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The Dynamics of Inter-firm Networks and Firm Growth*

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Abstract

Recent empirical evidence has revealed that firm age is one of the key determinants for firm growth, while other literature points out the importance of customer-supplier networks for firm growth. This paper investigates how the inter-firm transaction network evolves over the firm lifecycle and its relationship with firm growth using large-scale firm network data in Japan. Old firms are large in size and well connected compared to young firms. In particular, older firms are connected to other older firms exhibiting positive assortativity of age. Younger firms tend to add and drop links more frequently, and the stability of a transaction link increases with its duration of active relationships, implying gradual learning of link-specific productivity over time. Moreover, firm's sales growth is positively related with the expansion of transaction partners in various measures, conditional on firm age. This suggests that the observed relationship between firm age and firm growth may be due to the lifecycle pattern of building inter-firm networks.

Keywords: Inter-firm network, Firm growth, Firm size, Firm age, Network formation

JEL classification: D22, D85

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1 Introduction

It is of great importance to analyze the relationship between firms' life cycle and their growth pattern since they determine the evolution of aggregate productivity. A large body of literature has studied the link between firm size and firm growth, but recent empirical evidence suggests an important role played by firm age, not firm size. Another growing literature has investigated the relationship between firm growth and supplier-customer networks. Theoretical models of inter-firm networks claim that a firm's performance rises with its suppliers' and customers' quality and size , and there are a number of empirical papers that support the theoretical implications. Despite the importance of age and inter-firm networks on firm growth, there exists little empirical evidence on the evolution of inter-firm network over firm life cycle and its impact on firm growth. The main contribution of this research is to fill the gap by providing new empirical evidence.

This paper investigates how the inter-firm network evolves over firms' life cycle, and its relationship with firm growth using large-scale firm network data in Japan. Our database consists of a firm panel with supplier-customer information covering about a million firms for 10 years, and allows us to analyze the dynamics of inter-firm networks. To the best of our knowledge, this is the first research which provides empirical evidence on the evolution of large-scale production networks.

The main results are summarized as follows. Old firms are large in size and well-connected compared to younger firms. In general, older firms are connected to other older firms (positive assortativity of age). As a firm age rises, the average age of its partners rises as well. Younger firms tend to add and drop links more, and the stability of a transaction relationship (survival rate of a link) increases with its tenure implying gradual learning of link-specific productivity over time. Firm's sales growth is positively related with the expansion of transaction partners in various measures, and the relationship pattern varies across different age groups. This suggests the relationship between firm age and firm growth in the literature might be caused by inter-firm transaction network.

As mentioned above, the current paper is related to the literature of firm growth and industry dynamics but adds a new dimension of firm characteristics, supplier and customer networks. Gibrat (1931) attempts to explain log-normal size distribution by a growth process in which a firm's growth is proportional to its current size. Dunne, Roberts and Samuelson (1988, 1999) analyze the U.S. Census data and find that the probability of survival increases with firm size and firm growth rates decrease in size conditional on survival. Jovanovic (1982) and Hopenhayn (1992) consider a selection model for industry evolution with ex-ante productivity uncertainty. Other papers in the literature of firm growth and size distributions include Axtell (2001), Luttmer (2007), Klette and Kortum (2004), and Davis et al. (1996).

Haltiwanger et al. (2013) argue that many of those empirical papers suffer from measurement pitfalls and misleading interpretations. After conducting a careful analysis, they find that age is more important than size to explain firm growth. A large part of the inverse relationship between firm size and growth can be attributed to the positive relationship between age and size. This underscores the important role of business start-ups and young businesses in aggregate growth. Evans (1987) also report the inverse relationship between firm age and the growth, variability of growth and exit probability. Coad et al. (2014) find that sales growth for new ventures is characterized by positive autocorrelation while it becomes increasingly negative for old firms.

This paper is also related to the models on network formation from the research of social networks and graph theory. Many researchers have analyzed different probabilistic configurations of network formation and the properties of the resulting networks.[1] These network formation models are mechanical and do not have economic structures. Recent papers (Oberfield (2016), Lim (2016), and others) have proposed a network formation model with production functions and explicit input-output interactions but their focus is to provide theoretical frameworks and they present little empirical evidence on the network dynamics. Bernard et al. (2015) consider a model of inter-firm production network formation with search costs, and test the theoretical implications by exploiting the opening of high-speed train in Japan. Using the same dataset of buyer-supplier linkages as in this paper, they find significant growth in firm sales and creation of new links for firms located along the new railroad. Carvalho et al. (2014) confirmed the effect of a production network on firm sales in the opposite direction.

[1]Barabasi and Albert (1999) propose a preferential attachment process, in which the probability of a new link formation is proportional to the number of existing links, to explain scale-free degree distributions that are prevalent in social networks. Watts (1999) generates networks that exhibit the "small world" property and high clustering coefficients by revising some links randomly from an initially symmetric network. Jackson and Rogers (2007) studies a network formation process of "meeting strangers and friends of friends." A new node is added to the network every period forming a link randomly. For incumbent nodes, there are two ways for being contacted: randomly and through their friends. If the probability of meeting friends of friends is large, well-connected nodes gain even more links resulting in a scale-free degree distribution. This process also explains other stylized facts of social networks.

Comparing buyer-supplier networks and firm sales growth before and after the Great East Japan Earthquake in 2011, they find that the supply chain disruption negatively affects firm performance, and the adverse effect propagates through inter-firm networks. These empirical results indicate an important role played by production networks on firm performance. Other researchers studied inter-firm network formation empirically, but all of their data are of a particular industry lacking the generality of their results (Molina-Morales et al. (2015), Balland et al. (2013), and Ter Wal and Boschma (2011)).

We find that the stability of a link (survival rate of a transaction relationship) rises with the length of active relationship. A similar stylized fact is observed in macro labor literature. Jovanovic (1979) builds a general equilibrium model to explain the decreasing job turnover rate in tenure.[2] He argues that match specific productivity between firm and employee is revealed only after forming the match. Due to the learning process and selection, a high-quality match remains over time and younger workers tend to switch jobs if they find out the match specific productivity is low. Another explanation for this pattern is the accumulated relationship capital. As firms and workers build a common capital together, they tend not to separate as time progresses. There may exist a similar mechanism in the matching process of suppliers and customers in our network data. Firms do not have complete information regarding their partners, so if the link-specific productivity is revealed to be low, they terminate the relationship within a few years. The selection mechanism leads to the positive correlation between the stability and the length of transaction relationships. Also, firms may build shared capital, both tangible and intangible, with their partners, and the empirical fact can be explained by the mutual investment on the relationship capital over time.

This paper is organized as follows. Section 2 describes the Japanese firm-level data on inter-firm transaction networks. Section 3 provides several empirical facts regarding the inter-firm network dynamics and firm age. Section 4 presents the results of regression analysis on the evolution of networks, and Section 5 concludes.

2 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

[2] Farber (1999) provides empirical evidence for these stylized facts.

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 two sets of data for our analysis. First, we build a firm-by-year panel, wherein 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. The total of 1,899,437 firms are covered in this panel with the median duration covered being 7 years (minimum is 1 and maximum is 10 years). Second, we construct a link-by-year panel. It contains, for each link at each year, information of both buyer's and seller's sales, employment, age, the number of degrees (both in- and out-degree), and the geographical distance between buyers and sellers (using the location of headquarters). We use this link panel to investigate how buyer's and seller's characteristics can account for the stability of links.

Table 1 summarizes the data by year. The first three columns display the number of firms in the sample, the number of newly born firms (age zero or one), and the average age of firms. The next four columns are the total number of transaction links, newly formed links, terminated links, and average links per firm. The number of covered firms

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

has been increasing as well as the total number of links, but link/firm is stable over time around 3.4. The average age of firms in the sample is steadily increasing. On average, around 17% of transaction links are terminated and 18% are newly formed every year indicating a higher rate of metabolism of links compared to that of firm entry and exit. Figure 1 displays the kernel density estimation of firm age in 2016. For most of our analyses, firms who are older than 75 years are dropped for winsorization. There is a spike at age 26 indicating that there are disproportionately large number of firms born in 1989.

3 Empirical Facts

3.1 Metabolism of Inter-firm Networks

Like firm entry and exit in industry dynamics, new transaction links are formed and some existing links die every year. Let N_t be the total number of links in year t, A_t be the number of new links and D_t be the number of terminated links between years $t-1$ and t so that $N_t = N_{t-1} + A_t - D_t$. Define added and dropped link shares as $\frac{A_t}{N_t}$ and $\frac{D_t}{N_{t-1}}$ respectively. From Table 1, we see that the rate of new link addition peaked in 2009 and dropped sharply in 2010, which coincides with the breakout of the Great Recession (remember most of the firms are surveyed in the previous year). Due to the Great East Japan Earthquake followed by devastative tsunami in 2011, the Japanese economy had been in turmoil until 2015. The lower rate of link addition during this period may indicate the cyclical nature of new link formation. No systematic relationship between added and dropped link shares is confirmed.

Next, link survival rates are examined. We focus on the links existed in year 2007 to maximize the duration of our survival analysis, and see how many of them survived in the following years. Three samples are investigated: all links, manufacturing pairs (both supplier and customers are in manufacturing sectors) and non-manufacturing pairs. Figure 2 displays the link survival rates. The blue solid line is for all links. Within a year, about 17% of the links were terminated, so 83% survived in 2008. Within six years, half of the links are gone. Combined with the previous results, we confirm that the rate of metabolism of inter-firm networks is higher than that of firm entry and exit, which is about a few percent in many countries. This is natural since the fixed cost of forming/terminating a link is lower than the cost of establishing/closing a firm. Figure 2 also shows that transaction links between manufacturers tend to survive more compared to non-manufacturing pairs. Fujii (2015) reports that supplier-customer sales comovement is higher for manufacturing firms.[4] These results highlight the importance of inter-firm linkages for manufacturers due to the use of physical intermediate input and a higher degree of input specificity.

3.2 Firm Age and Degrees

We study the dynamics of firm size and inter-firm linkages over the life-cycle of firms. Figure 3 shows that the levels of firm size (sales and employment) and inter-firm linkage (in-degree and out-degree) increase as firms age. Specifically, the figure plots the average level of sales, employment, in-degree, and out-degree, together with the 95 confidence interval against firm age. For example, 70-year-old firms are about 6.2 times larger than 10-year-old firms measured by employment. In terms of sales, 70-year-old firms are about 7.6 times larger than 10-year-old firms. As firms age and grow, the number of buyers and sellers increase. We next examine whether young firms grow faster than old firms. Do they build inter-firm linkages faster than old firms? Figure 4 plots the rates of growth of firm size (sales and employment) and inter-firm linkage (in-degree and out-degree). As shown in the figure, the mean, 25 and 75 percentiles of annual growth rates of sales, employment, in-degree and out-degree decreases as firms age. As firms become older, their growth rates decline.

3.3 Assortativity

Figure 5 plots the age of a firm against its suppliers and customers average age by employing local polynomial smoothing. It is clear that the average age of both customers and suppliers increases in a firms age confirming there exists positive assortativity by firm age. Combined with the previous result, we can see that as a firm becomes older, they tend to connect to more and older partners. For new entrants (group of age zero firms), the average age of their partners are about 47 years old. The average age of partners for 40-year-old firms is about 55 years old. A possible explanation of this positive assortativity is the selection of old links. If the survival rate of a link decreases with the link age (tenure), then the resulting networks exhibit this feature. This possibility is further investigated below.

[4]Cravino and Levchenko (2015) also find that the degree of sales comovement between manufacturing firms and their overseas subsidiaries is higher than that of firms in service sectors.

4 Regression Analysis

4.1 Adding and Dropping Links

We study how a firm adds and drops links with its buyers and sellers. To do so, we focus on the links between buyers and sellers that survive across two periods, allowing us to exclude the links added and dropped due to firm attrition. Using this continuing firm only sample, we regress (1) the number of newly added links, (2) the number of dropped existing links, and (3) the number of links that continue to exist in the following years against firm age, controlling for the number of existing links and industry fixed effects. Columns (1) to (3) in Table 2 show the results for in-degree and columns (4) to (6) report the results for out-degree. In sum, young firms exhibit more link creation and destruction than old firms. Firm age has statistically significant impacts on addition of new links and deletion of existing links for both in-degree and out-degree. These results may support the "noisy selection" mechanism of inter-firm links. As Jovanovic (1982) in the context of firm-employee match survival patterns, learning process of specific productivity between buyers and sellers may be leading to this age-dependence of link creation and deletion patterns. Furthermore, the presence of accumulation of relation-specific capital and organization capital between buyers and sellers also can lead to age-dependence patterns as we have shown. As shown in Figure 4, the number of links that continue to exist in the following years is positively associated with firm age, even after controlling the size of existing links and other characteristics.

4.2 Link Survival Rate by Firm Age

This sub-section focuses on both sides of transaction, i.e., supply side and buyer side because transaction occurs when both sides agree. More specifically, we examine the link-level information, rather than the firm-level one, and considers relationships between the survival probability of links and their characteristics. We look at information of buyers and sellers separately for each link. The probability of link survival may depend on buyer's age and seller's age differently. This asymmetry might be an important feature of inter-firm linkage dynamics. We examine these points more explicitly in Table 3 where we ran probits of whether a link continues to exist in the following year. The right hand side variables include buyer's and seller's age, buyer's and seller's sales, the distance of links, and industry dummies. Column (1) reports that both buyer's age and seller's age are positively and significantly correlated with the probability of link survival, with industry dummies as additional controls. Column (2) adds buyer's sales and seller's sales and finds a neg- active coefficient for buyer's sales and a positive coefficient for seller's sales. This finds a 10% increase in seller's sales is associated with a 0.08% increase in the probability of link survival. On the contrary, this also says a 10% increase in buyer's sales is associated with a 0.11% fall in the probability of link survival. This negative association between buyer's sales and a link survival probability may be indicating that buyers' search cost is decreasing in their size and they can easily switch to other suppliers as they grow. Column (3) includes distance of links and the above results remain strong and significant.

We next consider the role of link age in determining the stability of links. Specifically, we investigates the association between link survival and link characteristics including link age dummies. As discussed above, inter-firm network appears to become more stable as firm age increases. Old firms keep more links to the next period than young firms, but does this depend on duration of inter-firm links itself rather than firm age? To examine this point, we use our link panel to run probits of whether a link continues to exit in the following year where the right hand side variables are link age, buyer's and seller's age, buyer's and seller's sales, the distance of links, industry dummies and time dummies. In Columns (4) in Table 3, we report that link age dummies are strongly positively and significantly associated with the probability of link survival, albeit that the inclusion of link age dummies makes the coefficient of buyer's age negative and less significant. As seen in the table, these coefficient of age dummies show that the older each link, the more likely that it continues to exit in the following years.

4.3 Network Dynamics and Firm Growth

As discussed above, firm age plays a quantitatively important role in shaping the dynamics of firms and inter-firm linkages. In this sub-section, we investigate the inter-relationships between firm growth and inter-firm network dynamics. We regress sales growth rates of firms on firm age, employment size, the number of degree, the continuation rates of degree, the creation rates of degree, controlling for industry and time fixed effect. We begin by showing the results for our all-pooled sample in column (1) in Table 4. This suggests that firm growth is negatively associated with firm age but positively correlated with firm size (employment), the number of degree, the continuation and creation rates of degree, and all coefficients are statistically significant. We next consider this regression form for five different groups of firm: firm age from 0 to

4, 5 to 9, 10 to 19, 20 to 39, 40 and older. Column (2) - (6) corresponds these different age group, respectively. The coefficients from (2) - (6) show the following dynamic implications concerning firm growth and inter-firm-linkage dynamics. First, the impact of firm age on firm growth rates decreases as we move towards older age groups. Second, the importance of degree for firm growth also decreases as firms become older. Third, the coefficients for the continuation rates of degree become larger and more significant as firm age rises. Finally, on the contrary to the third point, adding new links is more strongly associated with firm growth for younger firms than matured firms. As such, investigating firm growth by each age group of firms reveals apparent non-linear relationships between the dynamics of inter-firm links and firm growth over the lifecycle. The larger reliance of young firms on building new buyer-customer relationships for their growth has following aggregate implications too. When aggregate shocks, including financial crisis and natural disaster shocks (e.g. earthquake as in Carvalho et al. (2016)) hit the economy and they adversely affect inter-firm link creation dynamics, young firms hurt more than old firms. Moreover, this may operate as an endogenous propagation mechanism by which even idiosyncratic shocks drive persistent economic dynamics, as in the "granular" mechanism studied by Gabaix (2009) and Acemoglu et al. (2012).

5 Conclusion

This paper examined how the inter-firm network evolves over firms life cycle, and its relationship with firm growth using large-scale firm network data in Japan. We find the following empirical results. Old firms are large in size and well-connected compared to younger firms. In general, older firms are connected to other older firms (positive assortativity of age). As a firm ages, the average age of its partners rises as well. Younger firms tend to add and drop links more, and the stability of a transaction relationship (survival rate of a link) increases with its tenure implying gradual learning of link-specific productivity over time. This is analogous to the firm-employee matching literature in labor economics. Ex ante, firms do not know much about the relation-specific productivity gain. After forming an actual link (started trading), both supplier and customer gain more refined knowledge about the quality of the link. Over time, both firms learn the true quality of the match and younger firms may reshuffle their links. An older link implies survival conditional on a good match. Another possibility is that both customer and supplier invest in the relationship capital over time. Due to this accumulated investment, older links are more attractive for both ends. We also find that firm sales growth is positively related with the expansion of transaction partners. This suggests a potentially large impact of policies that promote firm-to-firm matching on aggregate growth.

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A Tables

year	firms	entrants	average age	links	new links	terminated links	link/firm
2016	1224950	22687	28.3	4194850	759841	682439	3.42
2015	1198840	20831	28.0	4117448	834012	675083	3.43
2014	1211590	20379	27.6	3958519	667712	697099	3.27
2013	1213765	19820	27.3	3987906	685341	712436	3.29
2012	1201136	18871	27.0	4015001	673160	640799	3.34
2011	1160461	17726	26.8	3982640	698107	626270	3.43
2010	1127705	17058	26.6	3910803	718351	607268	3.47
2009	1075747	16809	26.6	3799720	775106	617728	3.53
2008	1031324	13910	26.8	3642342	723669	598697	3.53
2007	1006160	12273	26.5	3517370			3.50

Table 1: Year summary

	In-degree			Out-degree		
	(1)	(2)	(3)	(4)	(5)	(6)
	Add	Drop	Continue	Add	Drop	Continue
Age	-0.0240***	-0.0111***	0.00376***	-0.0248***	-0.00931***	0.00708***
	(0.000491)	(0.000324)	(0.000173)	(0.000483)	(0.000340)	(0.000220)
In-degree	0.283***	0.272***	0.951***			
	(0.000885)	(0.000792)	(0.000173)			
Out-degree				0.270***	0.256***	0.935***
				(0.000847)	(0.000734)	(0.000280)
N	1,097,972	1,097,972	1,097,972	1,097,972	1,097,972	1,097,972
R^2	0.293	0.386	0.972	0.284	0.331	0.950
Industry F.E.	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Robust standard errors are reported

Table 2: Firm-level link age dynamics

	Probit: $I_{Survival>0}$			
	(1)	(2)	(3)	(4)
Log buyer's age	0.0283***	0.0372***	0.0367***	-0.000448
	(0.00147)	(0.00160)	(0.00160)	(0.00163)
Log seller's age	0.0878***	0.0689***	0.0676***	0.0254***
	(0.00143)	(0.00154)	(0.00154)	(0.00157)
Log buyer's sales		-0.00361***	-0.000732***	-0.00209***
		(0.000402)	(0.000413)	(0.000415)
Log seller's sales		0.0190***	0.0226***	0.0188***
		(0.000454)	(0.000468)	(0.000471)
Log link distance			-0.0174***	-0.0147***
			(0.00057)	(0.000573)
Age dummy 2				0.175***
				(0.00290)
Age dummy 4				0.232***
				(0.00316)
Age dummy 6				0.356***
				(0.00264)
N	3,282,948	3,211,750	3,211,750	3,211,750
Industry F.E.	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Robust standard errors are reported

Table 3: Stability of inter-firm linkages

	(1) All ages	(2) Age 0-4	(3) Age 5-9	(4) Age 10-19	(5) Age 20-39	(6) Age 40+
Log age	-0.0679***	-0.327***	-0.104***	-0.0599***	-0.0319***	-0.0334***
	(0.000970)	(0.0135)	(0.0113)	(0.00586)	(0.00352)	(0.00419)
Log employment	0.0178***	-0.00642	0.0116***	0.0199***	0.0208***	0.0153***
	(0.000532)	(0.00559)	(0.00231)	(0.00124)	(0.000771)	(0.000919)
Log degree	0.0137***	0.0151**	0.0123***	0.0133***	0.0138***	0.00845***
	(0.000635)	(0.00652)	(0.00295)	(0.00158)	(0.000923)	(0.00109)
Continuation rate	0.0605***	-0.0260	0.0202*	0.0362***	0.0616***	0.111***
	(0.00332)	(0.0225)	(0.0114)	(0.00675)	(0.00458)	(0.00754)
Creation rate	0.0525***	0.0843***	0.0639***	0.0440***	0.0431***	0.0479***
	(0.00142)	(0.00694)	(0.00424)	(0.00247)	(0.00178)	(0.00351)
Observations	682,391	19,358	46,468	115,032	288,006	213,527
R^2	0.029	0.081	0.019	0.015	0.017	0.022
Industry F.E.	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Robust standard errors are reported

Table 4: Firm growth rates by age groups

B Figures

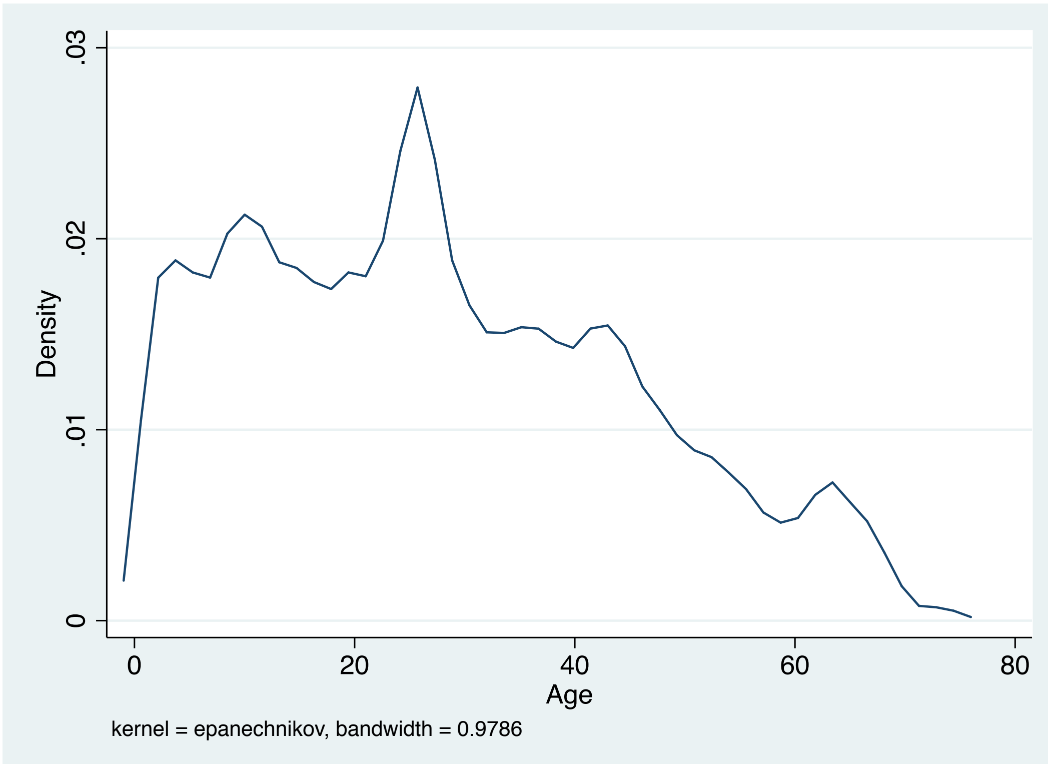

Figure 1: Age distribution in 2016

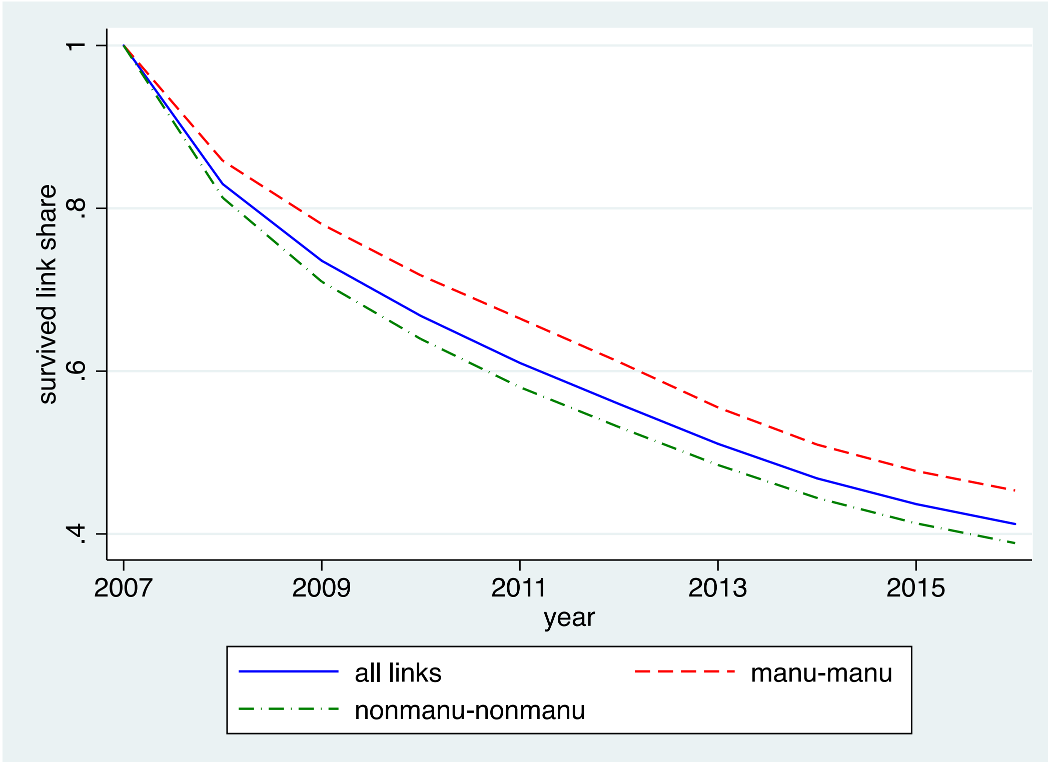

Figure 2: Link survival rates

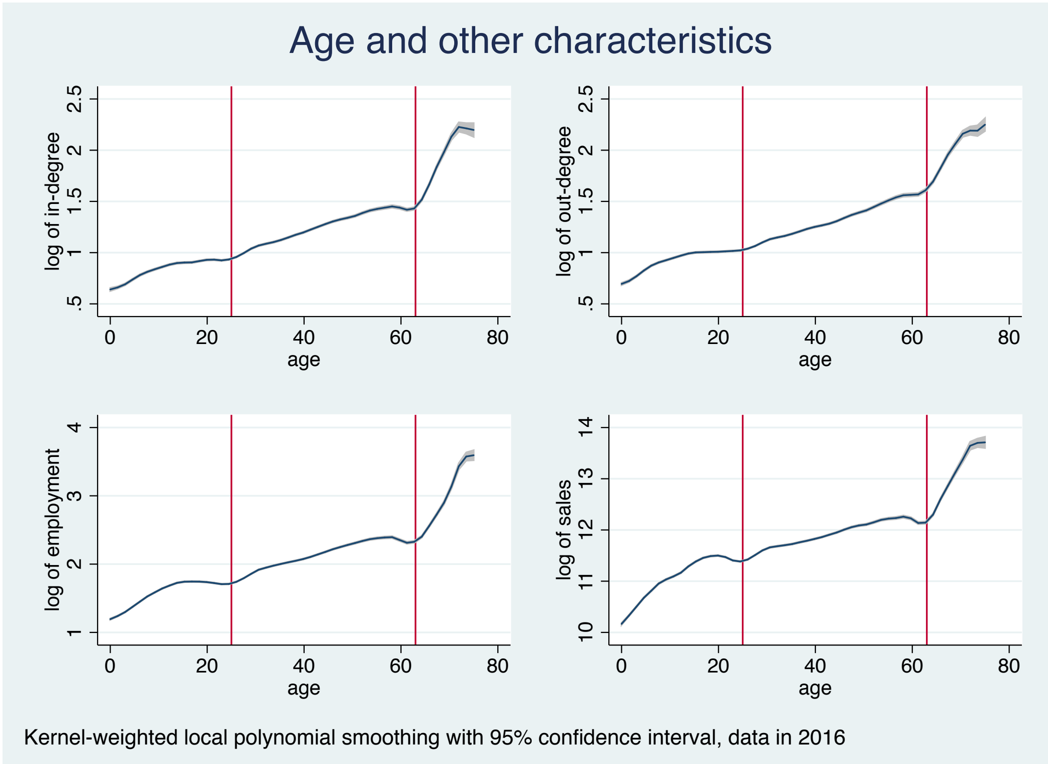

Figure 3: Age and firm size measures

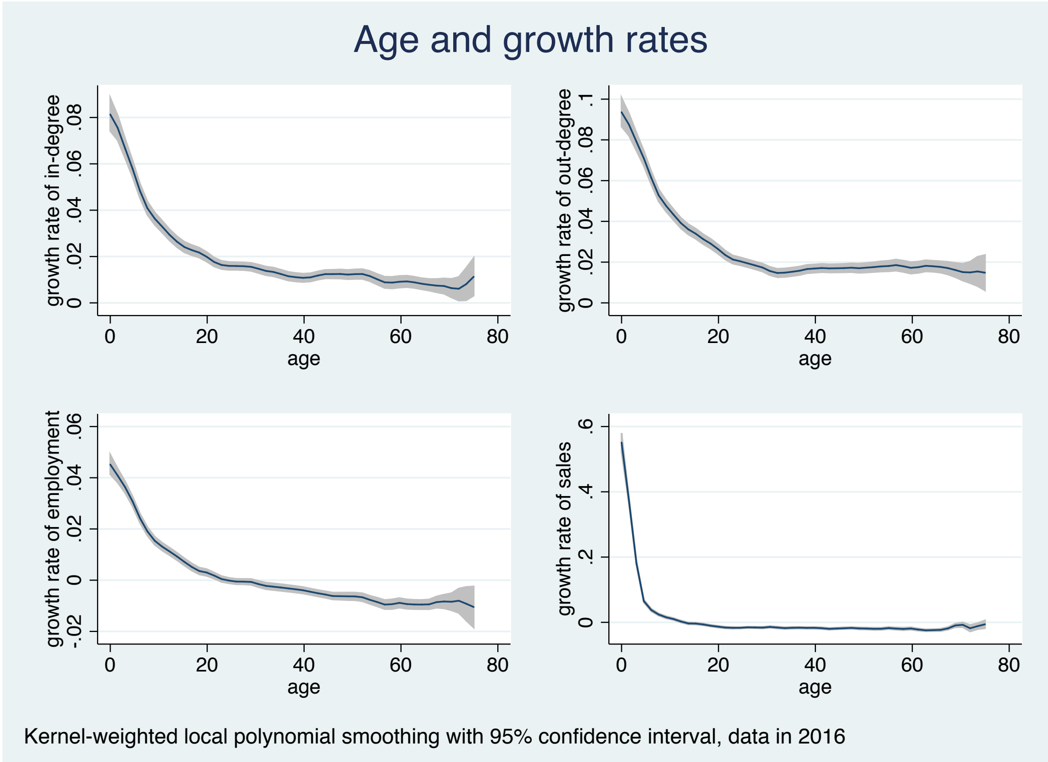

Figure 4: Age and firm size measures (growth rates)

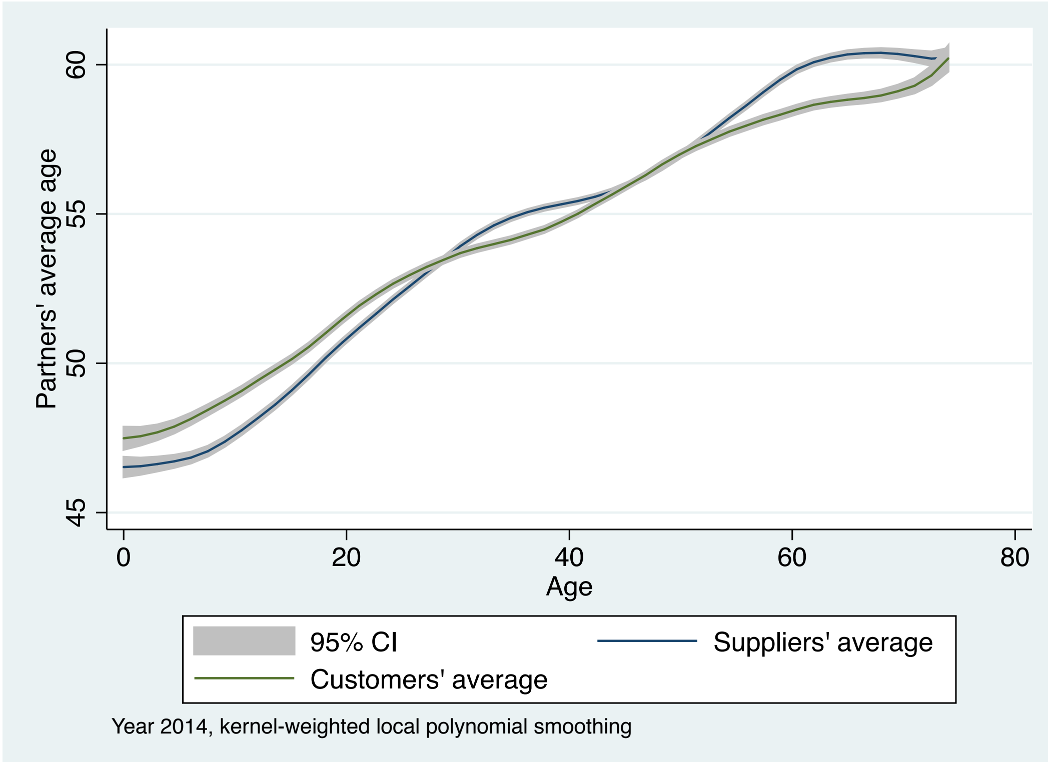

Figure 5: Assortativity (age)