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

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**Abstract:** This study investigates how structure of supply chain network of the domestic market influences FDI of firms embedded in the network. We firstly describe a binary choice of firms whether invest or not by a coordination game on fixed network with incomplete information on part of firms' profit, and addressed that the unique equilibrium of the game is represented by Katz-Bonacich centrality measure which captures both direct and indirect effects from the network. We also give empirical tests for the theoretical hypothesis with a large sized disaggregated data of Japanese firms, and verified that Katz-Bonacich centrality of each firm has a significantly positive effect on its FDI even when the sector-specific fixed effects and other attributes are controlled, as our theory anticipated.

*Key words*: *FDI, network game, supply chain, Katz-Bonacich centrality.*
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## 1. Introduction

For the companies considering to establish affiliates in a foreign market, finding good procurement for materials and sales channels for their products are big issues. Companies starting new transaction with local companies sometime suffer from various kinds of frictions like mismatch in design and quality of products and delivery system of them (e.g. Reid 1995); adjusting them is also difficult because of miscommunication between firms with different commercial custom and technical basis. Some firms therefore trade with the affiliates with the same home country to replicate the transaction partnerships in the domestic market (Hacket and Srinivasan 1998). Such replication of transaction will yield profit to both sides of transaction not only by smoothing trades of products but also by exchanging various useful information on the market and the government. As a result, it is considered that FDI of a firm, including expect for future investment as well as completed ones, stimulates investment of other firms in the same market through a supply-chain network which is a set of whole trades in the domestic market.

The main concern of the present study is how firms' FDI to a region is affected by the supply-chain network in the domestic market. Most of the literature about FDI like Helpman et al. (2004) focused on attributes of firms like productivity and those of invested region like barrier of international trade. Furthermore, a string of studies on country-of-origin FDI addressed agglomeration of investment from the same home countries attracts further investment from the country (e.g. Head et al. 1995, Chang and Park 2005, Chung and Song 2004). Specifically, the result of Belderbos and Carree (2002) about influence of group companies (*keiretsu*) of Japanese firms on FDI is implying some kinds of supply-chain-network effect. Further, Yamashita et al. (2013) uses actual transaction relationship data, instead of keiretsu data, and found the positive influence of transaction relationship on location decision. However, these studies only capture collective effects of supply-chain-networks and, to the best of the authors' knowledge, few studies have directly focused on the effect of network structure itself. We contrarily highlight how the decision on FDI of each individual firm is affected by detailed structure of entire network and its position in that structure. We firstly investigate this issue with a game-theoretic model, and then provide an empirical test for the result of it with a disaggregated data of Japanese firms.

Games with network employed in our study are actively applied to various issues in recent years, such as for technological choice of firms and education of households. To describe decision of firms whether they invest or not to a region, a theoretical network game presented by Bloch and Quérou (2012) is applied for our empirical study on FDI with some extension. Our model considers a simultaneous choice on a fixed network in which a pair of directly linked firms, interpreted as business partners in the domestic market, have incentives to invest together with each other. Furthermore, part of profit from FDI is assumed to be private information of each firm that is unobservable to the others, then decision of each firm relies on an expectation for partners' uncertain decision. In our model the stand-alone benefit yielded outside the transaction is uncertain as Bloch and Quérou (2012) supposed, while we suppose that the benefit of transaction also differs among firms and is private information.

In our incomplete information game, each firm expects the decision of its direct partners via expectation for all the indirect partners; i.e. partners of partners and then their partners, and so on. Through such diffusion of expectation over the network in various routes and it converges to a strategic equilibrium. Both Bloch and Quérou (2012) and this study demonstrated that under an assumption of uniformly distributed stand-alone payoffs the game has unique Bayesian-Nash equilibrium in which separated strategy of each player is characterized by its Katz-Bonacich centrality measure on network and more "central" players are more likely to invest[12]. Katz-Bonacich centrality, denoting how a node is accessible to all others[3], is also applied to describe Nash equilibrium of network games by some of our companion papers: Ballester, Calvó-Armengol and Zenou (2006: hereafter BCZ) and its empirical extension by Calvó-Armengol, Patacchini and Zenou (2009: hereafter CPZ). This is because the model of BCZ and ours has similar mathematical forms: a quadratic (expected) payoff function and hence 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 ours considers discrete choice (i.e. whether invest or not). Since the binary choice like ours cannot be simply explained by BCZ's model, we then extend the range of issues to which the Katz-Bonacich centrality is applicable.

Our final destination is to show an empirical evidence of the above theoretical

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1 Bloch and Quérou (2012) investigate whether each consumer embedded on network purchases one unit of indivisible network good or not. On the other hand, In Itoh (2012)'s binary choice model firms choose one location point from two (or more) asymmetric regions.

2 This measure was firstly proposed by Katz (1953) and generalized by Bonacich (1987), hence Ballester et. al. (2010) calls the index after their names.

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

hypothesis. Although the effect of Katz-Bonacich centrality of firms on FDI is therefore our primary focus, other attributes of firms like productivity is also important for firms' decision (e.g. Helpman et al. 2004). The incentive for FDI and effect of centrality will significantly differ among industry despite the entire network consists of firms of various industries. Furthermore, those attributes might correlate to the centrality of the firm. For example, a high productive or large firm might be also an important firm in the supply chain network. If so, estimate of the role of the centrality will be distorted if such variables are omitted in the estimation. Considering these empirical viewpoints, we extend the basic model with supposing some restricted information of firms so that the effect of non-network attributes of firms and industry specific influence on FDI are also tractable as well as Katz-Bonacich centrality[4].

We use a disaggregated data of more than 110,000 Japanese firms in manufacturing sector. In addition to various information of each individual firm like number of affiliates by country, number of employees, total product and credit ranking, information on main trading partners of each firm is also available for detailed composition of supply-chain network. This network information allows us to calculate Katz-Bonacich centrality representing detailed network structure of whole Japanese manufacturing sector with capturing inter-sectoral effect among small sectors.

Our empirical strategy is regressing firms' FDI behavior on the Katz-Bonacich centrality. Because of the computational burden, first, we use the eigenvalue centrality that is the special case of the Katz-Bonacich centrality, instead of using original Katz-Bonacich centrality. Then, we calculate original Katz-Bonacich centrality measure and estimate the role of the centrality on the FDI decision by restricting samples to the larger firms to check the robustness of the results.

Our empirical strategy imposes two critical assumptions. One is the simultaneous decision-making on the choice of FDI, and we consider the static game situation. The other one is the exogeneity of the network structure on the FDI decision. That is, the FDI behavior itself does not matter to the structure of the transaction network. However, these settings are considered to be appropriate for describing FDI of Japanese firms for

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4 Despite starting with similar theoretical model with ours, CPZ did not apply Katz-Bonacich centrality for their empirical tests. This is because effect of the value of error term diffuses via network in their complete information game and hence the problem of autocorrelation appears. On the contrary, our incomplete information simultaneous move game can escape such problem and we can describe the equilibrium probability of FDI by Katz-Bonacich centrality.

some reasons[5]. First, FDI of Japanese firms have been rapidly growing in these two decades; specifically in east Asian countries that increased more than twice in the decade of 1990s. The fact that most of Japanese firms' FDI concentrates within a limited span means that they have to promptly make their decision for FDI to rapidly growing markets even partners' decision might be sometime uncertain. Second, we have already seen the fact that affiliates have big incentive to replicate the relationship in the home country rather than starting new trading, and hence what matters for firms' FDI is the supply-chain network in the domestic market; such trunk relationship will be negligibly influenced by investment and is stable at least in the short-run. We therefore give fixed network although endogeneity problem of network is a considerable problem for such kind of research.

In the results, we successfully address significantly positive effect of Katz-Bonacich (eigenvalue) centrality on FDI with controlling various individual attributes of firms including fixed effects of each of four-digit sector[6]. Further, we confirm the robustness of the baseline results and the validity of using eigenvalue centrality by conducting estimation using the original Katz-Bonacich centrality.

The remainder of the paper is structured as follows. Section 2 gives a static coordination game with network and a theoretical examination for it. Then, section 3 presents data and framework for empirical analysis. Section 4 discusses about the baseline empirical results by using the eigenvalue centrality, and section 5 discusses the robustness of the baseline analysis by restricting samples to the larger firms. Finally, section 6 concludes the paper.

## 2. Model

This section presents a simultaneous move game with incomplete information to describe the decision of FDI by firms which prefer coordinated investment with their trading partners. Although our theoretical framework is similar to Bloch and Quérou (2012)'s, we consider incomplete information on transaction profit as well as stand-

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5 On the other hand, a few studies analyses dynamic games in which players sequentially change their choice with observation for others' choice (Morris 2000, Jackson and Yariv 2007), and such model is also applied for some empirical studies such as of an juveniles' smoking behavior by Nakajima (2007).

6 Manski (1993) addressed a detailed methodology for estimate spillover effects on networks while we simply estimate the influence of calculated centrality based on the theoretical results of ours.

alone profit. In the latter half, we translate their model into an empirically testable form considering various attributes of individual firms.

### 2.1 Inter-firm transaction and profit of affiliates

The set N = {1, 2, ..., n} is a finite set of risk-neutral firms which have a nationality of the home country (i.e. Japan), and an n×n matrix **G**={$\phi_{ij}$} denotes exogenously given transaction relationship among them: adjacency matrix of the supply-chain network in the domestic market. The parameter $\phi_{ij}$ equals one if firms *i* and *j* are trading and equals zero otherwise. We assume **G** is symmetric and then $\phi_{ij}=\phi_{ji}$ holds, and assume $\phi_{ij}= 0$ holds for diagonal components.

In the next we denote the set of the domestic firms having an affiliate in a foreign region *r* (e.g. eastern Asia) by $N_r \subset N$. We suppose that the affiliates have the same facilities as their domestic companies; hence a pair of affiliates can trade to yield a positive profit only if their parent companies are trading in the domestic market[7]. Suppose that a firm gains a constant additive profit from transaction with any other firms such as through efficient supply and procuration of an intermediate goods or service. We assume that the additive profit from transaction, denoted by $\tau_{ir} > 0$, differs among firms but is never influenced by any other transaction. Therefore, affiliates $i$ and $j$ must trade if $i, j \in N_r$ and $\phi_{ij}>0$ hold. At that time, the total profit of firm *i* gained from all transactions is denoted as $\tau_{ir} \sum_{j=1}^{n} \upsilon_{jr}\phi_{ij}$, where $\upsilon_{jr}$ is one when firm *j* has an affiliate in region *r* or $j \in N_r$, while zero otherwise.

The total profit of affiliate *i* in region *r* is given as follows;

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

Where $\upsilon_r = (\upsilon_{1r}, \dots, \upsilon_{jr})$ is a vector of investment in region *r*. Furthermore, $z_{ir}$ is a stand-alone profit of affiliate *i* in region *r* that is independent from transaction (Farrell and Saloner 1986). Stand -alone profit is influenced from economic condition of region *r* and attributes of individual firms, such as investment cost in region *r,* international trading costs like tariffs and transportation cost, and demand for firm *i*'s products by consumer and firms in *r*. This study assumes that $z_{ir}$ includes any other profit source

[7] If firm *i* invests to region *r* while its partner *j* doesn't, *i* must give up transaction to *j*'s affiliate and must choose whether it trades with *j*'s affiliate in the home country or finds a new alternative partner in region *r*. However, the former case requires tariffs and transportation costs while the latter causes loss from mismatches. These profits are therefore less than that from trade with the original partners; this study assumes their additional profit as zero.

except for the transaction on the network. Furthermore, a company gains zero profit if they have no affiliate.

We assume that only firm $i$ knows its own $\tau_{ir}$ and $z_{ir}$; hence marginal transaction profit and stand-alone profit of each firm are private information. Firms have some probabilistic information on others' $\tau_{ir}$ and $z_{ir}$, which is common knowledge among all the firms but is not guaranteed to be true because of biased and restricted information source. This setting gives an incompleteness of information to our model.

## 2.2 Decision making on FDI

Firms face a binary choice whether they should invest or not to region $r$ to establish an affiliate there. The decision making on investment to region $r$ must be independent from the other investments because the firms can invest to more than one regions and their profits are independent each other. All firms make their decision at the same time, hence firms intend to maximize expected value of the total profit. The present study assumes that entire network structure $\mathbf{G}$ is public information for all firms while only firm $i$ knows its own $z_{ir}$ and $\tau_{ir}$ at the timing of the decision making. In other words, firms know relationship of all other firms but have no information on their attributes. Therefore, the other firms only have some probabilistic expectation for the decision of other firms with given information: distribution functions of $z_{ir}$ and $\tau_{ir}$. At that time we suppose that firms expect $z_{ir}$ and $\tau_{ir}$ are independent from each other and any other observable variables.

At the timing of the decision making, the expected total profit of firm $i$'s investment in region $r$ is denoted as follow;

$$E(\pi_{ir} \mid \mathbf{p}_r, \mathbf{G}, z_{ir}, \tau_{ir}) = \tau_{ir} \sum_{j=1}^{n} p_{jr}\phi_{ij} + z_{ir} \tag{2}$$

where $p_{jr} = \Pr(v_{jr} = 1)$ denotes expectation of other firms on $j$'s probability of investing to $r$, and $\mathbf{p_r} = (p_{1r}, \dots p_{nr})$ is vector of them. Firm $i$ establishes an affiliate only when $\mathrm{E}(\pi_{ir} | \mathbf{p_r}, \mathbf{G}, z_{ir}, \tau_{ir}) \geq 0$ holds because the firm gains zero profit without investment. At that time, for given expectation vector $\mathbf{p_r}$, each firm has a best-response threshold $\theta_{ir}$ with which firms decide investment if and only if $z_{ir}/\tau_{ir} \geq \theta_{ir}$ holds; hence denoting best-response strategy of each firm is equivalent to denoting the threshold. From equation (2), best response threshold of firm $i$ is described as follows.

$$\theta_{ir} = -\sum_{j=1}^{n} p_{jr}\phi_{ij} \tag{3}$$

This equation implies that higher expectation for partners' investment decreases $\theta_{ir}$ and hence increases its own probability to invest. Note that lower threshold means higher incentive for investment. When firm $i$ is expected to decides according to equation (3), others' expectation on $i$'s probability for investment is denoted as follows;

$$p_{ir} = \Pr(z_{ir}/\tau_{ir} \geq \theta_{ir}) = \int_{-\infty}^{+\infty} l_r(\tau_{ir})[1 - F_r(\tau_{ir}\theta_{ir})]d\tau_{if} \tag{4}$$

Where $\mathrm{F_r}(\cdot)$ is accumulated distribution function of $z_{ir}$ and $\mathrm{l_r}(\cdot)$ is density function of $\tau_{ir}$. All the firms have common knowledge on these distribution functions and are informed that they are independent, although information of them is unnecessarily true. When a vector of threshold $\boldsymbol{\theta}_\mathbf{r}=(\theta_{1r},\ldots,\theta_{nr})$ is given, we can describe firm $i$'s best response threshold to others' thresholds is denoted as follows from equations (3) and (4).

$$\theta_{ir} = -\sum_{j=1}^{n}\left[\int_{-\infty}^{+\infty} l_r(\tau_{jr})[1 - F_r(\tau_{jr}\theta_{jr})]d\tau_{jr}\right]\phi_{ij} \tag{5}$$

By making a system of simultaneous equations consisting of $n$ equations of equation (5) and by solving it by $\boldsymbol{\theta}_\mathbf{r}$, we can derive the equilibrium of strategies of all firms.

### 2.3 Equilibrium under uniform distribution of random profit

Now we specify distribution of $z_{ir}$ in order to derive specific equilibrium. Supposing that firms expect that $z_{ir}$ is uniformly distributed within $[-a+\bar{z}_r, a+\bar{z}_r]$, the distribution function is denoted as,

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

where we assume $a>0$. Expected value of $z_{ir}$ denoted by $\bar{z}_r$ can be both positive and negative. We also suppose $\bar{z}_r - a < 0$ and $\bar{z}_r + a > (n-1)\tau_{ir}^m$, where $\tau_{ir}^m$ is the maximum value of $\tau_{ir}$. These assumptions guarantee the sufficiently wide support of $z_{ir}$ in which the best response threshold is always within $[-a+\bar{z}_r, a+\bar{z}_r]$ because $\theta_{ir} \in [0, n-1]$. It is interpreted that each firm never promises that it definitely makes a choice regardless of its stand-alone profit, even when the firm trading with all others expects that all the partners choose a choice in probability one. At that time, equation

(5) is rewritten as follows;

$$\theta_{ir} = -\sum_{j=1}^{n} \frac{a + \bar{z}_r - \bar{\tau}_r \theta_{jr}}{2a} \phi_{ij} \tag{7}$$

Where $\bar{\tau}_r$ is expected value of $\tau_{ir}$. We can denote simultaneous equation system of equation (7) by vector as

$$\boldsymbol{\theta}_\mathbf{r} = -\gamma\rho_r \mathbf{G1} + \gamma \mathbf{G} \boldsymbol{\theta}_\mathbf{r} \tag{8}$$

Where **1** is column vector of one, and we denote $\gamma = \bar{\tau}_r/(2a)$ and $\rho_r = (a + \bar{z}_r)/\bar{\tau}_r$ to simplify the notation. We should note that the above best-response functions denoted by equations (7) and (8) hold only when $-a + \bar{z}_r \leq \bar{\tau}_r \theta_{ir} \leq a + \bar{z}_r$ is satisfied for all *i,* but it is promised by the assumption of the sufficiently wide support of $z_{ir}$.

We should note that the above linear best-response function is very similar to that of BCZ, this is because multiplier of the linear payoff and linear probability yields our quadratic expected payoff that is similar to the one given in BCZ. Conclusively, the following equilibrium of our model is mathematically identical to that of BCZ, while the two models start from the different issues.

The equilibrium of the model, denoted as $\boldsymbol{\theta}_\mathbf{r}{*} = (\theta_{1r}^*, ..., \theta_{nr}^*)$, is derived by solving equation (8) by $\boldsymbol{\theta}_\mathbf{r}$. The system of linear equations represented in equation (8) has single interior solution if $\gamma$ is smaller than the inverse of the largest eigenvalue of $\mathbf{G}$[8]. Therefore, the strategies of firms necessarily converge to an unique interior equilibrium because any corner solution (i.e. $p_i$=1 or 0 for any $i$) can be omitted by the assumption of sufficiently wide support of $z_{ir}$ [9]. The equilibrium of the model is derived as follows;

$$\begin{aligned} \boldsymbol{\theta}_\mathbf{r}{*} &= -\rho_r \gamma \mathbf{G}(\mathbf{I} - \gamma\mathbf{G})^{-1}\mathbf{1} \\ &= -\rho_r - \sum\nolimits_{k=1}^{\infty} \gamma^k \mathbf{G}^k \mathbf{1} \end{aligned} \tag{9}$$

In equation (9), the equilibrium strategy of each individual firm is described as follows.

$$\begin{aligned} &\theta_{ir}^* = -\rho_r - b_i(\mathbf{G}), \\ \text{where} \quad &b_i(\mathbf{G}) = \sum\nolimits_{k=1}^{\infty} \sum\nolimits_{j=1}^{n} \gamma^k \phi_{ij}^{\{k\}} \end{aligned} \tag{10}$$

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[8] When $\boldsymbol{\theta}_\mathbf{r}$ diverges because $\gamma$ is larger than the largest eigenvalue, all firms definitely choose invest or not are both in equilibrium.

[9] The assumption of sufficiently wide support of $z_{ir}$ promises $\gamma < 1/(\mathrm{n} - 1)$. This restriction is actually more restricted than the one that $\gamma$ is smaller than the largest eigenvalue.

We should note that $\phi_{ij}^{\{k\}}$is *ij* component of $\mathbf{G^k}$ but not *k*-th power of $\phi_{ij}$. The function $b_i(\mathbf{G})$ in equation (10) is identical to a network measure called Katz-Bonacich centrality or alpha-centrality（Bonachich 1987; BCZ; Ballester and Calvo-Amengol 2009）. This measure is calculated by summing number of all *walks* of the network (i.e., 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 the Katz-Bonacich centrality is considering the influence from indirect relationship (i.e. the one from partners' partner) as well as from the direct partners; then entire network structure feedbacks to each node embedded there.

Our result represented in equation (10) implies more central players have larger incentive to invest for the following reason. Under the additively separable profit function given by equation (1), outgoing firms with many partners can potentially gain higher profit by FDI, hence other firms expect that such firms are more likely to invest. Furthermore, the partners of the outgoing firms also have large incentive to invest because they expect they can trade with the outgoing firms in the foreign markets with a high probability. When expectation for investment diffuses thorough any possible path in the network in such way, the more central player embedded in the hub of network receives larger influences, so called network externality.

Finally, other firms' expectation on *i*'s probability for investment in equilibrium is derived from equations (4) and (10) as follows;

$$p_{ir} = 2\gamma\rho_r + \gamma b(\mathbf{G}) \tag{11}$$

### 2.4 Attributes of firm and testable model

The final part of the section discusses how we should consider attributes of individual firms such as their productivities in our hypothesis, before we go to the empirical section. As we have mentioned, $z_{ir}$ is independent of network-based profit while influenced by various attributes of firm *i* as well as from economic conditions of region *r*[10]. Now we suppose a vector of attributes $\mathbf{X_i}=(x_{i1},\ldots,x_{im})$ which influences $z_{ir}$, and the

[10]For example, when product of the sector to which firm *i* belongs faces a growing demand in market *r*, such firm has big incentive to invest to the region. We give further detailed discussion on

following equation represents the true relation between $z_{ir}$ and $\mathbf{X_i}$'[11].

$$z_{ir}=\lambda_r+\boldsymbol{\omega}_\mathbf{r}\mathbf{X_i}'+\mu_{ir} \tag{12}$$

Where $\mu_{ir}$ is a random variable independent from $\mathbf{X_i}$' and $i$'s position in network, whose cumulative distribution function is denoted by $\mathrm{Q_r}(\mu)$. $\boldsymbol{\omega}_\mathbf{r}$ is vector of coefficients of each attribute, and $\lambda_\mathrm{r}$ is a parameter which is interpreted as an synthesis variable of economic condition of region $r$ giving the equivalent effect to all firms.

Furthermore, we suppose that $\tau_{ir}$ is actually deterministic and type specific parameter, and hence we denote $\tau_{ir}=\tau_{\mathrm{t}(i)r}$ where $t(i)$ is type of firm $i$. In particular, we specify the type of firms by industry and size (large or small) of them in the preceding sections.

Now suppose that there is an observer (i.e. the author(s) of this paper) who can observe $X_i'=(x_{i1},\ldots,x_{im})$ and industry of each firm, and knows distribution of $\mu_{ir}$. On the other hand, we suppose that firms have restricted information on distribution of $z_{ir}$ and $\tau_{ir}$, hence firms' behavior is still represented as equation (10). Firms consider that these variables are purely random and ignore influence of attributes[12]. At this time, firm $i$'s probability to invest that the observer prospects is derived as follows from equation (10) and (12);

$$\mathrm{P_{ir}^o}=\mathrm{Prob}\left(z_{ir}/\tau_{h(i)r}\geq\theta_{ir}^*\right)=1-\mathrm{Q_r}[-\tilde{\rho}_{h(i)r}-\tau_{h(i)r}b_\mathrm{i}(\mathbf{G})-\boldsymbol{\omega}_\mathbf{r}\mathbf{X}_\mathbf{i}'] \tag{13}$$

Where $\tilde{\rho}_{\mathrm{t}(i)r}=\lambda_\mathrm{r}+\tau_{\mathrm{t}(i)r}\rho_r$ represents a type-specific incentive for investing region $r$. In equation (13), probability for investment expected by the observer is described as a function of centrality and their other attributes of the firms. Note that equation (13) is different from equation (11) which represents the probability expected by firms without full information on others' attributes and equation (12). Since $\tau_{\mathrm{t}(i)}$ is positive, we can readily see $\partial\mathrm{P_{ir}^o}/\partial b_\mathrm{i}(\mathbf{G})>0$ from equation (13); hence centrality has positive effect on probability for investment as well as in equation (11). Further, $\frac{\partial\mathrm{P_{ir}^o}}{\partial\mathrm{x_k}}=\frac{\partial\mathrm{P_{ir}^o}}{\partial\mathrm{z_{ir}}}\frac{\partial\mathrm{z_{ir}}}{\partial\mathrm{x_k}}$

attributes of firms in the next section.

12 One reason for such insufficient information of firms is that they can observe no attribute of others. Although the assumption that $\mathrm{z_{ir}}$ including unobservable $\mathrm{X_i}$ is uniformly distributed might be failes information, we can justify it by assuming firms' information on $\mathrm{z_{ir}}$ is unnecessary true.

represents that attributes with positive effect on stand-alone profit increase probability for investment, and vise verse.

In the following section we challenge empirical tests for theoretical hypothesis represented in equation (13).

## 3. Data and Empirical Strategy

### 3.1 Data

We use the dataset compiled by a major credit research firm, Tokyo Shoko Research Incorporated (TSR). The dataset includes 826,169 large and small corporations in Japan and consists of two subsets: a dataset on firms' characteristics and a dataset on interfirm relationships. Field researchers of TSR, who not only utilize public sources such as financial statements, corporate registrations, and public relations documents, but also implement face-to-face interviews with firms, their customers and suppliers, and banks that extend loans to them collect necessary information for the dataset. The sub-dataset on firm characteristics includes information on a firm's 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 names of suppliers and customers of a firm. There exists an upper limit of 24 with regard to the number of counterparts each firm can report as its customers or suppliers. The total number of interfirm relationships is approximately four million. This dataset covers about half of the total of 1.52 million incorporated firms in Japan, and it describes actual intefirm relationship in Japan most comprehensively. The focus of this paper is manufacturing firm and it reduces sample size into 142,282.

We also use the dataset on the Japanese manufacturing foreign investments that was compiled by a major research firm, Toyo Keizai Shimpo sha (TKZ). The dataset contains information on locations (country and address), year invested, employment, name of owners and ownership ratio for whole foreign affiliations of Japanese firms.

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

[Table 1 here]

Totally, our dataset has 115,111 observations because merging between TSR and TKZ databases reduces samples. On FDI behavior, 2278 of total manufacturing firms are conducting FDI in 2010 (i.e, having at least one foreign affiliates at that period), and 2070 firms are conducting FDI to the South East Asian country. This suggests that the most of the FDI firms have affiliates in South East Asian countries[13].

### 3.2 Empirical strategy

To test the theoretical prediction presented by equation (13), we estimate the following equation,

$$\mathrm{FDI}_{ir} = \alpha_r + \beta_r \ln(\mathrm{centrality}_i) + \boldsymbol{\delta}_\mathbf{r}\mathbf{X}'_\mathbf{ir} + \varepsilon_{ir}, \tag{15}$$

where $\mathrm{FDI}_{ir}$ is the FDI dummy that takes one if firm $i$ is conducting FDI to region $r$, and zero otherwise; $\ln(\mathrm{centrality}_i)$ is the natural logarithm of Katz-Bonacich centrality, $\mathbf{X}'_\mathbf{ir}$ is the other covariates, and $\varepsilon_{ir}$ is the error term. Equation (15) is also applicable for pooled FDI data regardless of destination where each coefficient will be weighted average of corresponding ones in every destination. Further, if we estimate this equation with separated samples by industry and size of firms, estimated coefficients represent type-specific effects of centrality and other attributes on FDI.

To estimate this equation, we need to calculate Katz-Bonacich centrality. We calculate Katz-Bonacich centrality representing detailed network structure of whole Japanese manufacturing sector with capturing inter-sectoral effect among small sectors. Since, supply chain network is formed beyond the industry, a firm's FDI decision depends on the structure of the whole manufacturing transaction network rather than the network within the industry to which the firm belongs. For example, the FDI decision of a tire-producing firm that is classified to the rubber industry depends on the behavior of the other firms that belongs not only rubber industry, but also the other industries like motor vehicle industry.

Considering the network including whole manufacturing firms causes computational difficulty in calculating Katz-Bonacich centrality. The calculation of the Katz-Bonacich centrality requires calculating inverse matrix of the adjacency matrix. If we consider the

[13] Following the model, we assume that all these FDIs are simultaneously established in green-fields where there is no prior investor. This assumption is justified by the fact that FDI is rapidly increasing in these two decades.

whole manufacturing firms' transaction network, the adjacency matrix $\mathbf{G}$ has 115,111 $\times$115,111 elements. To avoid calculating the large inverse matrix, first, we use the other measure of the centrality instead of using the Katz-Bonacich centrality for the estimation. By assuming the value of the decay parameter $\gamma$ in eq. (10) by the inverse of the largest eigenvalue of $\mathbf{G}$, we obtain a measure so called eigenvalue centrality as a special case of the Katz-Bonacich centrality. The eigenvalue centrality does not need the calculation of the inverse matrix of the adjacency matrix, and is applicable for the huge network. Thus, in all the estimations of section 4, we use this eigenvalue centrality as a proxy for the Katz-Bonacich centrality. Then, in Section 5, in order to check the validity of using eigenvalue centrality and the robustness of the results, we fully estimate the empirical model including the decay parameter $\gamma$ by using a subset of whole supply chain network. Hereafter, we present the way of the baseline analysis that specifies the decay parameter by the inverse of the largest eigenvalue of the adjacency matrix of the supply-chain network $\mathbf{G}$.

We estimate eq. (15) by the logit and linear probability model. To assure the consistency of the estimates, we should argue on the concern of omitted variable bias and reverse causality.

One most important factor that causes omitted variable problem is the heterogeneity of the firm productivity. As pointed by Helpman et al. (2004), firm productivity strongly affects the firm's FDI decision. Further, the location in the supply chain network might be correlated to the firm's productivity. For example, high-productive firm may attracts many customers and increase the Katz-Bonacich centrality. To deal with this concern, we introduce labor productivity that is the sales divided by the number of workers, as a measure of firm-productivity. Other than the productivity, firms' performances, like product quality, credibility also might affect both the firms' FDI decision and the Katz-Bonacich centrality. We include firm age and listed firm dummy that takes one if the firm is listed firm, and zero otherwise. Further, we include the firm credibility variable as a measure of the firm's comprehensive evaluation that captures other unobserved firm-heterogeneity. The firm credibility is a measure that is created by TSR originally. Since, TSR is the credit research company, it provides information on a firm's credibility that represents the total performance of the firm, and is actually used in the choice of transaction partners by the user companies. The credibility value is ranged from zero to 100, and originally generated by TSR by using public sources of firm information and face-to-face interviews. We include this firm credibility into the regression equation to control firms' unobservable performances.

Network structure to which the agent belongs is one of the most important identification issues on empirical research of estimating network effect on the agents' behavior. In our case, one may concern about the FDI decision itself may affect the structure of the transaction network. For example, two firms that have no transaction relationships between them established their foreign affiliates at the same industry complex, then, after the establishment, their geographical proximity may facilitate starting transaction between them. In this case, FDI behavior itself affects the structure of the transaction network. However, newly starting transaction relationship between foreign affiliates is not so frequently occurred. As Reid (1995) pointed, companies starting new transaction with local companies sometime suffer from various kinds of frictions like mismatch in design and quality of products and delivery system of them, and then, as Hacket and Srinivasan (1998) pointed, trade with the affiliates with the same home country to replicate the transaction partnerships in the domestic market. Foreign affiliates have big incentive to replicate the relationship in the home country rather than starting new trading, and hence what matters for firms' FDI is the supply-chain network in the domestic market; such trunk relationship will be negligibly influenced by investment and is stable at least in the short-run. Actually, the majority of the FDI reason is still the request from transaction partners, and the existence of the request for the transaction partner itself suggests the difficulty of finding new transaction partners in foreign countries. Further, we take five-year lags between FDI and network data.

Further, Japanese firms have been conducting FDI to the various countries. In the estimation, first we pool every FDIs that are conducted various countries not only North American countries, European Unions, and Asian countries but also other small countries. In this case, the FDI dummy takes one if the firm is conducting FDI in regardless to the destination country, and zero otherwise. However, Baldwin and Okubo (2012) suggested that the foreign affiliations in Japan is making closed supply chain network within regions, like Southeast Asia, North America. To include those closed network activity, and then, we separately focus on the FDI behavior by region.

## 4. Empirical Results

### 4.1 Baseline results

This section shows the estimation results. First, Figure 1 shows the distribution of the logarithm of Katz-Bonacich centrality with specifying decay parameter by the inverse of the largest eigenvalue of adjacency matrix; through section 4 we employ this eigenvalue centrality. The figure clearly shows the difference between FDI and Non-FDI firms. The distribution is shifted rightward in the FDI firms. This strongly suggests that the firms that are conducting FDI have higher value of the Katz-Bonacich centrality.

[Figure 1 here]

Now, Table 2 shows the baseline estimation results using pooled FDI data regardless of their destinations. Column (1) shows the benchmark result that includes all manufacturing firms in Japan and estimated by the logit procedure. The coefficient for the Katz-Bonacich centrality is positively significant. This is consistent to our theoretical prediction that the increase of the Katz-Bonacich centrality increases the probability of conducting FDI. Further, we obtain reasonable coefficients for the other covariates. The coefficients for worker productivity, credit score, listed firm dummy, and firm age are positively significant. Those suggest the validity of the model specification.

Following the discussion of Helpman et al. (2004), firm productivity and its size can affect to the firm's FDI decision. We separately estimate equation (15) by the size of the firm. Column (2) shows the result on the sample that is restricted the number of workers are less than 100 (smaller firms), and Column (3) shows the result on the sample that is restricted the number of workers are more than 100 (larger firms). In both columns, the coefficients for Katz-Bonacich centralities are positively significant. Interestingly, the coefficient for Katz-Bonacich centrality in larger firms is larger than that in smaller firms. This is consistent for the prediction of Helpman et al. (2004). Because of the large fixed cost for FDI, smaller firms cannot pay for the FDI and are difficult to conduct FDI in the first place. Network structure has a weaker effect for the FDI strategy for the smaller firms. On the other hand, constraint of fixed cost for FDI is smaller in the larger firms, and the network structure has larger effect for the decision of FDI for larger firms.

[Table 2 here]

A firm's FDI decision depends on the products that the firm is producing. To control such heterogeneity of the products, we include industry fixed effects in the estimation equation whose results are presented in column (4) to (6). Specifically, we use four-digit industrial classification in JSIC, and estimate by the linear probability model to reduce computation time. Column (4) shows the results. Even controlling industry fixed effects, the coefficient for Katz-Bonacich centrality is still positively significant, and the coefficient for all of the other covariates are also positively significant. This strongly supports our theoretical prediction. Column (5) shows the small firm, and Column (6) shows large firm results. Very interestingly, the difference in the coefficient for Katz-Bonacich centrality between larger and smaller firms becomes much larger. By controlling industry fixed effects, the difference in the role of the transaction network on the decision of FDI between large and small firms becomes much more sharp.

In sum, our theoretical prediction is strongly supported by the empirical results. Katz-Bonacich centrality that represents the firm's importance in the position in the interfirm transaction network significantly and positively affects the decision of the firm's FDI, and it is robust even in controlling firm's industry classification.

**4.2 Heterogeneity in destination countries**

In the above analysis, we include every FDI regardless to their destinations. But as Baldwin and Okubo (2012) suggested, the purpose of FDI would be different by the destinations. We, then, focus on the specific destination countries of FDI. Table 3 shows results.

[Table 3 here]

Column (1) shows results on FDI to Asian countries. In the estimation, dependent variable is the FDI to Asian country dummy that takes one if a firm conducting FDI to Asian countries, and zero otherwise, and we estimate it by linear probability model with including industry fixed effects. The coefficient for the Katz-Bonacich centrality is significantly positive, and all of the coefficients for other covariates are also positively significant. Column (2) shows the small firm, and Column (3) shows large firm results.

In both estimations, the coefficients for Katz-Bonacich centrality and the other variables are still positively significant. Further, the magnitude of the Katz-Bonacich centrality is still larger in the result in large firms than in small firms. Column (4) to (6) shows results of the same estimations on FDI to North America. In the estimation, dependent variable is the FDI to North America dummy that takes one if a firm conducting FDI to North America, and zero otherwise. The all firm results represented in Column (4) shows the coefficient for the Katz-Bonacich centrality is significantly positive, and all of the coefficients for other covariates are also positively significant. Column (5) shows the small firm, and Column (6) shows large firm results. In both estimations, the coefficients for Katz-Bonacich centrality and the other variables are still positively significant. Further, the magnitude of the Katz-Bonacich centrality is still larger in the result in large firms than in small firms. Very interestingly, the magnitude of the Katz-Bonacich centrality is much smaller than the result in FDI to Asian countries in the every estimation (baseline, small firms, and large firms). The effect of the transaction network on the decision of FDI is much more stronger in the FDI to Asian countries than to the North America.

### 4.3 Industry heterogeneity

Finally, to examine the industry heterogeneity in the decision of FDI, we estimate the equation by two-digit industry in JSIC. The results are shown in Table 4.

[Table 4 here]

The coefficient of the Katz-Bonacich centrality is significantly positive in every industry other than Lumber and Wood Industry. This suggests in most industries, the location of a firm in the interfirm network significantly affects the firm’s FDI behavior.

## 5. Robustness

Previous analysis is conducted with using eigenvalue centrality by specifying decay parameter $\gamma$ of Katz-Bonacich centrality with the inverse of the largest eigenvalue of adjacency matrix of the whole supply-chain network $\mathbf{G}$. Now, we check the robustness of the results without exogenously specifying the decay parameter of Katz-Bonacich centrality.

To implement the estimation, we need to reduce the size of adjacency matrix of the whole supply-chain network. We restrict samples by the number of employments. We extract largest 15000 firms in the number of employments from sample, and conduct estimation by the following procedure.

First, we provide a candidate value of $\gamma$, and calculate the Katz-Bonacich centrality with the given $\gamma$. Next, we estimate the equation (15) by OLS by using the calculated Katz-Bonacich centrality, and obtain point estimates of $\beta$, and $\delta$ and sum of squared residual, $SSR$. We search the value of $\gamma$ that minimizes $SSR$, and the minimizers of the $SSR$ to be point estimates of $\gamma$, $\beta$, and $\delta$. The standard errors for the estimated parameters are obtained by 100 bootstrap iterations.

The results are shown in Table 5. First of all, the coefficient for the log of Katz-Bonacich centrality is positively significant at the 1 % level. Katz-Bonacich centrality still has a positive effect on FDI even without exogenously specifying the decay parameter. Further, the point estimate of $\gamma$ is 0.015 and is positively significant. This implies that the length of the network has a statistically significant decay effect on the decision of FDI. Furthermore, we cannot reject the null hypothesis that our point estimate of $\gamma$ is equal to the inverse of the eigenvalue of adjacency matrix (0.019) at the conventional level. This strongly suggests the validity of using the inverse of the eigenvalue of adjacency matrix as the decay parameter and the results in the previous section.

## 6. Concluding remarks

This paper investigates how structure of supply chain network of the domestic market influences FDI of firms embedded in the network. We firstly describe a binary choice of firms whether invest or not by a coordination game on fixed network with incomplete information on part of firms' profit. This model has a unique equilibrium which is represented by Katz-Bonacich centrality measure capturing both direct and indirect effects from the network when supposing stand-alone profit follows a uniform distribution with a sufficiently wide support. Following the theoretical results, we give empirical tests for the theoretical hypothesis with a large sized disaggregated data of Japanese firms, and verified that Katz-Bonacich centrality of each firm has a significantly positive effect on its FDI as our theory anticipated. This result is almost robust even when we consider FDI by destination and industry specific effects on FDI. These estimations also show us that impact of Katz-Bonacich centrality is relatively larger for large firms than for small firms. Furthermore, note that most of our estimation employs specific eigenvalue centrality instead of generalized Katz-Bonacich centrality and hence our results might depend on such assumption. However, our estimation for the decay parameter of Katz-Bonacich centrality does not reject the eigenvalue centrality; hence some robustness of our results is represented.

Finally, in the present model there remained a few problems to be solved although part of them is justified by the existing evidences. First, although we suppose a simultaneous decision making and hence neglect the effect of firms' observation on partners' FDI, an extension to dynamic sequential games considering such observation will be potentially important issue. Estimation of such dynamic model will enable us to identify the effect of the expectation from that of observation. Second, we suppose the restricted information of firms for which firms only know structure of network but do not attributes of others. However, firms' FDI will be naturally influenced from some easily accessible information on partners such as industries and scales of them. To consider such effects on equilibrium decision making, we must apply further extended centrality measures weighted by attributes of each player such as presented by Ballester and Calvó-Armengol (2010). However, for these extensions we always face restrictions both in data availability and burden of computation. The latter is particularly intractable because calculating inverse matrices in our large sample data is impossibly difficult in the present but is essential for estimating network models like ours. Reducing samples is therefore inevitable for implementing such extended analysis as in section 5 of this paper, but we must be careful enough to avoid sample bias in such treatment of data.

**References**


1. Baldwin, R. and Okubo, T. (2012), "Networked FDI: Sales and sourcing patterns of Japanese foreign affiliates", RIETI discussion papers No. 12027.
2. Ballester. C., Calvó-Armengol, A. and Zenou, Y. (2006), "Who's who in networks: wanted the key player", Econometrica 74(5), 1403-1417
3. Ballester, C. and Calvó-Armengol, A. (2010), "Interactions with hidden complementarities", Regional Science and Urban Economics 40(6), 397-406.
4. 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.

5. Bloch, F. and Quérou, N. 2012. Pricing in Social Networks, mimeo.
6. Bonacich, P. (1987), "Power and centrality: a family of measures", American Journal of Sociology 92(5), 1170-1182.
7. Calvó-Armengol, A., Patacchini, E. and Zenou, Y. (2009), "Peer effects and social networks in education", Review of Economic Studies 76, 1239-1267.
8. Chang, S-J. & Park, S. (2005), "Types of firms generating network externalities and MNCs' co-location decisions", Strategic Management Journal 26, 595-615.
9. Chung, W. & 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.
10. Farrell, J., and Saloner, G. (1985), "Standardization, Compatibility, and Innovation," Rand Journal of Economics 16(1), 70-83.
11. 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.
12. Head, K., Ries, J. & 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.
13. Helpman, E., Melitz, M.J. and Yeaple, S.R. (2004), "Export Versus FDI with Heterogeneous Firms", American Economic Review 94(1), 300-316.
14. Jackson, M.O., and Yariv, L. (2007), "The diffusion of behavior and equilibrium structure properties on social networks", American Economic Review (Papers and Proceedings) 97(2), 92 -98.
15. Katz, L. (1953), "A New Status Index Derived from Sociometric Analysis," Psychometrika 18, 39-43.
16. Kimura, F and Ando, M. (2005), "Two-dimensional fragmentation in East Asia: Conceptual framework and empirics", International Review of Economics & Finance 14(3), 317-348.
17. MacDuffie, J.P. (2011), "Inter-organizational trust and the dynamics of distrust", Journal of International Business Studies 42, 35-47.
18. Manski, C. F. (1993), "Identification of Endogenous Social Effects: The Reflection Problem", Review of Economic Studies 60(3),531-542.
19. Morris, S. (2000), "Contagion", Review of Economic Studies 67(1), 57-78.
20. Nakajima, R. (2007), "Measuring Peer Effects on Youth Smoking Behavior", Review of Economic Studies 74(3), 897-935.
21. Reid, N. (1995) "Just-in-time inventory control and the economic integration of

Japanese-owned manufacturing plants", Regional Studies 29, 345-355.

22. Tsui-Auch, L.S. & Mollering, G. (2010), "Wary managers: Unfavorable environments, perceived vulnerability, and the development of trust in foreign enterprises in China", Journal of International Business Studies 41(6), 1016-1035.
23. 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.
24. Yeaple, S.R., (2003), "The complex integration strategies of multinationals and cross country dependencies in the structure of foreign direct investment", Journal of International Economics, 60 (2), 293-314.

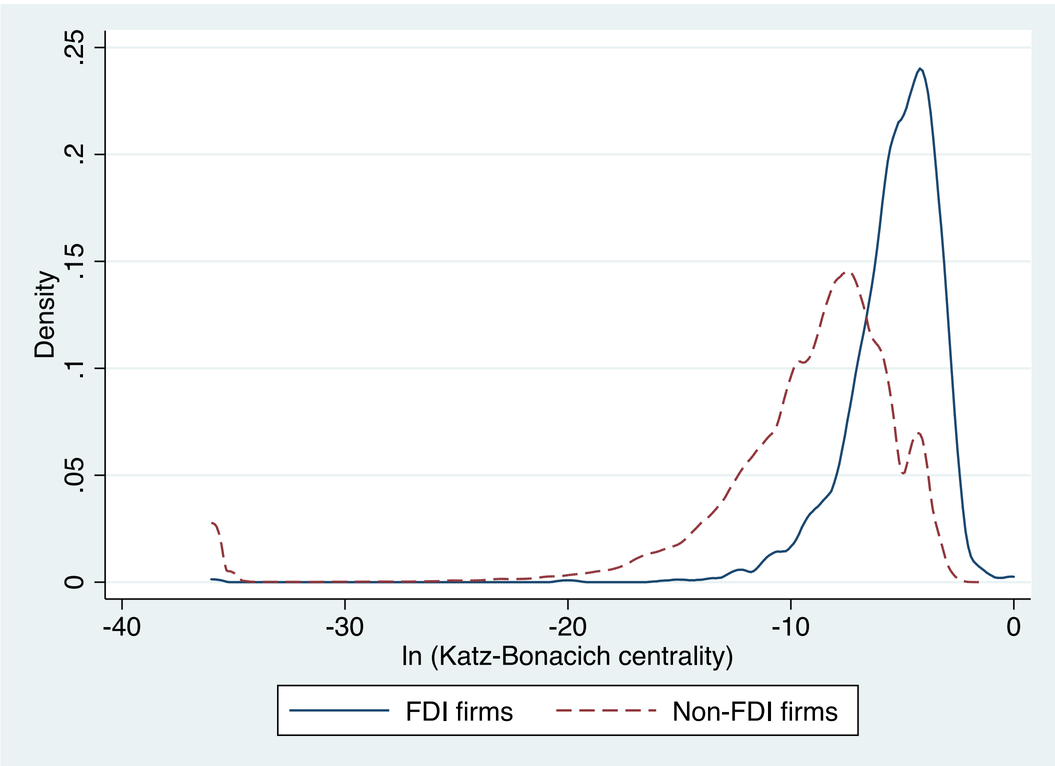


Figure 1 Distribution of Katz-Bonacich centrality

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 |

Note:

Table 2 Baseline results

| Dependent: FDI dummy | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| ln (Katz-Bonacich centrality) | 0.375*** | 0.220*** | 0.296*** | 0.000797*** | 0.000216*** | 0.0125*** |
| | (0.0177) | (0.0327) | (0.0200) | (0.0000404) | (0.0000267) | (0.00140) |
| ln (Labor productivity) | 0.603*** | 0.515*** | 0.573*** | 0.00775*** | 0.00243*** | 0.0604*** |
| | (0.0335) | (0.0663) | (0.0443) | (0.000487) | (0.000337) | (0.00456) |
| ln (Credit score) | 7.212*** | 6.572*** | 2.996*** | 0.123*** | 0.0269*** | 0.298*** |
| | (0.233) | (0.477) | (0.287) | (0.00441) | (0.00230) | (0.0286) |
| Listed firm dummy | 3.046*** | 3.639*** | 2.373*** | 0.695*** | 0.323*** | 0.538*** |
| | (0.102) | (0.640) | (0.0908) | (0.0132) | (0.0912) | (0.0149) |
| ln (Age) | 0.495*** | 0.216* | 0.353*** | 0.00717*** | 0.000916*** | 0.0323*** |
| | (0.0659) | (0.111) | (0.0664) | (0.000650) | (0.000347) | (0.00546) |
| Constant | -38.57*** | -35.95*** | -19.89*** | -0.581*** | -0.132*** | -1.820*** |
| | (0.891) | (1.754) | (1.191) | (0.0186) | (0.00953) | (0.123) |
| Industry FEs | No | No | No | Yes | Yes | Yes |
| Estimation | Logit | Logit | Logit | Linear Prob. | Linear Prob. | Linear Prob. |
| Sample | All | Small firms | Large firms | All | Small firms | Large firms |
| Observations | 114765 | 103914 | 10335 | 114765 | 103914 | 10335 |
| Adjusted R-squared | | | | 0.288 | 0.019 | 0.322 |

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

Table 3 Results by FDI destinations

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| 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 |
| ln (Katz-Bonacich centrality) | 0.000734*** | 0.000190*** | 0.0126*** | 0.000189*** | 0.0000285*** | 0.00656*** |
| | (0.0000390) | (0.0000257) | (0.00138) | (0.0000196) | (0.00000680) | (0.000918) |
| ln (Labor productivity) | 0.00713*** | 0.00207*** | 0.0576*** | 0.00239*** | 0.000438*** | 0.0241*** |
| | (0.000467) | (0.000316) | (0.00451) | (0.000268) | (0.000115) | (0.00311) |
| ln (Credit score) | 0.113*** | 0.0228*** | 0.300*** | 0.0543*** | 0.00474*** | 0.250*** |
| | (0.00422) | (0.00210) | (0.0280) | (0.00293) | (0.000941) | (0.0226) |
| Listed firm dummy | 0.649*** | 0.250*** | 0.504*** | 0.495*** | 0.111* | 0.426*** |
| | (0.0140) | (0.0856) | (0.0155) | (0.0154) | (0.0610) | (0.0161) |
| ln (Age) | 0.00641*** | 0.000956*** | 0.0258*** | 0.00248*** | -0.000163 | 0.0170*** |
| | (0.000624) | (0.000316) | (0.00530) | (0.000394) | (0.000167) | (0.00361) |
| Constant | -0.535*** | -0.113*** | -1.801*** | -0.247*** | -0.0226*** | -1.271*** |
| | (0.0177) | (0.00883) | (0.119) | (0.0124) | (0.00392) | (0.0940) |
| Industry FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| Estimation | Linear Prob. | Linear Prob. | Linear Prob. | Linear Prob. | Linear Prob. | Linear Prob. |
| Sample | All | Small firms | Large firms | All | Small firms | Large firms |
| Observations | 114765 | 103914 | 10335 | 114765 | 103914 | 10335 |
| Adjusted R-squared | 0.275 | 0.016 | 0.307 | 0.303 | 0.012 | 0.316 |

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