Chapter 18
Empirical Analysis of Firm-Dynamics on Japanese Interfirm Trade Network

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Abstract We analyze Japanese interfirm trade network data for 20 years from the viewpoint of the metabolism of scale-free network evolution. We find that the preferential attachment effect of established firms is stronger than that of merged firms. This shows that merging firms should choose counterparties using delicate business strategies that may not be related to the degree. We also find that the distribution of lifespan of links is approximated well by an exponential function with the characteristic time of 6 years. The results imply the link creation and deletion is well characterized by a Poisson process.

18.1 Introduction

In 2009, the Federal Reserve Board of Governors implemented bank stress testing to check banks' asset health.[1] The results could indicate what kind of reaction big banks would have under certain bad situations. Because banks are among the most

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[1] http://www.federalreserve.gov/newsevents/press/bcreg/20090507a.htm.

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H. Takayasu et al. (eds.), *Proceedings of the International Conference on Social Modeling and Simulation, plus Econophysics Colloquium 2014*, Springer Proceedings in Complexity, DOI 10.1007/978-3-319-20591-5_18

important economic agents, it would be useful to assess the robustness of each bank and to consider this for precautionary actions in each situation.

Likewise, it is important for Japanese society to grasp the extent of each firm's capacity to deal with certain kinds of stresses because firms are also among the most important economic agents. Furthermore, the assessments would be particularly applicable to the real world if we could evaluate each firm as a part of the system that considered relationships among economic agents. As Fujiwara [1] commented, outer stresses could have very serious effects on firms' performances. This is in addition to serious effects from inner stresses, based on research about the reasons for bankruptcies in Japan.

Based on this discussion, some studies evaluate robustness using the system of economic agents. Iyetomi and his collaborators [2] developed an agent-based model to simulate firms' dynamics, which was constructed based on the relationship between firms and banks. In addition, Fujiwara and his collaborators [3] also analyzed lending networks between large firms and banks to evaluate their robustness in Japan. Those analyses would be beneficial to understand the strength of Japanese society from a macro viewpoint.

Here, as a first step toward developing a model that quantitatively estimates robustness of relational economic systems, we empirically analyze statistical properties of time evolution of real Japanese interfirm trade networks using a large time-series firm database.

18.2 Large Time-Series Firm Database

18.2.1 Japanese Interfirm Trade Networks

Business practices in Japan are unique. When building trustworthy relationships or managing credit risk, Japanese people first tend to gather their business partners' detailed corporate information. Then, professional third-party organizations are used to search their partners' credit status. TDB is one of the largest corporate research providers in Japan; it has assessed the credit status of firms for 115 years. Their credit research reports include detailed information of the financial statements of firms, their history, business partners, management and banking transactions.

In Sect. 18.3 of this study, we use three kinds of time-series data provided by TDB because the data have been stored using digitalization for several decades. As summarized in Table 18.1, the following data types are used: interfirm trade network data (which link the direction from consumers to suppliers, and have been stored from 1994 to 2014); interfirm bank trade network data (which link the direction from banks to firms, and have been stored from 1981 to 2014); and bankrupt firms data (which have been stored from 1980 to 2014).

Table 18.1 Dataset detail

Type	Time series	Total nodes	Total links
Trade network	From 1994 to 2014	19,527,573	68,608,558
Bank–trade network	From 1981 to 2014	Bank: 49,461, firm: 2,519,473	77,878,253
Bankrupt firms data	From 1980 to 2014	494,890	–

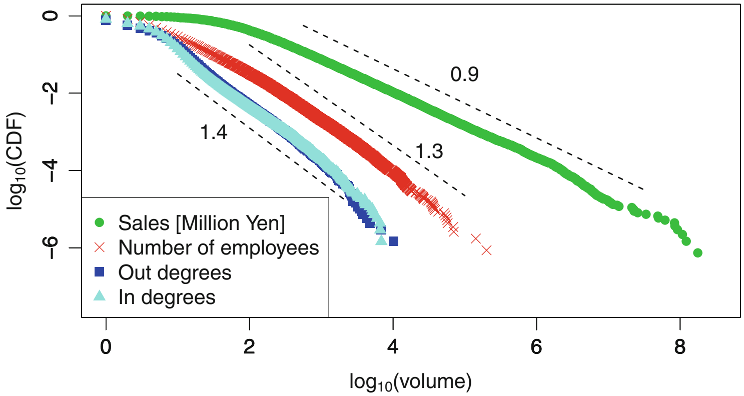

Fig. 18.1 Cumulative distribution of number of links, sales and number of employees in log-log scale (*green circles* for sales, *red crosses* for number of employees, *blue squares* for out degrees and *light blue triangles* for in degrees; the *dashed line* indicates the relationship with 0.9, 1.3, 1.4 and 1.4, respectively, for 2013)

18.2.2 Basic Properties

In 2007, M. Takayasu and her collaborators [4] published the first paper about the basic properties of the Japanese interfirm trade network. Using a different database, they found that those distributions follow power laws.

First, we confirm consistent power law distributions of link numbers, sales, and employees with exponents of about 1.4, 0.9, and 1.3, respectively, for 2013, as shown in Fig. 18.1. As for links on the Japanese interfirm trade network, there are directed money flows from buyer firms to supplier firms, that is, each node has in and out degrees. Therefore, we confirm consistent power law distributions of in and out link numbers and both distributions follow power-laws with exponents of about 1.4. Moreover, all of those distributions are almost identical in other years. Recently, Mizuno, Watanabe and Souma reported asymmetric distributions of in and out degrees based on the TDB data; however, their results cannot be reproduced [5].

18.3 Empirical Data Analysis

In 1999, Barabasi and Albert [6] proposed a simple model (BA model) of network growth realizing a power law with the concept of preferential attachment in which a new link is more likely to be attached to a node that has a larger number of links. Their simple algorithm creates an ever-growing network with cumulative distribution of link numbers following a power law with an exponent of two. In 2006, Moore and his collaborators [7] proposed a revised model with the event of node annihilation into the evolution process. This is suitable for such networks as *WorldWideWeb* because web pages are often deleted. However, like the BA model, their model could create only networks that obey the same power law.

Based on this discussion, Miura, Takayasu and Takayasu [8] proposed a new general network evolution model (MTT model).

Their model is described as follows:

Starting with any given network structure with directed links, one of the following three processes are chosen at one time step:

1. With probability a, one node is chosen randomly and it is annihilated together with the connecting links.
2. With probability b, one node is created. The new node has one in-link and one out-link. The partner nodes connecting to these new links are chosen randomly following the preferential attachment rule which is explained in the third section.
3. With probability c, a pair of nodes are chosen randomly and they coagulate making one node with conserving links. Merging nodes are chosen randomly following the preferential attachment rule which is also explained in the third section.

The parameters satisfy, $a + b + c = 1$, and the processes are repeated.

Their model seems to be suited to apply business network evolution for the following two reasons. First, their model realizes a statistically steady state in which cumulative distribution of the number of links of networks obeys a power law with an exponent close to the empirical value of 1.4 by tuning the parameters. Second, their stochastic model directly treats firm events of establishment, bankruptcy and merger that can be compared with the real data.

For these reasons, we analyze the data from the viewpoint of the MTT model.

1. Exponent of preferential attachment
   As for the analysis of the "Exponent of preferential attachment," the MTT model realizes cumulative distribution of number of links of business networks when both preferential exponents of creation nodes and coagulation nodes are the same. Here, we consider not only establishments but also mergers as the event of node creation; that is, we analyze both preferential exponents of creation nodes (establishments) and coagulation nodes (mergers).

2. Properties of bankrupt firms
   As for the analysis of the "Properties of bankrupt firms," the MTT model assumes an independent annihilation node in its process. We check this in the data.
3. Lifespan of trades
   Finally, we analyze the "Lifespan of trades" using trade network data and bank–trade network data. Through business activities, firms try to forge new relationships with others to earn money and to exchange old trades with ones that have better conditions. That is, links in the Japanese interfirm trade network also follow a constant metabolism, as do nodes. The MTT model indirectly assumes that the metabolism of links is replaced randomly by using the process of annihilation nodes. With regard to research analysis, there are some economic studies on these topics in the form of firm–firm trades and firm–bank trades in economic field [5, 9].

18.3.1 Exponent of Preferential Attachment

As mentioned above, preferential attachment is a key concept that means that a new link is more likely to be attached to a node with a larger number of links. Although the MTT model considered the exponents of preferential attachment of creation nodes and those of coagulation nodes as different parameters, the model assumed that both parameters had the same values when they were simulated to reproduce the properties of the Japanese interfirm trade network. Therefore, we check this assumption empirically.

Here, we follow the manner of adopting the MTT model in order to observe the preferential exponent.

$$\kappa(k) = \int_0^k \frac{Q(k)}{N(k)} dk \sim k^{\alpha+1} \qquad (18.1)$$

where $Q(k)$ is the probability of connecting to an old firm with degree k and $N(k)$ is the number of nodes with degree k. We observe the following integrated attachment rate function to reduce fluctuation, as introduced by Jeong et al. [10]. As shown in Fig. 18.2, all of the obtained $\kappa(k)$ of established firms and that of merged firms are approximated by power laws with exponents of 2.4 and 1.5, respectively. In addition, both distributions of in degrees and out degrees are roughly the same.

Miura et al. [8] used the data that cannot be distinguished between established firms and merged firms. Therefore, they decided to set each preferential exponent $\lambda_b = \lambda_c = 1$ for their simulation. In this study, we use the data that can be distinguished between established firms and merged firms. We find that the preferential attachment's effect of established firms is stronger than that of merged firms with exponents of about 1.4 and 0.5, respectively. This makes sense because

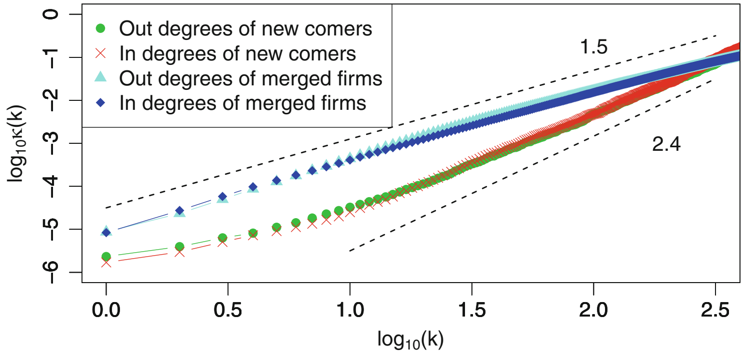

Fig. 18.2 Cumulative distribution of number of trades of firms that were attached by newcomers or merged firms in log-log scale (*green circles* for out degrees of firms that were attached by newcomers and *red crosses* for in degrees, *light blue triangles* for out degrees of firms that were attached by merged firms and *blue squares* for in degrees). The *bottom-dashed* guideline shows a line segment with *slope* $\simeq 2.4$ that fits well with the newcomers' distribution from 1.0 to 2.5 of the horizontal axis (*Adjusted R squared* > 0.99) and the *top-dashed* guideline shows a line segment with *slope* $\simeq 1.5$ that fits well with merged firms' distribution from 0.0 to 2.5 of the horizontal axis (*Adjusted R squared* > 0.99)

merger firms should choose counterparties with delicate business strategies that may not be related to the degree.

18.3.2 Properties of Bankrupt Firms

In the annihilation process of the MTT model, a node is chosen randomly. To verify the validity, Miura and his collaborators observed and empirically checked the lifespan of firms. As a result, the distribution was confirmed to be approximated well by an exponential function and they confirmed the validity of this process. Similarly, we observe the lifespan of about 500,000 bankrupt firms with data stored from 1990 to 2014. By comparison, we observe the years of existence of about 1,400,000 firms in 2013.

Figure 18.3 shows both distributions are roughly the same and well characterized by an exponential function, $P \geq (t) \propto \exp(\frac{-t}{\tau})$, where $\tau \simeq 23$ years ($\tau \simeq 19$ in Miura et al. [8]). It seems to be reasonable to annihilate a node randomly in the network evolution process from the viewpoints of lifespan of firms.

We know that bankruptcy is caused by various kinds of factors. For instance, we compare the distribution of sales of nonbankrupt firms with that of sales just before bankruptcy. As shown in Fig. 18.4, both distributions follow power laws, but the exponents are 1.3 and 0.9, respectively, and so, firms with obviously low sales tend to go bankrupt more than firms with high sales. Although random choice of the annihilation node is reasonable from the viewpoint of the lifespan of firms,

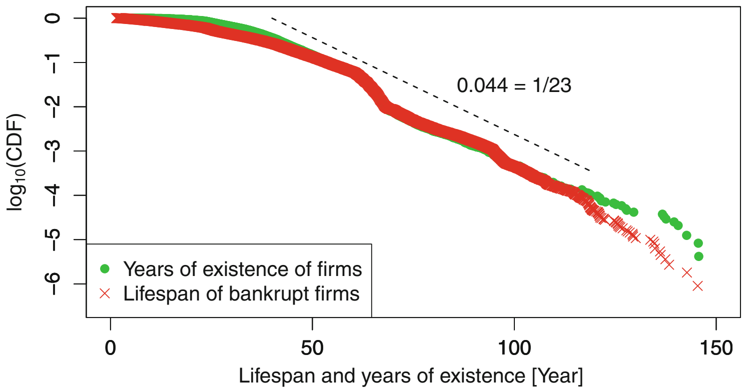

Fig. 18.3 Cumulative distribution of lifespan of firms in semi-log scale (*green circles* for the years of existence of firms for 2013 and *red crosses* for the lifespan of bankrupt firms for 1990–2014). The *dashed* guideline shows an exponential distribution with $\tau \simeq 23$

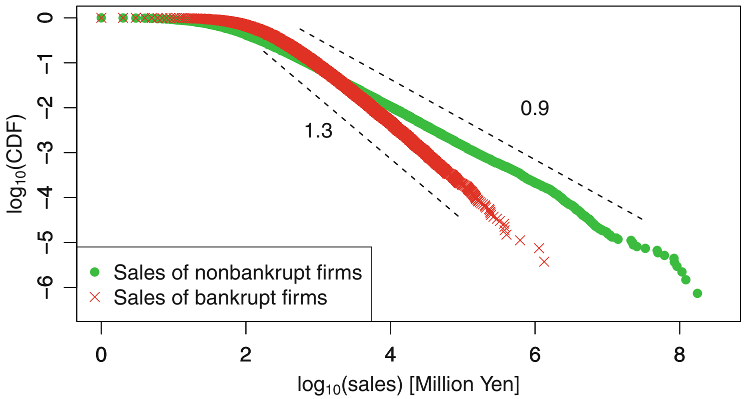

Fig. 18.4 Cumulative distribution of sales in log-log scale (*green circles* for sales of nonbankrupt firms for 2013 and *red crosses* for sales just before bankruptcy from 1990–2014). The *dashed* guidelines show power laws with 0.9 and 1.3

it is not suitable from a practical point of view. As for the model for Japanese interfirm network evolution, we should take account of various states of firms by using financial statements.

18.3.3 Lifespan of Trades

To clarify the behavior of links from the viewpoint of metabolism, here, we estimate the lifespan of links on the Japanese interfirm trade network.

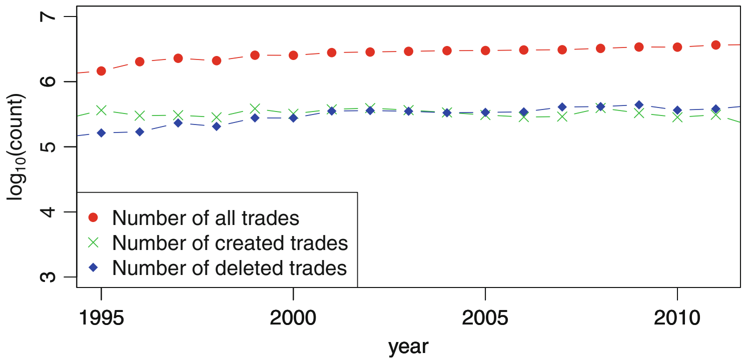

Fig. 18.5 Time evolution of the numbers of all trading links, newly created links and deleted links in semi-log scale (*red circles* for the number of all trades, *green crosses* for the number of created trades and *blue squares* for the number of deleted trades)

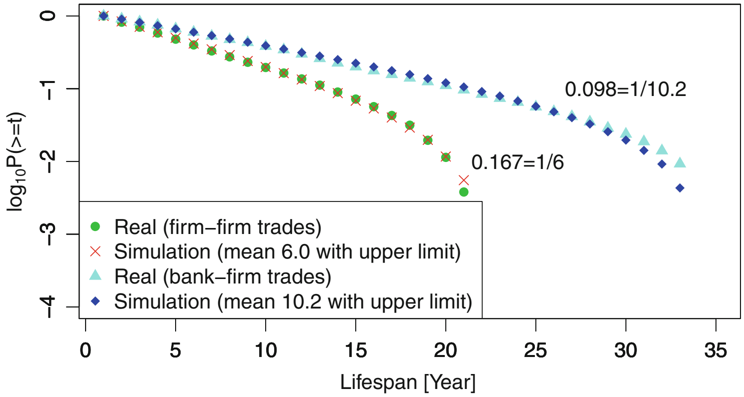

Fig. 18.6 Distribution of lifespan of firm–firm trades and bank–firm trades in semi-log scale (*green circles* for real trades for 1994–2014, *red crosses* for simulation of exponential distribution with the mean 6.0 and upper limit, *light blue triangles* for real bank–trades for 1981–2014 and *purple squares* for simulation of exponential distribution with the mean 10.3 and upper limit)

First, we stack all time-series Japanese interfirm trade network data from 1994 to 2014 and then, we estimate the start date and end date for each trade link. As shown in Fig. 18.5, the numbers of all trade links, created links and deleted links per year are almost steady. We find that about 15 % of trades are replaced each year.

Moreover, we observe the lifespan of trades by using stacked trade network data by the green circles in Fig. 18.6. These are expected to be characterized by the following exponential function just like the case of the lifespan of firms.

$$P_{firm-firm}(\geq t) = \exp(\frac{-t}{\tau}) \tag{18.2}$$

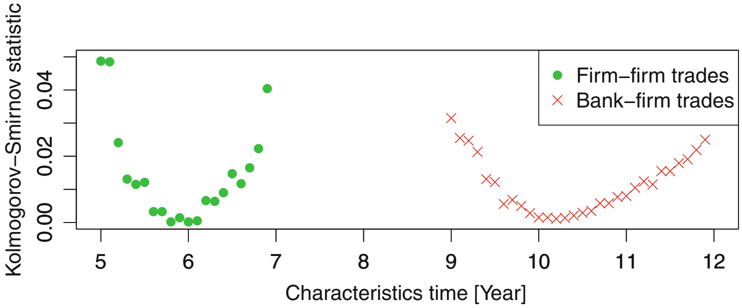

Fig. 18.7 Two-sample Kolmogorov-Smirnov statistical distribution between real data and simulation (*green circles* for firm–firm trades for 1994–2014 and *red crosses* for bank–firm trades for 1981–2014). As for firm–firm trades, Kolmogorov-Smirnov statistics take the minimum values 0.0006 when the characteristic time takes 6.0. As for bank–firm trades, Kolmogorov–Smirnov statistics take the minimum values 0.0010 when the characteristic time takes 10.2

The value of τ can be estimated by the survival rate of links per year, $1 - 0.15$, which should be given by $\exp(-\frac{1}{\tau})$. Then, we have $\tau \simeq 6$ years. We check the validity of this result by simulating the lifespan of trades following Eq. (18.2) and observing lifespan with the time window of 20 years, that is, the length from 1994 to 2014. As for the evaluation function to estimate the characteristics time τ, we use the two-sample Kolmogorov–Smirnov test [11], which can be used to test whether two distributions differ. The definition of the test statistic is $4D^2 \frac{n_1 * n_2}{n_1 + n_2}$, where D is a maximum vertical deviation between two distributions and n_1 *and* n_2 are the number of samples of each distribution. That is, if there is a small difference between two distributions, the test statistics take a small value. Figure 18.7 shows the statistical distributions of firm–firm trades by the green circles. It seems to be reasonable that the characteristic time is $\tau = 6.0$ for the firm–firm trade distribution. The red crosses in Fig. 18.6 show the simulation results with the characteristic time $\tau = 6.0$, which fits well with the real data.

In addition, we analyze the lifespan of bank–firm trades. The light blue triangles in Fig. 18.6 show the lifespan of that by using stacked data from 1981 to 2014. As shown by the statistical distributions of the red crosses in Fig. 18.7, it seems to be reasonable that the characteristic time is $\tau = 10.2$. The purple squares in Fig. 18.6 show the simulation results with the characteristic time, which fits well with the real data. We derive the following exponential distribution, meaning that about 10 % of bank–firm trades are replaced in each year.

18.4 Conclusion

In this study, we empirically analyzed time-series Japanese interfirm trade networks from the viewpoint of scale-free network evolution and we found some new properties of the Japanese interfirm trade network. As for our analysis of preferential exponents, we found that the preferential attachment effect of established firms is stronger than that of merged firms with exponents of about 1.4 and 0.5, respectively. With regard to our analysis of the lifespan of firm–firm trades and bank–firm trades, we confirmed that they follow exponential distribution with means about 6.0 and 10.2, respectively. The results imply the link creation and deletion is well characterized by a Poisson process, so this shows that the metabolism of links is replaced randomly. For our future work, we aim to check the robustness of the metabolism of trades from the viewpoints of firm characteristics such as sales scale and business categories.

Acknowledgements We would like to express our appreciation to Center for TDB Advanced Data Analysis and Modeling, Tokyo Institute of Technology for providing the datasets. This study is partially supported by the Grant-in-Aid for Scientific Research (C), Grant Number 24540395 and (B), Grant Number 26310207.

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