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The structure of global inter-firm networks

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Abstract. We investigate the structure of global inter-firm relationships using a unique dataset containing information on customers, suppliers, licensors, licensees and strategic alliances for each of 412,814 major incorporated non-financial firms in the world. We focus on three different networks: customer-supplier network, licensee-licensor network, and strategic alliance network. In/out-degree distribution of these networks follows a Pareto distribution with an exponent of 1.5. The shortest path length on the networks for any pair of firms is around six links. The networks have a scale-free property.

Keywords: Inter-firm relationship, Scale-free network

1 Introduction

The structural weakness of supply chains in the world was exposed by the 2011 Thailand floods. On 8 October 2011, Rojana industrial estate which housed many manufacturing plants flooded by the 2.5 meter high water. The economies of countries besides Thailand were significantly impacted by the flood. For example, many of the factories that make hard disk drives were flooded. As a result, most hard disk drive prices nearly doubled worldwide. Thailand's flood contributed to a total estimated US$259 billion in economic losses for the first nine months of 2011. These losses represented 80% of the world's total economic losses, and the floods emphasized the importance of understanding the structure of inter-firm networks to avoid production disruptions.

The study of networks, which is an active area of scientific research inspired by the small-world network model published in 1998 [1], has attracted attention as a new paradigm that explains such real-world phenomena as computer and social networks. In previous works, network scientists also studied inter-firm networks, e.g. the relationship between firms and banks [2], customer-supplier networks [3][4][5][6][7], and shareholder and ownership networks [8]. In this paper, we introduce the key structures of three different networks of major international firms: customer-supplier network, licensee-licensor network, and strategic alliance network.

Our dataset was compiled by Standard & Poor's Financial Services LLC (S&P). The dataset covers 412,814 major incorporated non-financial businesses, including all the listed companies in the world. Information on global inter-firm relationships is recorded in this dataset. The dataset records the lists of core partners (i.e. customers, suppliers, licensors, licensees, and strategic alliances) for a firm, with their IDs. For example, numbers of core customers and suppliers for IBM are 446 firms and 216 firms, respectively for recent two years (2012 and 2013). There is the relationship between customers and suppliers. When firm j is a supplier to firm i, firm i is a customer of firm j. We also use an inverted list of customers and suppliers from the above list of core partners. We also make an inverted list of licensors and licensees, and one of strategic alliances by the same method.

2 Scale-Free Networks of Major Global Firms

We show the global network of customer-supplier relationships in Fig. 1. We will investigate the network structure. In Fig. 2 We show the cumulative distribution functions (CDFs) of links across firms for the customer linkages, supplier linkages, licensor linkages, licensee linkages, and strategic alliance linkages. The horizontal axis is the number of links, and the vertical axis represents the cumulative densities. Both the horizontal and vertical axes are in logarithm. The CDFs of the supplier links show a linear relationship between (the log of) the number of links and (the log of) the corresponding cumulative probability. The slope is about -1.5:

$$\text{Supplier} : P_{>}(N_s) \propto N_s^{-1.5}. \tag{1}$$

For the number of customer links, licensee links, licensor links and strategic alliance links, we again find a linear relationship between (the log of) the number of links and (the log of) the corresponding cumulative density. Moreover, these slopes of the linear relationship are close to the slope for the supplier links. These linkage slopes are about -1.5, and thus the CDFs for the number of links, which are denoted by N_c, N_{le}, N_{lo} and N_{sa}, can be characterized by

$$\text{Customer} : P_{>}(N_c) \propto N_c^{-1.5}, \tag{2}$$

$$\text{Licensee} : P_{>}(N_{le}) \propto N_{le}^{-1.5}, \tag{3}$$

$$\text{Licensor} : P_{>}(N_{lo}) \propto N_{lo}^{-1.5}, \tag{4}$$

$$\text{Strategic alliance} : P_{>}(N_{sa}) \propto N_{sa}^{-1.5}. \tag{5}$$

Equations (1)-(5) show that the number of links follows a Pareto distribution. Such a network is called a scale-free network. Moreover, those exponents are close to unity. Pareto distributions with exponent of 1, which are found in various phenomena including firm size distributions, are referred to as Zipf's law. This result suggests that firm size is related to the number of links.

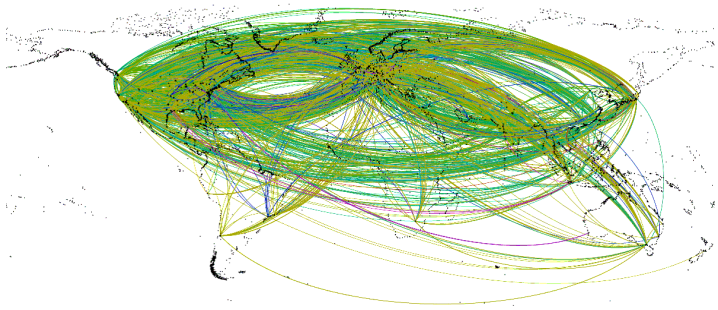

Fig. 1. Global network of customer-supplier relationships. The color expresses a community structure in the network.

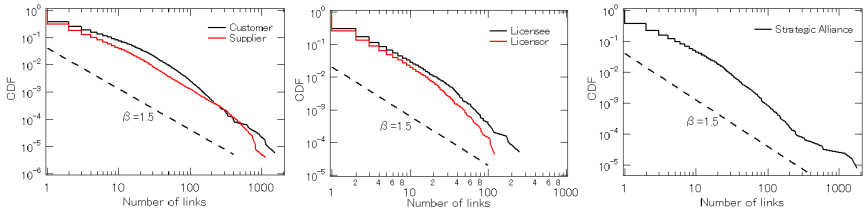

Fig. 2. Cumulative distributions for numbers of (left) customer and supplier links, (right) licensee and licensor links, (bottom) strategic alliance links. Dashed lines show Pareto distributions with an exponent of 1.5.

3 Closely Interconnected Firms and Firm Growth

The number of firms that did business continuously on the customer-supplier network was 345,909, so there are about 119 billion pairs of firms. We calculated the shortest path lengths for each pair of firm i and firm j (i.e. the shortest cut among alternative paths connecting firm i to firm j) on the non-directed customer-supplier network. The number of firms in the maximum connected component of this network is 318,080, that is 92% of all firms. It is observed that 65.5% of all pairs are connected, but 34.5% cannot be connected regardless of how many path lengths there are. Figure 3 shows the distribution of the shortest path lengths for those connected pairs. The mode of distribution is five path lengths, and about 78.8% of the pairs are connected by six path lengths or fewer. We also investigate the mode for the directed customer-supplier network in order to consider the money and intermediate product flow. The mode is also short, only seven path lengths. We also show the mode is short for the non-directed licensee-licensor network and for the non-directed strategic alliance network in Fig. 3. Their modes are six path lengths.

Closely interconnected networks are called small-world networks. A representative example is an airline route map. Hub airports create close interconnections between areas. World inter-firm networks also have hub firms that collect many linkages, as is the case for airline route maps, because the number of links follows a Pareto distribution. The presence of such hub firms implies that even a local firm can be connected to a large number of firms in the world; once a local firm finds a path to one of the hub firms (probably by several path lengths), it is then connected to many firms in the world to which the hub firm is linked.

Close interconnectedness among firms implies that an idiosyncratic shock to a firm could diffuse widely to other downstream firms through business relationships on the networks. To investigate such diffusion on the networks, we compute the correlation in daily stock price returns between two firms, firms i and j, which is represented by ρ_{ij}. I use logarithm price returns of listed firms from 01/04/2010 to 05/27/2014 in NYSE. We then examine how ρ_{ij} is related to the shortest path length between firms i and j. The results are shown in Fig. 4, which depicts the logarithm price return correlation between firm i and j is related to the shortest path length l_{ij} between them. Y-axis expresses the average of ρ_{ij} conditional on that the shortest path length is l. The correlation decreases with the shortest path length. This result indicate that there is a positive correlation between the stock price return s for firms i and j if they are close to each other in the networks.

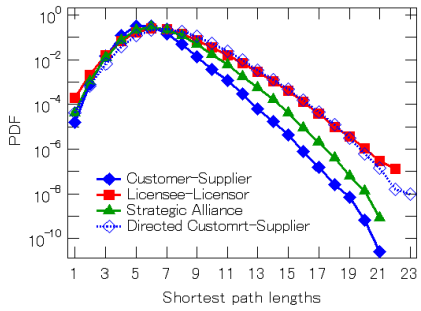

Fig. 3. Probability density function of shortest path lengths for all pairs of firms.

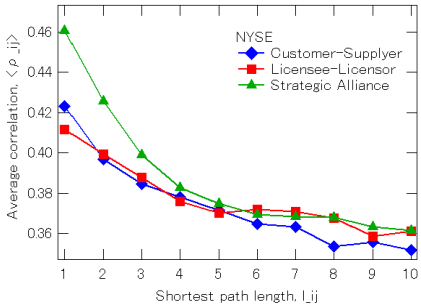

Fig. 4. Average of the stock price return correlations between pairs of firms conditional on the shortest path length between the pairs.

4 Conclusion

We investigated the structure of world inter-firm relationships using a unique dataset that contains information of business relationships for each of 412,814 incorporated non-financial firms. We focused on the characteristics of the number of customer, supplier, licensor, licensee and strategic alliance links per firm. The distribution for the number of links has a heavier upper tail than log-normal distributions and follows a Pareto distribution. Firms are closely interconnected with many other firms by hub firms in the Pareto distribution's tail. The mode of the shortest path lengths for all pairs of firms is about six links, suggesting that firm performance potentially depends on many more firms in various countries and not simply the number of direct business partners.

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