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Firm Performance and Asymmetry of Supplier and Customer Relationships [1]

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Abstract

This paper examines how transaction relationships are correlated with firm performance focusing on differences between supplier and customer relationships. In theory, both suppliers and customers positively affect sales and profit but their channels are different. A supplier set affects a firm's productivity lowering its marginal cost of production whereas a customer set only expands the size without affecting productivity. We consider a simple model of production with intermediate inputs, and examine whether theoretical implications are consistent with empirical evidence by estimating panel regressions using Japanese inter-firm transaction network data. We find that sales elasticities of in- and out-degree are positive. In- and out-degrees exhibit complementarity on sales implying that the marginal benefit of having more suppliers increases with the number of customers, and vice versa. Also, the elasticity of in-degree increases with size while that of out-degree is constant. This is also consistent with the theory, which predicts a leveraged effect of lowering a marginal cost when the scale is large.

Keywords: inter-firm network, firm growth, supplier, customer, network formation
JEL classification: D22, D85

[1]This study is conducted as a part of the Projects ”Dynamics of Inter-organizational Network and Geography” undertaken at Research Institute of Economy, Trade and Industry (RIETI) and ”Evaluation of Long-term Policy and Analysis of Growth Process of Japanese Small and Medium Enterprises” undertaken at the Small and Medium Enterprises Agency of the Ministry of Economy, Trade and Industry (METI).

1 Introduction

In the past decade, many empirical studies have revealed that our economy comprises complex interfirm production networks, which are the backbone of modern economic prosperity. Through the production networks, heterogeneous firms can trade comparative advantages to produce their goods efficiently. Since most of the intermediate goods and services are traded directly via firm-to-firm transactions rather than centralized markets, a firm's performance largely depends on the sets of its suppliers and customers.

This paper investigates asymmetric relationships of suppliers and customers on firm performance using a large-scale panel data of firm-to-firm transactions in Japan. To guide empirical analysis, we first build a simple production model, in which a firm combines labor and intermediate inputs from its suppliers to produce a final good. The final good is demanded by its customers with a constant elasticity. Assuming a CES (constant elasticity of substitution) production aggregator with constant returns to scale, the firm's marginal cost, and hence output price, decreases in the number of suppliers or the "quality" of suppliers. The firm's sales to each customer is additively separable, so the total sales is linearly increasing in the number of customers or the demand base of customers. Notice that the supplier set affects the network-augmented productivity whereas the customer set only affects the sales of the firm. This asymmetry implies a number of things. The marginal benefit of having more or better suppliers increases with size, but the marginal benefit of having more customers does not. Also, the theory predicts the complementarity between in- and out-degrees. Empirical evidence is consistent with the model. We find that both in-degree and out-degree are positively correlated with sales. In-degree exhibits a higher sales elasticity than out-degree.

A number of theoretical models of production network formation have been proposed recently. The model in this paper is a simplified partial equilibrium version of Baqaee

(2017) and Lim (2017). In the static part of Lim's model, firms have incentives to form as many supplier and customer relationships as possible due to "the love for variety" in the production process and constant returns to scale. He assumes that sellers must incur random fixed costs to maintain the transaction links to counterbalance the incentives. The model in this paper also assumes the fixed cost for maintaining a link but that is not a crucial assumption. Antras (2017) consider a model of global sourcing. In their framework, complementarity between productivity and the supplier set plays a key role for the strict hierarchy of outsourcing partners in a productivity dimension. Our model also exhibits a super-modularity between productivity and out-degree, but not in-degree. The complementarity between productivity and out-degree incentivizes productive firms to form more customer links. Due to the complementarity between out- and in-degrees, this leads to more supplier links.

Section 2 presents the theoretical framework in which a firm combines labor and intermediate inputs from its suppliers to produce a final good. After deriving a number of theoretical predictions, Section 3 confirms if they are consistent with empirical evidence estimating panel regressions. Section 4 concludes.

2 Model

2.1 Discrete Case

A firm combines labor and intermediate inputs to produce a differentiated good. Let $\mathbb{S}$ be the set of suppliers and S be the total number of suppliers. The firm buys a differentiated input from each supplier. Suppliers are indexed by j. Technology is defined by the following production function

$$y = \left[[\phi l]^{\frac{\sigma-1}{\sigma}} + \sum_{j=1}^{S} \alpha x_j^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where y is the quantity produced, l is the amount of labor, and x_j measures the intermediate input from a supplier j. The firm's fundamental productivity is given by ϕ, σ is the elasticity of substitution between intermediate inputs (assumed to be larger than one), and α measures the share of intermediate inputs.[1] Wage is used as a numeraire and let p_j denote the price of an intermediate input x_j. The marginal cost (MC) of the firm is given by

$$c = \left[\phi^{\sigma-1} + \alpha^{\sigma-1} \sum_{j=1}^{S} p_j^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{2}$$

Due to constant returns to scale, the marginal cost is constant, and is decreasing in productivity ϕ and intermediate input share α given the set of suppliers.[2] It is also decreasing in the number of suppliers. Consider the effect of adding another supplier whose price is p_k. The MC will be

$$\hat{c} = \left[\phi^{\sigma-1} + \alpha^{\sigma-1} \sum_{j=1}^{S} p_j^{1-\sigma} + p_k^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$$

Since the inside of the square bracket increases, $\hat{c} < c$ for any p_k. Access to an additional supplier includes the choice of not outsourcing ($x_j = 0$), so the MC is not increasing.

[1]We assume that $\sigma > 1$ and $0 \leq \alpha < 1$.

[2]

$$\frac{\partial c}{\partial \phi} = -\phi^{\sigma-2} \left[\phi^{\sigma-1} + \alpha^{\sigma-1} \sum_{j=1}^{S} p_j^{1-\sigma} \right]^{\frac{\sigma}{1-\sigma}} < 0$$

$$\frac{\partial c}{\partial \alpha} = -\alpha^{\sigma-2} \left[\phi^{\sigma-1} + \alpha^{\sigma-1} \sum_{j=1}^{S} p_j^{1-\sigma} \right]^{\frac{\sigma}{1-\sigma}} < 0$$

Due to the CES structure, the first small unit of x_j gives an infinite marginal return to the production, so x_j is positive as long as p_j is finite.

Demand for this firm comes from the final good consumer and other firms. The demand elasticity is σ for all firms and final good consumption, but the demand shifter is heterogeneous. The set and the number of customers are denoted by $\mathbb{C}$ and C respectively. For brevity, the final good consumer is also counted as one of the customers. They are indexed by i and e_i is the demand shifter of customer i. Hence, the quantity demanded by customer i is

$$x_i = e_i p^{-\sigma}$$

Due to the monopolistic competition, price is given by $p = \frac{\sigma}{\sigma-1}c$, where c is from (2). The sales of the firm is

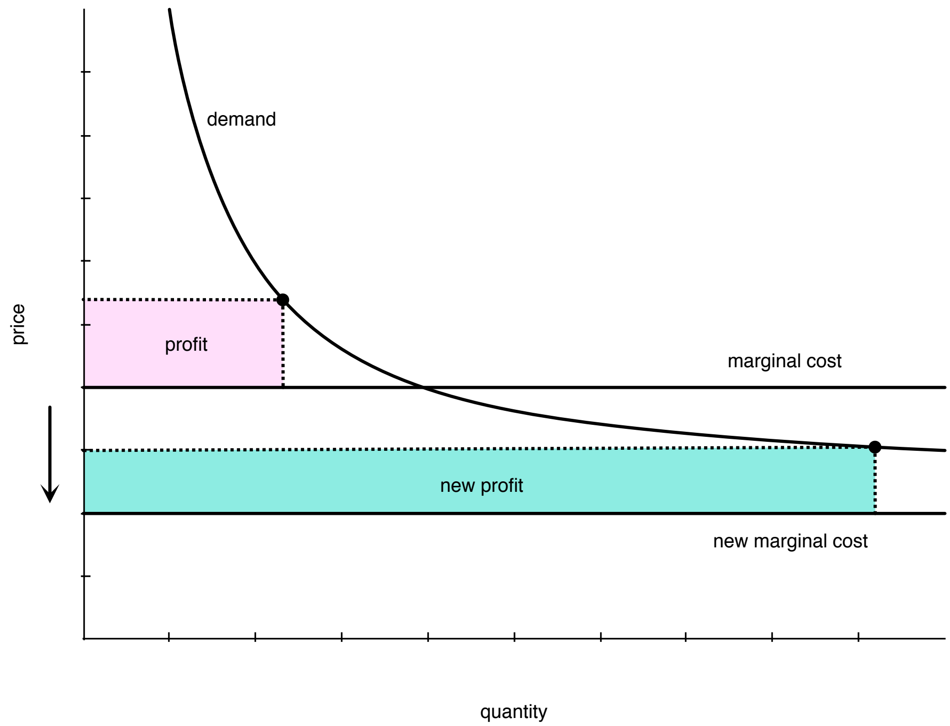
$$X = p^{1-\sigma} \sum_{i=1}^{C} e_i$$

and the profit is $\pi = \frac{X}{\sigma}$. Using (2), we can write

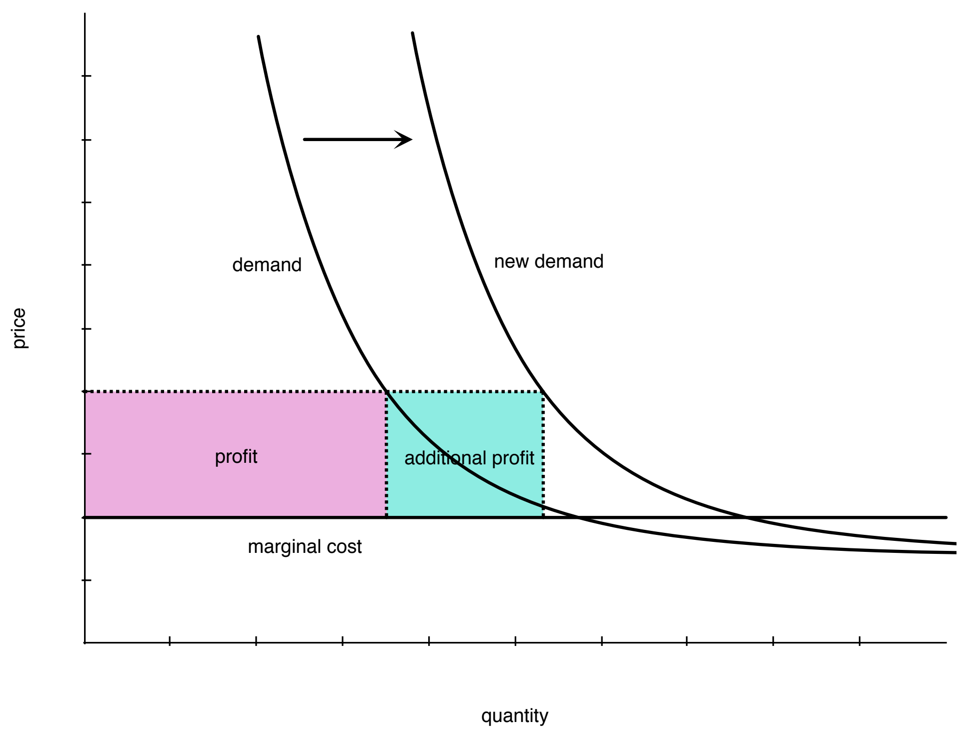
$$X = \lambda \sum_{i=1}^{C} e_i \left[\phi^{\sigma-1} + \alpha^{\sigma-1} \sum_{j=1}^{S} p_j^{1-\sigma} \right] \tag{3}$$

where λ is a constant. Sales (and profit) is increasing in $\sum_{i=1}^{C} e_i$ (aggregate demand base) and $\sum_{j=1}^{S} p_j^{1-\sigma}$ (aggregate intermediate productivity). Especially, sales is increasing in the extensive margin, but decreasing in the intensive margin of $\sum_{j=1}^{S} p_j^{1-\sigma}$.

Although both the numbers of customers and suppliers raise the sales and profit, underlying mechanism is different. The number of suppliers raises productivity by reducing the marginal cost. Since the demand is elastic, this increased productivity leads to sales growth. The number of customers only affects the scale and does not affect the productivity. The difference is illustrated in Figure 1. These results imply that the benefit of connecting to more or better suppliers is leveraged by the number of cus-



(a) Having more suppliers



(b) Having more customers

Figure 1: Differential effects of changing supplier and customer sets

tomers, but the benefit of connecting to an additional customer does not depend on the current customer set. The positive elasticity of in-degree (the number of suppliers) on sales should increase in size, but the elasticity of out-degree (the number of customers) should be constant.

Suppose there exists a partner-specific fixed cost for maintaining a transaction link. For a customer i, this is denoted by f_i and for a supplier j, this is denoted by g_j. Let N_c be the set and number (with abuse of notation) of potential customers the firm can choose, and define N_s for suppliers analogously. Then, the firm's optimal link formation problem is

$$\begin{aligned}\max_{I_i \in \{0,1\}_{i=1}^{N_c}, J_j \in \{0,1\}_{j=1}^{N_s}} \pi\left(\phi, I_1, .., I_{N_c}, J_1, ..., J_{N_s}\right) =& \frac{\lambda}{\sigma} \sum_{i=1}^{N_c} I_i e_i \left[\phi^{\sigma-1} + \alpha^{\sigma-1} \sum_{j=1}^{N_s} J_j p_j^{1-\sigma}\right] \\ & - \sum_{i=1}^{N_c} I_i f_i - \sum_{j=1}^{N_s} J_j g_j\end{aligned}$$

where I_i and J_j are indicator variables. In general, this optimization problem is complex, and one needs to search all possible combinations of I_i and J_j to find a global maximum. To simplify the analysis, we assume that the demand shifter is common across all customers ($e_i = e$ for all i) and the quality of intermediate inputs is common across all suppliers ($p_j = p$ for all j). Also, order customers according to their fixed costs f_i such that f_1 is the lowest. Similarly, order suppliers based on the values of g_j so that g_1 is the lowest. Due to this monotonicity, the above problem reduces to find a threshold customer and supplier C^* and S^* such that customers 1 through C^* and suppliers 1 through S^* are included in the firm's trading partner set.

2.2 Continuous Case

For more theoretical implications, consider a continuum of customers and suppliers. Customer x's fixed cost is given by $f(x)$. Due to the ordering based on the fixed cost, $f(x)$ is increasing in x. Assume that this fixed cost for customers is given by the following function

$$f(x) = x^{\gamma_c} \text{ for } x \in [0, \infty)$$

As a firm sells to more customers, the marginal fixed cost for link maintenance increases. We assume that $\gamma_c > 1$ so that $f'(x)$ is also increasing in x. A higher γ_c means that the fixed costs for maintaining customers are high, which prohibits the firm to have many customers. Similarly, assume the fixed cost for maintaining suppliers $g(x)$ is given by the following function

$$g(x) = x^{\gamma_s} \text{ for } x \in [0, \infty)$$

We also assume $\gamma_s > 1$.

We maintain the assumption that demand shifters are common across customers and intermediate input prices are common across suppliers. From equation (3), if a firm chooses C and S as its customer and supplier sets, the sales is given by

$$X(C, S) = \lambda e C \left[\phi^{\sigma-1} + \left(\frac{\alpha}{p}\right)^{\sigma-1} S\right] \tag{4}$$

The profit maximization problem is

$$\max_{C,S} \pi(C, S) = \frac{\lambda}{\sigma} e C \left[\phi^{\sigma-1} + \left(\frac{\alpha}{p}\right)^{\sigma-1} S\right] - \int_0^C x^{\gamma_c} dx - \int_0^S y^{\gamma_s} dy$$

which reduces to

$$\max_{C,S} \pi(C,S) = \frac{\lambda}{\sigma} eC \left[\phi^{\sigma-1} + \left(\frac{\alpha}{p}\right)^{\sigma-1} S\right] - \frac{1}{\gamma_c+1} C^{\gamma_c+1} - \frac{1}{\gamma_s+1} S^{\gamma_s+1}$$

The first order conditions are

$$\begin{aligned} \frac{\lambda}{\sigma} e \left[\phi^{\sigma-1} + \left(\frac{\alpha}{p}\right)^{\sigma-1} S\right] &= C^{\gamma_c} \\ \frac{\lambda}{\sigma}\left(\frac{\alpha}{p}\right)^{\sigma-1} eC &= S^{\gamma_s} \end{aligned}$$

Then, we can pin down the optimal C^* and S^* using the above two equations.

From the expression (4), we obtain the following

$$\begin{aligned} \frac{\partial X}{\partial C} &= \lambda e \left[\phi^{\sigma-1} + \left(\frac{\alpha}{p}\right)^{\sigma-1} S\right] \\ \frac{\partial X}{\partial S} &= \lambda e \left(\frac{\alpha}{p}\right)^{\sigma-1} C \\ \frac{\partial^2 X}{\partial C \partial S} &= \lambda e \left(\frac{\alpha}{p}\right)^{\sigma-1} > 0 \end{aligned}$$

The third result tells us that the customer and supplier sets are complementary. The more customers a firm has, the more attractive an additional supplier is, and vice versa. Also, the elasticity of out-degree (number of customers) on sales is constant at one, but that of in-degree is

$$elas = \frac{\left(\frac{\alpha}{p}\right)^{\sigma-1}}{\frac{1}{S}\phi^{\sigma-1} + \left(\frac{\alpha}{p}\right)^{\sigma-1}}$$

which is increasing in in-degree. We will check if empirical evidence is consistent with these results in the next section.

3 Empirical Results

3.1 Data

We use the data form Tokyo Shoko Research (TSR) Ltd. to build our datasets. TSR is a credit reporting company, which collects detailed information on Japanese firms to assess their credit scores. Firms provide their information in the course of obtaining credit reports on potential suppliers and customers or when attempting to qualify as a supplier. The information is updated at an annual frequency, and the datasets compiled between 2007 and 2016 are provided to the authors by the Small and Medium Enterprise Agency.

For each firm, information of company code, address of headquarters, year of establishment (by which age is calculated), four-digit industry classification, number of employees, and sales are reported. The unique feature of the TSR data comes from information of transaction partners. Firms report their suppliers, customers, and major shareholders up to 24 firms. Despite this truncation threshold, we can grasp the inter-firm network quite well by merging self- and other-reported data. We can also compute in- and out-degrees (the number of suppliers and customers) from this database. Some firms are reported to have thousands of transaction partners while most of the firms have only several partners exhibiting a scale-free degree distribution.[3] Due to this skewed degree distribution, only a small fraction of firms fill up the list of 24 partners. If a firm has more than 24 partners, they do not show up on the self-reported list, but if the transaction is considered to be important by the partners, the links are reported by them. Thus, the only case we miss an existing link is that it is not important for both ends.

We build a firm-by-year panel of manufacturing firms (2-digit JSIC 09-32), wherein

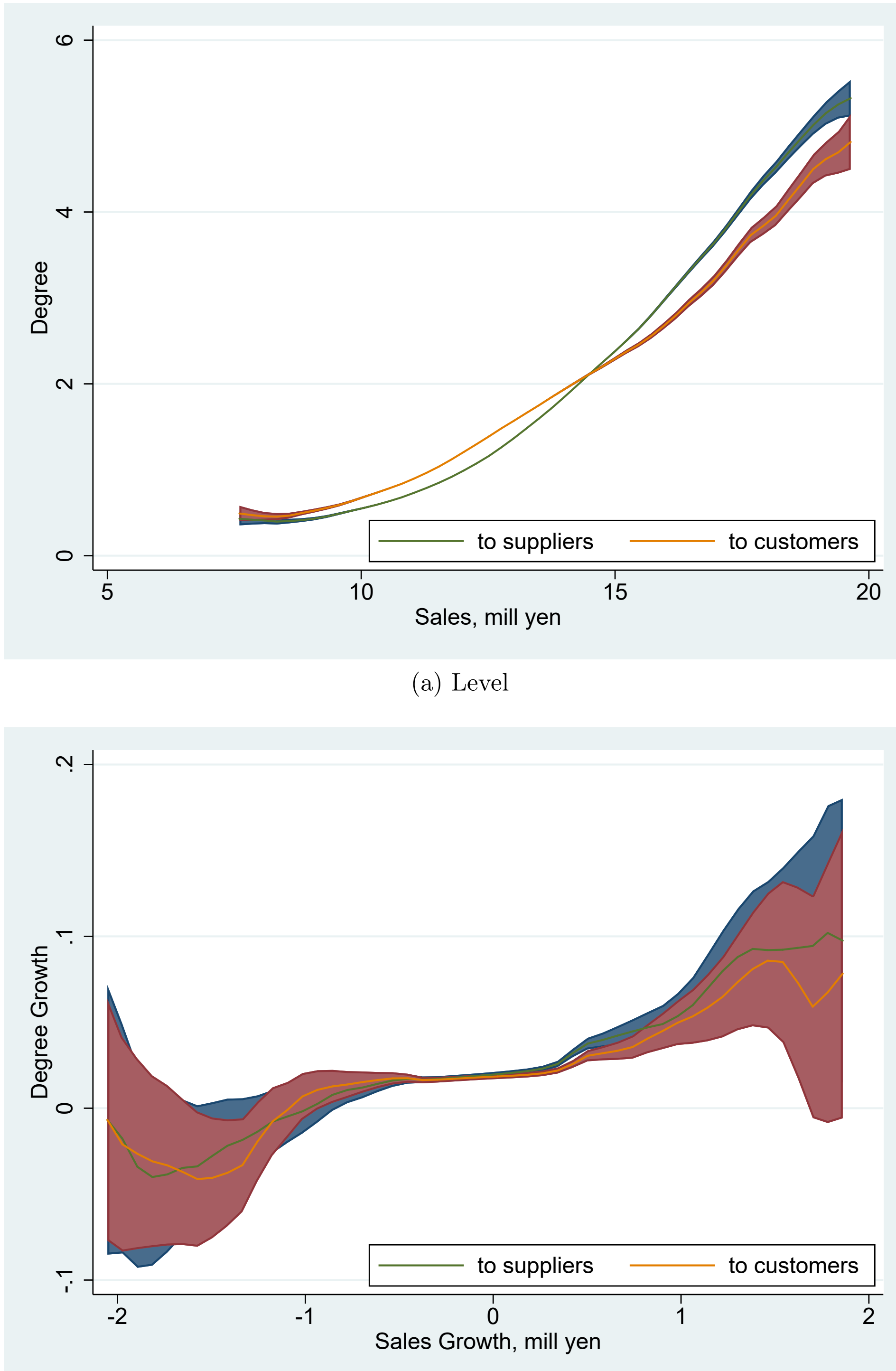
[3]For more data description, see Saito et al. (2007), Bernard et al. (2015), Carvalho et al. (2014), and Fujii (2016).

for each firm in each year, we have the number of buyers (out-degree) and sellers (in-degree), sales, employment and firm age. We use this firm panel to examine the dynamics of inter-firm linkages and its relationship with the characteristics of each firm. We focus on manufacturers since the model considered in this paper is most suitable for firms that deal with physical inputs and outputs.

Figure 2 illustrates the relationship between sales and degrees (both in- and out-degrees). Scatterplots are smoothed by kernel-weighted local polynomials. The top panel shows the relationship in levels and the bottom panel shows that in growth rates. There is a clear positive relationship between sales and degrees in levels. Growth rates also exhibit positive relationships but with larger confidence bands around tails. Figure 3 shows the relationship between indegree and out-degree. We can confirm a clear positive relationship between indegree and out-degree in both levels and growth rates. These facts are consistent with the basic model considered in the previous section.

3.2 Panel Regression Results

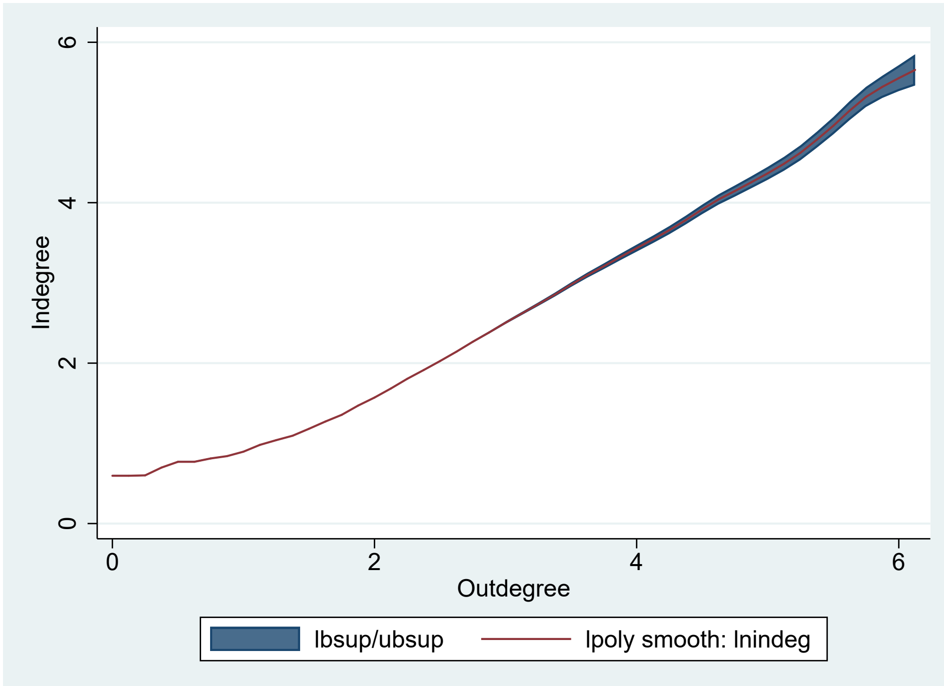
To see if the theoretical model is consistent with empirical evidence, we estimate panel regression models of sales on in-degree and out-degree. We consider sales mainly due to data availability, but the variable profit is proportional to sales in the model so sales should be a plausible proxy. Tables 1 and 2 present the results without firm fixed effects and with firm fixed effects respectively. All variables are in logs except age. All estimated coefficients are significant at 1% level. The first three columns of Table 1 show that both in-degree and out-degree are positively correlated with sales. In-degree exhibit a higher sales elasticity than out-degree. This implies a high demand elasticity or a low elasticity of substitution between intermediate inputs. If the intensive margin of all customers are equal, the elasticity of out-degree must be one at least theoretically. In reality, most of the sales goes to final good consumer whose intensive margin is



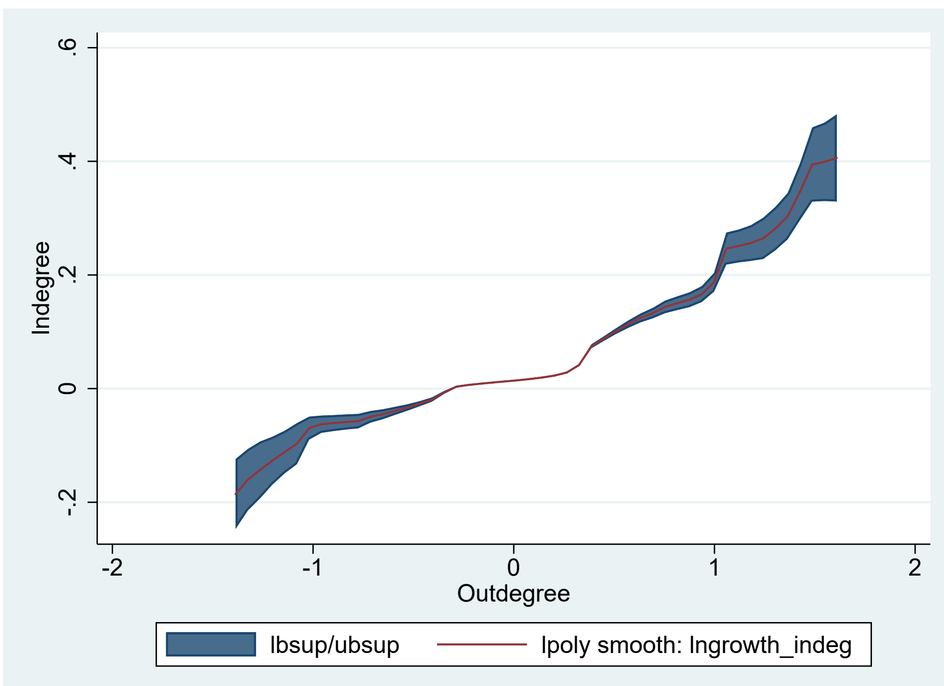
(a) Level

(b) Growth

Figure 2: Degree and sales



(a) Level



(b) Growth

Figure 3: In-degree and out-degree

disproportionately large, so one percent increase of out-degree does not result in one percent sales increase. The fourth column shows that the ratio of new links is positively associated with sales for both in- and out-degrees. Again, in-degree exhibits a higher elasticity. These ratios of new links are proxies for the quality of supplier and customer sets. Firms have incentives to form new links only if they bring benefits to them either through lower intermediate costs (suppliers) or higher demand base (customers). Even the total number of links remains the same, if a firm reshuffles many of the existing partners, the new set of partners should have a better quality. Columns 5 and 6 show that the interaction term of in- and out-degree is positive. This is also consistent with the theory which predicts the cross partial of in- and out-degree on sales is positive. The marginal benefit of having more suppliers is amplified by the number of customers, and vice versa. The last two columns consider the interaction terms with age. In-degree interaction term is positive whereas out-degree interaction is negative (but the magnitude is small). If we treat age a a proxy for size, then the marginal benefit of having more suppliers is increasing in size whereas that of having more customers is decreasing or at least remains constant. This is also consistent with the theory considered in the previous section.

Table 2 presents the estimated coefficients with firm fixed effects. All the qualitative features are the same as the case of no firm fixed effects. Hence, the results are not driven by the heterogeneity across firms, and hold for change to change over firm life cycle. The first three columns show that the growth of in- and out-degrees are positively associated with sales growth. Again, the coefficient is larger for in-degree. The last three columns also confirm the robustness of the positive impact of the customer and supplier sets, and the complementarity between in- and out-degrees.

To see the difference in sales elasticities across size groups, we divided firms into ten groups based on their mean sales across time. Table 3 presents the elasticities on sales by different size groups after controlling the effect of employment. Figure 4 depicts the estimated elasticities of in- and out-degrees by size groups. We can see that the elasticity of out-degree is approximately the same for all groups while that of in-degree increases with size. Again, this confirms the increasing marginal benefit of having more suppliers for size. Since better or more suppliers lowers the marginal cost, its positive impact is leveraged when sales is large.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Sales	Sales	Sales	Sales	Sales	Sales	Sales	Sales
In-degree	1.118***		0.871***	0.881***	0.747***	0.761***	0.611***	0.630***
	(0.000556)		(0.000746)	(0.00348)	(0.00108)	(0.00379)	(0.00190)	(0.00528)
Out-degree		0.927***	0.433***	0.429***	0.299***	0.299***	0.304***	0.300***
		(0.000638)	(0.000730)	(0.00287)	(0.00106)	(0.00275)	(0.00172)	(0.00384)
Ratio of new in-degree				0.350***		0.348***		0.332***
				(0.0649)		(0.0646)		(0.0631)
Ratio of new out-degree				0.156***		0.151***		0.136***
				(0.0105)		(0.0105)		(0.0104)
In-degree × out-degree					0.0788***	0.0764***	0.0754***	0.0717***
					(0.000459)	(0.000511)	(0.000508)	(0.000583)
In-degree × age							0.00328***	0.00321***
							(4.23e-05)	(5.56e-05)
Out-degree × age							-0.000969***	-0.000794***
							(4.09e-05)	(5.36e-05)
Constant	10.94***	10.92***	10.91***	10.83***	11.04***	10.96***	11.18***	11.10***
	(0.00630)	(0.00661)	(0.00704)	(0.0121)	(0.00704)	(0.0123)	(0.00719)	(0.0128)
Observations	7,191,843	6,512,372	4,930,832	4,418,792	4,930,832	4,418,792	4,695,762	4,209,399
R-squared	0.453	0.390	0.531	0.540	0.534	0.544	0.528	0.537

Table 1: Panel regression results (without firm fixed effects)

	(1)	(2)	(3)	(4)	(5)	(6)
	Sales	Sales	Sales	Sales	Sales	Sales
In-degree	0.158***		0.146***	0.156***	0.0922***	0.105***
	(0.000480)		(0.000564)	(0.000646)	(0.000758)	(0.000839)
Out-degree		0.101***	0.0796***	0.0889***	0.0272***	0.0392***
		(0.000433)	(0.000493)	(0.000579)	(0.000695)	(0.000779)
Ratio of new in-degree				0.0323***		0.0323***
				(0.000426)		(0.000426)
Ratio of new out-degree				0.0229***		0.0225***
				(0.000411)		(0.000410)
In-degree × out-degree					0.0435***	0.0413***
					(0.000407)	(0.000434)
In-degree × age						
Out-degree × age						
Constant	12.01***	11.98***	12.17***	12.14***	12.22***	12.18***
	(0.000626)	(0.000627)	(0.000908)	(0.00105)	(0.001000)	(0.00114)
Observations	7,191,843	6,512,372	4,930,832	4,418,792	4,930,832	4,418,792
R-squared	0.968	0.968	0.971	0.973	0.971	0.973

Table 2: Panel regression results (with firm fixed effects)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
In-degree	0.0359	0.0268	0.0276	0.0482	0.0407	0.0513	0.0624	0.0857	0.110	0.247
	(0.00471)	(0.00352)	(0.00316)	(0.00307)	(0.00284)	(0.00280)	(0.00287)	(0.00296)	(0.00329)	(0.00432)
Out-degree	0.0625	0.0489	0.0437	0.0392	0.0408	0.0480	0.0407	0.0496	0.0694	0.0846
	(0.00406)	(0.00320)	(0.00297)	(0.00295)	(0.00279)	(0.00283)	(0.00292)	(0.00297)	(0.00322)	(0.00371)
Employment	0.316	0.333	0.340	0.352	0.350	0.367	0.379	0.356	0.382	0.406
	(0.00444)	(0.00364)	(0.00349)	(0.00356)	(0.00349)	(0.00336)	(0.00356)	(0.00339)	(0.00346)	(0.00369)
Constant	9.919	10.57	10.90	11.13	11.39	11.59	11.82	12.18	12.47	12.95
	(0.00672)	(0.00719)	(0.00789)	(0.00894)	(0.00955)	(0.0101)	(0.0117)	(0.0125)	(0.0146)	(0.0203)
Observations	112,600	112,587	112,704	112,467	112,576	112,585	112,587	112,587	112,586	112,577
R-squared	0.839	0.526	0.450	0.421	0.399	0.400	0.416	0.481	0.652	0.961

Table 3: Results by different size groups

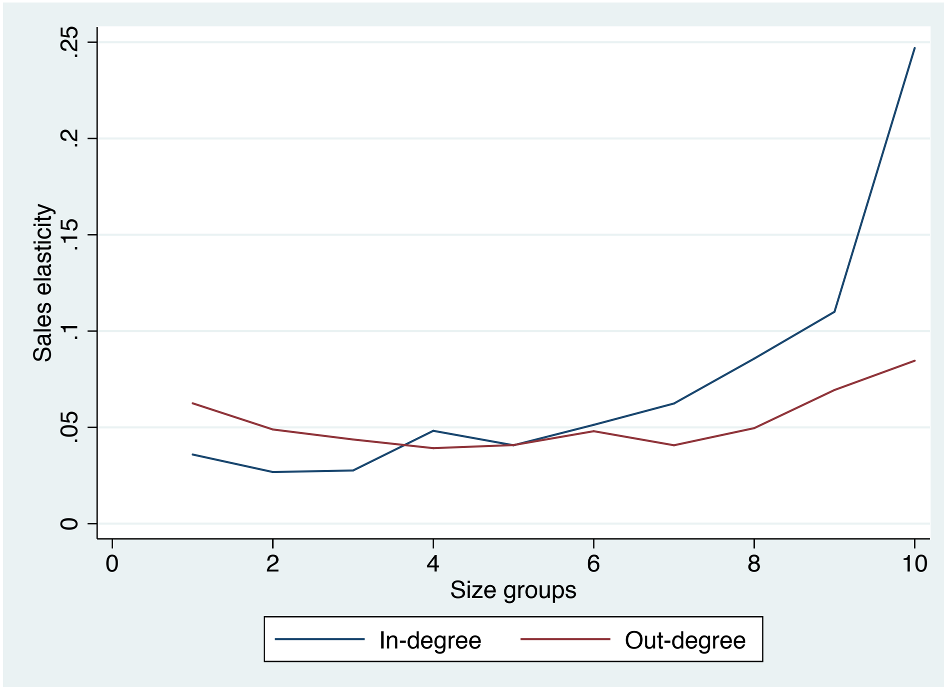


Figure 4: Elasticity of degree on sales by size groups

4 Conclusion

This paper examines how transaction relationships are correlated with firm performance focusing on differences between supplier and customer relationships. In theory, both suppliers and customers positively affect sales and profit but their channels are different. A supplier set affects firm's productivity lowering its marginal cost of production whereas a customer set only expands the size not affecting productivity. We consider a simple model of production with intermediate inputs, and see if theoretical implications are consistent with empirical evidence by estimating panel regressions using Japanese inter-firm transaction network data. We find that sales elasticities of in- and out-degree are positive. In- and out-degrees exhibit complementarity on sales implying that the marginal benefit of having more suppliers increases with the number of customers, and vice versa. Also, the elasticity of in-degree increases with size while that of out-degree is constant. This is also consistent with the theory, which predicts a leveraged effect of lowering a marginal cost when the scale is large.

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