cause endogeneity bias. On the other hand, by using the equilibrium characteristic of the theoretical model, we propose a simple method to estimate the role of the supply chain network in FDI decisions without the above endogeneity bias, and we then empirically test it.

We consider a simultaneous decision making of firms on whether they should invest or not in a region. We assume a fixed network consisting of a pair of directly linked firms, interpreted as business partners in the domestic market, that have incentives to invest simultaneously with each other. Furthermore, part of the profit from FDI is assumed to be private information for each firm and unobservable to the other, and the decision of each firm depends on its partner's uncertain decision. The network game is basically similar to the theoretical model presented by Bloch and Quérou (2013), but we make an extension. In our model, the stand-alone benefit gained outside the transaction is uncertain, as Bloch and Quérou (2013) supposed, but we also suppose that the benefit of the transaction differs between the firms and comprises private information.

In our incomplete information game, each firm expects the decision of its direct partners to depend on the expectations of all their indirect partners, that is, the partners of partners and their partners, and so on. Through the diffusion of such expectations over the network in various routes, each firm's decision converges to a strategic equilibrium. Following Bloch and Quérou (2013), we demonstrate that—assuming uniformly distributed stand-alone payoffs—the game has a unique Bayesian Nash equilibrium, with the threshold strategy of each player characterized by its Katz-Bonacich centrality measure on the network and the more "central" players more likely to invest[1,2]. Katz-Bonacich centrality denotes how a node is accessible to all others[3]; some of our companion papers apply it to describe the Nash equilibrium of network games (Ballester, Calvó-Armengol, and Zenou 2006; hereafter BCZ) and its empirical extension (Calvó-Armengol, Patacchini, and Zenou 2009; hereafter CPZ).[4]

Our final aim is to provide empirical evidence for the above theoretical hypothesis. We use the disaggregated data of more than 110,000 Japanese firms in the manufacturing

1 Bloch and Quérou (2013) investigate whether each consumer embedded in the network purchases one unit of indivisible network good or not.
2 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.
3 This index is equivalent to a linear function of centralities of directly linked nodes.
4 The BCZ model and our model have similar mathematical forms: a quadratic (expected) payoff function and, hence, a linear best-response function. However, issues of the two studies differ fundamentally; BCZ consider a continuous choice (e.g., quantity of effort or money spent for education), while we consider a discrete choice (i.e., whether to invest or not).

sector. In addition to the data of each individual firm such as number of employees, total product, and credit ranking, the data of the main trading partners of each firm are also available for detailed composition of the supply chain network. This network information allows us to calculate the Katz-Bonacich centrality representing the detailed network structure of the whole Japanese manufacturing sector by capturing the inter-sectoral effects among the small sectors. Merging this firm-level data with 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. [5]

Our results show significantly positive effects of Katz-Bonacich centrality on the firms' FDI decision by controlling for the various individual attributes of firms, including the industry fixed effects and headquarters' location fixed effects. Furthermore, quantitatively, the magnitude of Katz-Bonacich centrality is similar to the productivity pointed out as the main engine of FDI (Helpman et al. 2004). This suggests the importance of considering the supply chain network in the FDI decision of firms. Further, we confirm the robustness of the baseline results and validity of using eigenvalue centrality by using the original Katz-Bonacich centrality.

Our theoretical framework itself can be widely applied to many agent behavior and network structure issues as well as the firms' FDI decision problems. In this regard, we propose a theory-based estimation methodology with a network game. The application of our theory and empirical framework to the FDI of Japanese firms, however, has highly desirable features. First, the FDI of Japanese firms does not change the structure of the supply chain network. In our empirical strategy, we regress the behavior of firms (FDI decision) by the network structure (Katz-Bonacich centrality). For example, in the case of a network of classmates' test scores, the students' abilities (test score) affect the students' mate selection. In the FDI case, once the FDI decision affects the network structure, our empirical strategy becomes invalid. However, we have already seen that the affiliates of firms have large incentives to replicate the relationship in the home country rather than start new trading, and hence what matters for the FDI of firms is the supply chain network in the domestic market; such a trunk relationship will be negligibly influenced by investment and be stable at least in the short run. We therefore use the fixed network although network endogeneity is a considerable problem for such

[5] Manski (1993) addressed a detailed methodology to estimate the spillover effects on networks, while we simply estimate the influence of the calculated centrality based on our theoretical results.

research models.

Second, our framework requires us to observe only one market. Bajari et al. (2010) proposes an estimation strategy under an incomplete information game that includes our network game. However, their estimation strategy requires a large number of market observations as repetitions of the game, because their asymptotic analysis is built on the number of markets. By focusing on the stock market and considering the market of each period as a repetition of the market, they obtain a huge number of markets. However, the situations for us to obtain information in many repetitive markets are limited, and so our empirical strategy can be widely applied to various issues.

The remainder of this paper is structured as follows. Section 2 presents a static coordination game with a network and 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 restricting the samples to larger firms. Finally, section 6 concludes the paper.

2. Theory and Testable Prediction

In this section, we present a simultaneous move game with incomplete information and describe the FDI decision of firms based on coordinated investments with trading partners. Our theoretical framework is basically similar to Bloch and Quérou's (2013) model, notwithstanding a few dissimilar settings.

2.1. Inter-firm transaction and profit of affiliates

Set $\mathrm{N} = \{1,2,\ldots,\mathrm{n}\}$ is a finite set of risk-neutral firms from the home country (i.e., Japan), and the n×n matrix $\mathbf{G}=\{\phi_{ij}\}$ denotes an exogenously given transaction relationship between the firms, that is, the supply chain network adjacency matrix in the domestic market. 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 and $\phi_{ij}=\phi_{ji}$ holds, and that $\phi_{ii}=0$ holds for diagonal components.

Next, we denote the set of domestic firms with an affiliate in foreign region *r* (e.g., Eastern Asia) by $\mathrm{N_r} \subset \mathrm{N}$. We assume that products and services the affiliates supply are similar to those of their domestic companies; hence, a pair of affiliates can trade to yield a positive profit only if their parent companies also trade in the domestic market[6]. Suppose that a firm gains a constant additive profit from transactions with other firms, such as through the efficient supply and procurement of intermediate goods or services. We assume that the additive profit from the transactions, denoted by $\tau_{ir} > 0$, differs between firms but is never influenced by any other transaction. Therefore, affiliates i and j must trade if $i, j \in \mathrm{N_r}$ and $\phi_{ij} > 0$ holds. Then, the total profit that firm i gained from all transactions is denoted by $\tau_{ir} \sum_{j=1}^{n} v_{jr}\phi_{ij}$, where v_{jr} is one when firm j has an affiliate in region r or $j \in N_r$ and zero otherwise.

The total profit of affiliate i in region r can be given as follows:

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

where $v_\mathrm{r} = (v_{1r}, \ldots, v_{jr})$ is a vector of investment in region r. Furthermore, z_{ir} is the stand-alone profit of affiliate i in region r; that is, it is independent of the transaction (Farrell and Saloner 1985). Stand-alone profits can be influenced by the economic condition of region r and attributes of individual firms, such as investment costs in region r, international trading costs like tariffs, and transportation cost, and the demand for firm i's products by the consumers and firms in r. This study assumes that z_{ir} includes any cost and profit source other than transactions on the network; hence z_{ir} can be both positive and negative.

We assume that only firm i knows its own z_{ir} and τ_{ir}. While 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. Firms generally have some probabilistic information about other firms' τ_{ir} and z_{ir}, which is common knowledge among all the firms. This setting gives an incompleteness to the information of our model.

2.2. Decision making on FDI

[6] If firm i invests in region r while its partner j does not, i must give up transactions with j's affiliate and must choose whether to trade with j's affiliate in the home country or find a new alternative partner in region r. However, the former case would lead to tariffs and transportation costs while the latter causes loss from mismatches. Such profits are therefore less than that from trade with the original partners; this study assumes such additional profit as zero.

Firms face the binary choice of whether to invest or not in region r to establish an affiliate there. The decision to invest in region r must be independent of other investment decisions because firms can invest in more than one region and their profits of all investments are independent, as equation (1) indicates. Therefore, without any special necessity, the remaining of this paper omits subscript r from all variables and parameters for simplicity of notation.

We assume that all firms make their decisions simultaneously, and hence aim to maximize the expected total value of their profits. We further assume that the entire network structure $\mathbf{G}$ is public information for all the firms whereas only firm i knows its own z_i and τ_{ir} at the time of making its decision. In other words, the firms are aware of the relationship of all other firms but have no information about their attributes. Therefore, each firm has only some probabilistic expectation of the decision of other firms with given information, that is, the distribution functions of z_i and τ_i. Thus, we assume that each firm expects its z_i and τ_i to be independent of other firms and any other observable variables.

At the time of decision making, firm i's expected total profit from its investment in region r can be denoted as

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

where $p_j = \Pr(v_j = 1)$ represents the other firms' expectations of j's probability of investing in r and $\mathbf{p_r} = (p_1, \dots p_n)$ their vector. Firm i establishes an affiliate only when $\mathrm{E}(\pi_i|\mathbf{p}, \mathbf{G}, z_i, \tau_i) \geq 0$ holds, because the firm would gain zero profit without investment. 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 $z_i/\tau_i \geq \theta_i$ holds; hence, the best-response strategy of each firm is equivalent to the threshold. From equation (2), the best-response threshold of firm i can be described as

$$\theta_i = -\sum_{j=1}^{n} p_j \, \phi_{ij} \quad (3)$$

This equation implies that higher expectations for partners to invest decreases θ_i and hence increases the firm's own probability to invest. Note that a lower threshold means a higher incentive to invest. When firm *i* is expected to decide according to equation (3), the other firms' expectation on firm *i*'s probability to invest can be denoted as

$$p_i = \text{Prob}(z_i/\tau_i \ \geq \theta_i) = \int_{-\infty}^{+\infty} l(\tau_i)[1 - F(\tau_i\theta_i)]d\tau_i \tag{4}$$

where $\text{F}(\cdot)$ represents the accumulated distribution function of z_i and $\text{l}(\cdot)$ the density function of τ_i. All the firms have common knowledge of these distribution functions and know that they are independent. When the vector of threshold $\boldsymbol{\theta} = (\theta_1, ..., \theta_n)$ is given, from equations (3) and (4), we can describe firm *i*'s best-response threshold to the other firms' thresholds as follows:

$$\theta_i = -\sum_{j=1}^{n}\left[\int_{-\infty}^{+\infty} l(\tau_i)[1 - F(\tau_i\theta_i)]d\tau_i\right]\phi_{ij} \tag{5}$$

By creating a system of simultaneous equations consisting of *n* equations based on equation (5) and solving it by $\boldsymbol{\theta}$, we can derive the equilibrium strategy of all firms.

2.3 Equilibrium under uniform distribution of random profit

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

$$F(z) = \begin{cases} 0 & \text{if} \quad z < -a + \bar{z} \\ \dfrac{a - \bar{z} + z}{2a} & \text{if} \quad -a + \bar{z} \leq z \leq a + \bar{z} \\ 1 & \text{if} \quad z > a + \bar{z} \end{cases} \tag{6}$$

where $a > 0$. The expected value of z_i, denoted by $\bar{z}_r$, can be both positive and negative. We also assume that $\bar{z} - a < -(n-1)\tau_i^m$ and $\bar{z} + a > 0$, where τ_i^m is the maximum value of τ_i. These assumptions guarantee a sufficiently wide support for z_i, in which $\tau_i\theta_i$ is always within $[-a + \bar{z}, a + \bar{z}]$ and then excludes any corner solution because $\theta_i \in [-(n-1), 0]$ holds from equation (5). This can be interpreted to indicate that each firm will never promise to make a choice, regardless of its stand-alone profits, even when the firm trading with all the other firms expects all its trading partners to make a choice with a probability of one. In other words, with this assumption, both investing and non-investing firms are ex-ante possible. As we show later, these assumptions are sufficient to ensure a unique and interior equilibrium for the model.

Then, by equation (6), equation (5) can be rewritten as follows:

$$\theta_i = -\sum_{j=1}^{n} \frac{a + \bar{z} - \bar{\tau}\theta_j}{2a} \phi_{ij} \tag{7}$$

where $\bar{\tau}$ is the expected value of τ_i. We can denote the simultaneous equation system of equation (7) by vector as follows:

$$\boldsymbol{\theta} = -\gamma\rho\mathbf{G}\mathbf{1} + \gamma\mathbf{G}\boldsymbol{\theta} \tag{8}$$

where **1** denotes the column vector of one; we denote $\gamma = \bar{\tau}/(2a)$ and $\rho = (a + \bar{z})/\bar{\tau}$ to simplify the notation. Note that the above best-response functions denoted by equations (7) and (8) hold only when $-a + \bar{z} \leq \bar{\tau}\theta_i \leq a + \bar{z}$ is satisfied for all *i,* but this is ensured by the assumption of a sufficiently wide support for z_i.

Note also that the above linear best-response function is very similar to that of BCZ; this is because the multiplier of the linear payoff and linear probability yields a quadratic expected payoff similar to the one given in BCZ. Conclusively, the following equilibrium of our model is mathematically identical to that of BCZ, although the two models are based on different issues.

We derive the equilibrium of the model denoted as $\boldsymbol{\theta}^* = (\theta_1^*, \ldots, \theta_n^r)$ by solving equation (8) by $\boldsymbol{\theta}$. The system of linear equations shown in equation (8) has a single interior solution if γ is smaller than the inverse of the largest eigenvalue of $\mathbf{G}$ [7]. 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 by the assumption of a sufficiently wide support for z_i[8]. The equilibrium of the model can be derived as follows:

[7] When $\boldsymbol{\theta}$ diverges because γ is larger than the largest eigenvalue, all firms definitely choose to invest or not and both decisions are in equilibrium.
[8] The assumptions $\bar{z} - a < -(n-1)\tau_i^m$ and $\bar{z} + a > 0$ promise $\gamma < 1/(n-1)$. This restriction is actually more than when γ is smaller than inverse of the largest eigenvalue of $\mathbf{G}$.

$$\boldsymbol{\theta}^* = -\rho\,\gamma\mathbf{G}(\mathbf{I}-\gamma\mathbf{G})^{-1}\mathbf{1}$$
$$= -\rho\sum_{k=1}^{\infty}\gamma^k\mathbf{G}^k\mathbf{1} \tag{9}$$

In equation (9), each firm's equilibrium strategy can be described as follows:

$$\theta_i^* = -\rho b_j(\mathbf{G}),$$
$$\text{where } b_i(\mathbf{G}) = \sum_{k=1}^{\infty}\sum_{j=1}^{n}\gamma^k\phi_{ij}^{\{k\}}. \tag{10}$$

Note that $\phi_{ij}^{\{k\}}$is the *ij* component of $\mathbf{G^k}$ but does not have the *k*-th power of ϕ_{ij}.

The function $b_i(\mathbf{G})$ in equation (10) is identical to a Katz-Bonacich centrality network measure or alpha-centrality (Bonachich 1987, BCZ, Ballester and Calvo-Armengol 2011). Since a lower threshold means a higher incentive (and then probability) for investments, we come to the following theoretical finding.

Finding.

The incentive for investment of each firm increases in its Katz-Bonacich centrality $b_i(\mathbf{G})$.

This finding appears also in Bloch and Quérou (2013) without incomplete information on τ_i. Although our result depends on linearity of the model, and this is an approximation, this finding shows that Katz-Bonacich centrality represents the equilibrium of strategic interaction between firms. We empirically verify this finding on network structure in the following sections.

Katz-Bonacich centrality is calculated by summing all *walks* of the network (i.e., the routes on the network for which links can be traversed more than once) from *i* to *j* with decaying by their length by decaying parameter γ. The important characteristic of Katz-Bonacich centrality is considering the influence of indirect relationships (i.e., with one's partners' partner) as well as direct partners; then, the entire network structure feedbacks each node embedded therein.

More central players have larger incentives to invest for the following reasons.

Under the additively separable profit function given by equation (1), outgoing firms with many partners have the potential to gain higher profits by FDI and hence other firms expect them more likely to invest. Furthermore, the partners of outgoing firms also have large incentives to invest because they have a high probability of trading with the outgoing firms in the foreign markets. When the partners' prospects of investing diffuses thorough whatever possible path in the network in such a manner, the more central players embedded in the hub of the network receive larger influences, that is, the so-called network externality.

3. Data and Empirical Strategy

3.1 Data

We use the data compiled by a major credit research firm, the Tokyo Shoko Research Incorporated (TSR), for the year 2006. The dataset includes information of 826,169 large and small corporations in Japan and consists of two subsets: a dataset on firms' characteristics and a dataset on interfirm relationships. For compiling their datasets, field researchers of TSR utilize public sources such as financial statements, corporate registrations, and public relations documents and conduct face-to-face interviews with firms. The sub-dataset on firm characteristics includes information on the firms' name, address, industry classification code, products, year of establishment, number of employees, sales, business profit, and credit score. The other sub-dataset on interfirm relationships includes information on the firms' suppliers and customers. There is an upper limit of 24 with regard to number of customers or suppliers each firm can report. The total number of interfirm relationships is approximately four million. This dataset covers about half of the total incorporated firms in Japan and describes the actual interfirm relationships in Japan most comprehensively. The focus of this paper is on manufacturing firms, and this reduces our sample size to 142,282 firms.

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

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

[Table 1 here]

Our dataset has a total of 115,111 observations after merging the reduced samples of TSR and TKZ databases. On FDI behavior, a total of 2278 manufacturing firms have FDI in 2010 (i.e., with at least one foreign affiliate during that period), with 2070 firms having FDI in the Southeast Asian countries. This suggests that most of the FDI firms have affiliates in Southeast Asian countries[9].

3.2 Empirical strategy

To test our theoretical prediction in equation (10) and the finding in section 2.3, we estimate the following equation:

$$\mathrm{FDI}_{ir} = \alpha_r + \beta_r \ln(\mathrm{centrality}_i) + \boldsymbol{\delta}_\mathbf{r}\mathbf{X}'_\mathbf{ir} + \varepsilon_{ir}, \tag{11}$$

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. Equation (11) is also applicable to pooled FDI data regardless of destination, where each coefficient will be the weighted average of the corresponding coefficients in every destination. Further, if we estimate this equation with the samples by industry and firm size, the estimated coefficients will represent the type-specific effects of centrality and other FDI attributes.

To estimate this equation, we need to calculate Katz-Bonacich centrality. We calculate Katz-Bonacich centrality, representing the network structure of the whole Japanese manufacturing sector, by capturing the inter-sectoral effects. Since 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 the firm belongs to. For example, the FDI decision of a tire-producing firm classified under the rubber industry depends on the behavior of other firms belonging not only to the rubber

[9] Following the model, we assume that all FDIs are simultaneously established with no prior investor. This assumption is justified by the fact that FDI has been rapidly increasing during these two decades.

industry but also to other industries such as the motor vehicle industry.

Considering a network including all the manufacturing firms, leads to computational difficulty when calculating Katz-Bonacich centrality. The calculation of Katz-Bonacich centrality requires us to first calculate the inverse matrix of the adjacency matrix. If we consider the transaction network of all the manufacturing firms, the adjacency matrix $\mathbf{G}$ will have 115,111×115,111 elements. To avoid calculating such a large inverse matrix, we use another measure of centrality instead of Katz-Bonacich centrality for our estimation. By assuming the value of the decay parameter γ in eq. (10) by the inverse of the largest eigenvalue of $\mathbf{G}$, we obtain the so-called eigenvalue centrality as a special case of Katz-Bonacich centrality. Eigenvalue centrality does not require us to further calculate the inverse matrix of the adjacency matrix and can be applied to huge networks. Thus, in all estimations of section 4, we use eigenvalue centrality as proxy for Katz-Bonacich centrality. Then, in section 5, in order to check the validity of using eigenvalue centrality and the robustness of the results, we estimate the equation and the decay parameter γ simultaneously by using a subset of the whole supply chain network.

We estimate eq. (11) by using a logit and linear probability model. To assure consistency of our estimates, we discuss the concerns of omitted variable bias and reverse causality.

One very important factor causing the omitted variable problem is heterogeneity of firm productivity. As pointed by Helpman et al. (2004), firm productivity strongly affects the FDI decision of firms. Further, firm location in the supply chain network might be correlated to firm productivity. For example, a highly productive firm may attract many customers and increase Katz-Bonacich centrality. To deal with this problem, we introduce labor productivity, that is, sales divided by the number of workers, as a measure of firm productivity. Other than firm productivity, firm performance and firm credibility also might affect both 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. Further, we include the variable of firm credibility as a measure of comprehensive firm evaluation that captures other unobserved firm heterogeneity. Firm credibility is a measure originally created by TSR. Since TSR is a credit research company, it provides information on firm credibility; 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 by using public sources of information and face-to-face interviews. We include firm credibility in the regression equation to control for the unobservable performances of firms.

Further, one may concern that the FDI decision of a firm by itself may affect the structure of the transaction network. For example, two firms with no transaction relationships between them may establish foreign affiliates at the same industry complex, and after the establishment, their geographical proximity may facilitate transactions between them. In this case, the FDI behavior of the firms affects the structure of the transaction network, and endogeneity problem occurs. However, such new transaction relationships between foreign affiliates are not very frequent. As Reid (1995) has pointed, companies starting new transactions with local firms sometimes suffer from various kinds of frictions such as mismatches in design and product quality and delivery systems, and, as Hackett and Srinivasan (1998) have pointed, companies would prefer to trade with their affiliates in the same home country and replicate transaction partnerships in the domestic market rather than start new trading. Therefore, what matters for the FDI of firms is the supply chain network in the domestic market; such trunk relationships will be negligibly influenced by investment and would be stable at least in the short run. Actually, a majority of the FDI is still the result of requests from transaction partners, and the existence of such requests itself suggests the difficulty of finding new transaction partners in foreign countries.

Furthermore, the role of supply chain network on FDI decision may be different across targeted countries. Indeed, Japanese firms have been conducting FDI in various countries. In our estimation, we first pool every FDI conducted not only in the various North American, European Union, and Asian countries but also in other smaller countries. In this case, the FDI dummy takes the value of one if the firm is conducting FDI, regardless of destination country, and zero otherwise. However, Baldwin and Okubo (2012) suggested that the Japanese foreign affiliations have closed supply chain networks within regions such as Southeast Asia and North America. To include the activity of such closed networks, we also conduct analysis separately focusing on the Japanese FDI behavior by region.

4. Empirical Results

4.1 Baseline results

In this section, we present our estimation results. First, Figure 1 shows the distribution of the log of the eigenvalue centrality specifying the decay parameter by the inverse of the largest eigenvalue of adjacency matrix; we employ this eigenvalue centrality through section 4. The figure clearly shows the difference between FDI and non-FDI firms. The distribution is shifted rightward in FDI firms, strongly suggesting that firms conducting FDI have a relatively higher Katz-Bonacich centrality value.

[Figure 1 here]

Now, we show the results of baseline estimation using pooled FDI data regardless of destination in Table 2. Column (1) gives the benchmark results including all the manufacturing firms in Japan and 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 conducting 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.

From the discussions in Helpman et al. (2004), firm productivity and size can affect the FDI decision of firms. We separately estimate equation (11) by firm size. Column (2) gives the results of the sample with number of workers restricted to less than 100 (smaller firms), and Column (3) gives the results of the sample with number of workers more than 100 (larger firms). In both columns, the coefficients for Katz-Bonacich centrality are positively significant. Interestingly, the coefficient for Katz-Bonacich centrality is larger in larger firms than in smaller firms. This is consistent with the prediction of Helpman et al. (2004). Because of large fixed costs for FDI, smaller firms cannot afford FDI and find it difficult to conduct FDI in the first place. Network structure has a weak effect for the FDI strategy of smaller firms. On the other hand, the constraint of fixed costs for FDI is smaller in larger firms, and network structure has a larger effect for the FDI decision of larger firms.

[Table 2 here]

The FDI decision of a firm depends on the products of the firm. To control for such product heterogeneity, we include industry fixed effects in the estimation equation whose results are presented in Table 2 Columns (4) to (6). We use the four-digit industrial classification in Japan Standard Industrial Classification (JSIC) and carry out ordinary least squares (OLS) estimation (linear probability model) to reduce computation time. Column (4) gives the results. Even after controlling for industry fixed effects, the coefficient for Katz-Bonacich centrality is positively significant, and the coefficient for all the other covariates are also positively significant. Column (5) gives the results of small firms and Column (6) the results of large firms. Very interestingly, the difference 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 more sharp.

One may be concerned because both the FDI decisions and centrality of firms in the supply chain network depend on the firms' headquarter locations. Firms located in large metropolitan areas can find numerous transaction partners owing to their locational proximity with other firms and reduce transaction costs; furthermore, the concentration of firms may spillover the knowhow to conduct FDI, promote the entrance of mediate firms that support other firms' FDI, and facilitate the FDI decision of firms. To respond to this concern, we include the location fixed effects of firms by prefectural level. The results are shown in Table 2 Columns (7) to (9). Column (7) gives the OLS estimation results, which are quite similar to the previous results. Katz-Bonacich centrality is still positively significant, and the magnitude is also similar to the results in Column (4). Column (8) gives the results for small firms and Column (9) the results for large firms, and both are quite similar to the results in Columns (5) and (6), which exclude prefectural fixed effects. 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 by their standardized coefficients, which means one standard deviation increase in a variable leads to how much standard deviation increase in predicted FDI. For example, results presented in Column (7) implies that standardized coefficients of worker productivity is 0.410, while that of Katz-Bonacich centrality is 0.318. This result indicates 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 supply chain network is quite necessary to consider firms' FDI decisions.

4.2 Heterogeneity in destination countries

In the above analysis, we include every FDI regardless of destination. However, as Baldwin and Okubo (2012) suggested, the purpose of FDI would differ by destination. We therefore focus on specific FDI destination countries. Table 3 gives the results.

[Table 3 here]

Column (1) gives the results of FDI in Asian countries. In the estimation, the dependent variable is the dummy of FDI in Asian countries; this takes the value of one if the firm conducts FDI in Asian countries and zero otherwise, and we estimate the dummy by using a linear probability model including 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 and Column (3) 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 on FDI in North America. In the estimation, the dependent variable is the FDI dummy in North America; this takes the value of one if the firm has FDI in North America and zero otherwise. The results of all firms given in Column (4) show the coefficient for Katz-Bonacich centrality significantly positive; all the coefficients for the other covariates are also significantly positive. Column (5) shows the results for small firms and Column (6) the results for large firms. In both estimations, the coefficients for Katz-Bonacich centrality and the other variables are still significantly positive. Furthermore, the magnitude of Katz-Bonacich centrality is still larger for large firms than for small firms. Very interestingly, the magnitude of Katz-Bonacich centrality is much smaller than that for FDI in Asian countries in every estimation (baseline, small firms, and large firms). The effect of transaction networks on FDI decisions is much more strong in Asian countries than in North America.

Recently, Japanese firms have been conducting vast FDIs in China. Columns (7) to (9) in Table 2 give the results of Japanese FDI in China. Column (7) shows the baseline, Column (8) the small firm, and Column (9) the large firm results. In every result, the coefficient for Katz-Bonacich centrality is positively significant, with magnitude still larger for large firms than for small firms. Further, the magnitude of Katz-Bonacich centrality is intermediate between the results of FDI in the Asian and North American countries in every estimation (baseline, small firms, and large firms).

4.3 Industry heterogeneity

Finally, to examine industry heterogeneity in FDI decisions, we estimate the equation by a two-digit industry classification in JSIC. Since separating the samples by industry would reduce the sample size and make it difficult to include prefectural fixed effects, we exclude prefectural fixed effect 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. This suggests that in most industries requiring intense production networks, the location of a firm in the interfirm network significantly affects the firm's FDI behavior.

5. Robustness

We have conducted analysis using 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 whole supply chain network **G**. We now check the robustness of the results by estimating the decay parameter of the Katz-Bonacich centrality.

To implement our estimation, we need to reduce the size of the adjacency matrix of the whole supply chain network. We restrict the samples by the number of employments. We extract the largest 15,000 firms based on number of employments from the sample and conduct our estimation using the following procedure.

First, we fix γ and calculate the Katz-Bonacich centrality with the given γ. Next, we estimate equation (15) by 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.

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. Further, the point estimate of γ is 0.015 and positively significant. This implies that network length has a statistically significant decay effect on FDI decisions. Furthermore, we cannot reject the null hypothesis that our point estimate of γ is equal to the inverse of the largest eigenvalue of adjacency matrix (0.019) that is used for calculating eigenvalue centrality at the conventional level. This strongly suggests the validity of specifying decay parameter by the inverse of the adjacency matrix eigenvalue and the results of the previous section that used this eigenvalue centrality.

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 the binary choice of firms of whether to invest or not by using a coordination game on a fixed network with incomplete information on the firms' profits. When we assume a uniformly distributed stand-alone profit f with a sufficiently wide support, the model has a unique equilibrium represented by the Katz-Bonacich centrality measure, which captures the diffusion of the strategic FDI threshold both from direct and indirect relationships of the network.

Then, we conducted empirical tests for the theoretical hypothesis of the model with large disaggregated data of Japanese firms and successfully verified that the Katz-Bonacich centrality of each firm has a significantly positive effect on FDI, as our theory anticipated. Further, 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 and industry-specific effects, and headquarters' locations. These estimations also show that the impact of Katz-Bonacich centrality is relatively larger for large firms than for small firms. Note that most of our estimations employ the special case of Katz-Bonacich centrality (eigenvalue centrality) obtained by specifying the decay parameter with the inverse of the largest eigenvalue of the adjacency matrix of whole supply chain network. We then estimate decay parameter in the smaller sample, and confirm the validity of using eigenvalue centrality as a proxy for Katz-Bonacich centrality. From these results, Katz-Bonacich centrality gives us a good sketch for the equilibrium outcome of the strategic interaction between firms, and its influence is inevitably important when discussing their FDI.

Finally, a few problems remain to be solved in our model, although existing evidence justify part of them. First, although we suppose simultaneous decision making of firms and therefore neglect the effect of firms' observation on their partners' FDI, an extension to dynamic sequential games considering such observations is a potentially important issue. The estimation of such a dynamic model will enable us to identify the effect of expectations from that of observations. Second, we assume restricted information of firms, by which the firms are aware of only the structure of their network but not the attributes of others. However, the FDI of firms will be naturally influenced by some easily accessible information of their partners, such as their industries and scales. To consider such effects on equilibrium decision making, we must apply centrality measures that are further extended by the weighted attributes of each player, such as those presented by Ballester and Calvó-Armengol (2011). However, for these extensions, we will always have to face restrictions in both data availability and burden of computation. The latter is particularly intractable, because we cannot calculate inverse matrices using our large sample data, although this is essential for estimating network models such as ours. Reducing the sample size is therefore inevitable for implementing such extended analyses, as shown in section 5 of this paper, but we must be careful to avoid sample bias in such treatment of data.

References

1. Bajari, P., Hong, H., Krainer, J., and Nekipolov, D. (2010), "Estimating static models of strategic interactions," Journal of Business and Economic Statistics 28, 469-482.

2. Baldwin, R. and Okubo, T. (2012), "Networked FDI: sales and sourcing patterns of Japanese foreign affiliates," RIETI Discussion Papers No. 12027.
3. Ballester. C., Calvó-Armengol, A., and Zenou, Y. (2006), "Who's who in networks: wanted the key player," Econometrica 74(5), 1403-1417.
4. Ballester, C. and Calvó-Armengol, A. (2011), "Interactions with hidden complementarities," Regional Science and Urban Economics 40(6), 397-407.
5. Belderbos, B. and Carree, M. (2002), "The location of Japanese investments in China: agglomeration effects, Keiretsu, and firm heterogeneity," Journal of the Japanese and International Economies 16, 194-211.
6. Bloch, F. and Quérou, N. (2013), "Pricing in social networks," Games and Economic Behavior 80, 443-461.
7. Bonacich, P. (1987), "Power and centrality: a family of measures," American Journal of Sociology 92(5), 1170-1182.
8. Calvó-Armengol, A., Patacchini, E., and Zenou, Y. (2009), "Peer effects and social networks in education," Review of Economic Studies 76, 1239-1267.
9. Chang, S-J. and Park, S. (2005), "Types of firms generating network externalities and MNCs' co-location decisions," Strategic Management Journal 26, 595-615.
10. Chung, W. and Song, J. (2004), "Sequential investment, firm motives, and agglomeration of Japanese electronics firms in the United States," Journal of Economics & Management Strategy 13(3), 539-560.
11. Farrell, J. and Saloner, G. (1985), "Standardization, compatibility, and innovation," Rand Journal of Economics 16(1), 70-83.
12. Hackett, S. C. and Srinivasan, K. (1998), "Do supplier switching costs differ across Japanese and U.S. multinational firms?" Japan World Economy 10, 13-32.
13. Head, K., Ries, J., and Swenson, D. (1995), "Agglomeration benefits and location choice: evidence from Japanese manufacturing investments in the United States," Journal of International Economics 38(3-4), 223-247.
14. Helpman, E., Melitz, M. J., and Yeaple, S. R. (2004), "Export versus FDI with heterogeneous firms," American Economic Review 94(1), 300-316.
15. Katz, L. (1953), "A new status index derived from sociometric analysis," Psychometrika 18, 39-43.
16. Manski, C. F. (1993), "Identification of endogenous social effects: the reflection problem," Review of Economic Studies 60(3), 531-542.
17. Reid, N. (1995) "Just-in-time inventory control and the economic integration of Japanese-owned manufacturing plants," Regional Studies 29, 345-355.
18. Yamashita, N., T. Matsuura, and K. Nakajima (2013), "Agglomeration effects of

inter-firm backward and forward linkages: evidence from Japanese manufacturing investment in China," Keio/Kyoto Global COE Discussion Paper Series, DP2012-042.

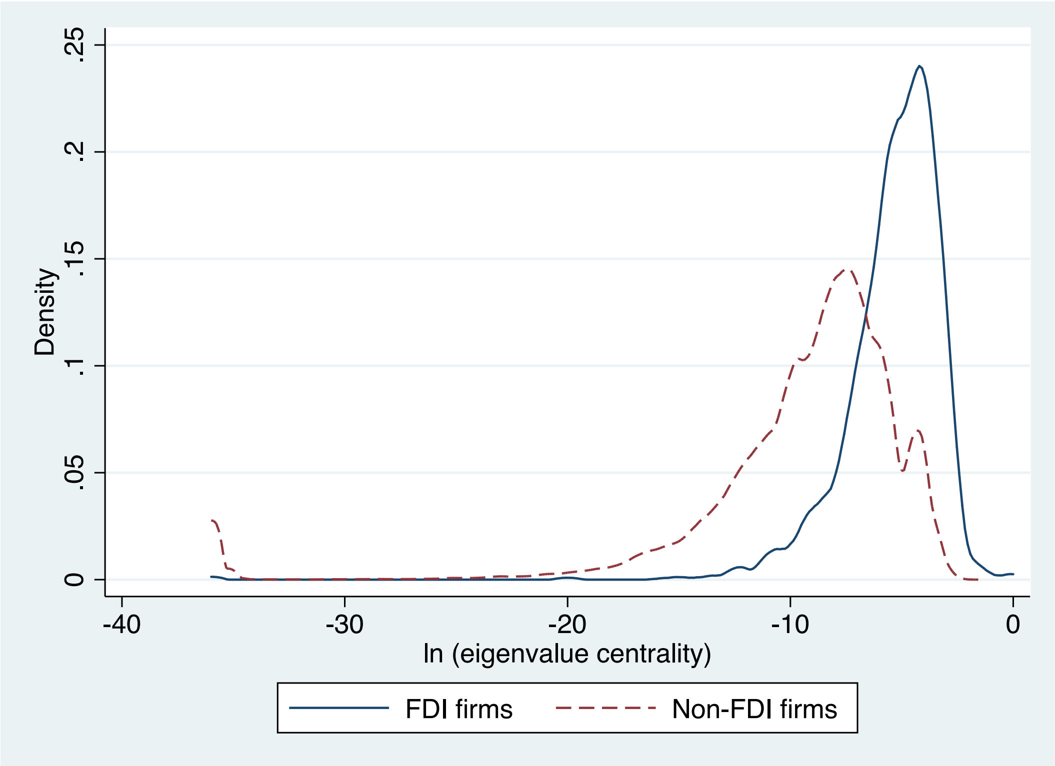

Figure 1 Distribution of Katz-Bonacich centrality

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 square parentheses.

Table 3 Results by FDI destinations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent	FDI to South East Asia	FDI to South East Asia	FDI to South East Asia	FDI to North America	FDI to North America	FDI to North America	FDI to China	FDI to China	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)	Constant	Gamma	Observations
0.044***	0.039***	0.015***	-0.073***	0.237***	-0.699***	0.015**	15000
[0.01]	[0.004]	[0.003]	[0.002]	[0.019]	[0.095]	[0.006]	

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