Proceedings of the 2016 Winter Simulation Conference
T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, eds.

THE IMPACT OF HUMAN RELATIONSHIP ON BANKRUPTCY-RELATED EVOLUTION OF INTER-FIRM TRADE NETWORK

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ABSTRACT

This paper studies the impact of human relationship on the evolution of inter-firm trade network emerged from bankruptcy. Based on the extracted properties of Japanese firm data in 10 years, we propose an agent-based model and conduct series of simulation experiments to evaluate several aspects of human relationship effects. The simulation results indicate that human relationship delays the bankrupt spread and promotes the average performance of firms. By examining different scenarios, we found the influential features of human relationship that are likely to help firms to survive in the bankrupt propagation process.

1 INTRODUCTION

The dynamic evolution of inter-firm trade network, which is generated from firms' business interactions and represents economic activities (Ohnishi et al. 2010), attracts more and more attention in recent years. Like most inter-firm networks, inter-firm trade network keeps evolving slowly over time. However, when facing external influences like bankrupt, the evolution becomes very dramatic (Aggarwal and Subbian 2014).

The bankrupt evolution of the inter-firm trade network, commonly known as bankrupt chain (Ikeda et al. 2007), has been interesting to many scholars. After a company goes bankrupt, the bankruptcy often causes a snowball effect within a short period (Gatti et al. 2009). Researches not only studied the statistical features by empirical analysis (Fujiwara 2008, Hong et al. 2007), but also modeled the dynamic bankrupt propagation using agent-based simulation approach (Battiston et al. 2007). However, the underlying factors of such evolution have often been ignored in the current literature. While the evolving phenomenon of inter-firm trade network is very complicated, it is important to understand its internal factors. Therefore, using an agent-based model, we aim to fill the gap of understanding one important mechanism of inter-firm bankrupt evolution, which is the human relationship.

In this paper, human relationship is conceptualized as the inter-firm human-related tie by using senior executive information. As some of the executives belong to more than one firm, such human-related ties are constructed among the firms. We analyze the features from Japanese firms and based on which propose an agent-based model. By simulating the inter-firm trade network evolution, we made two main contributions on the impact of human relationship: first, evaluate the influence of human relationship in the inter-firm trade network evolution rising by bankrupt; second, measure the importance of different inter-firm human relationship in bankrupt diffusion process.

The rest of this paper is organized as follows. In Section 2, we propose our research hypotheses and review their theoretical and practical base. Section 3 presents our agent-based model with the ODD protocol. In Section 4, we describe the detailed simulation setup, whereas several experiments and their results are discussed in Section 5. Finally, we summarize this paper and our future work.

2 HUMAN RELATIONSHIP IMPACT HYPOTHESIS

In this work, the following two hypotheses are studied, as well as their theoretical and practical explanations.

- Hypothesis 1: Human relationship influences inter-firm trade network bankrupt evolution.
- Hypothesis 2: Good human relationship brings positive influence to firms in bankrupt diffusion.

2.1 Theoretical Base

Entrepreneurs generally play an important role in the organization science. Executives and founders are considered as *resource coordinators* for a firm (Bhide 2000), since they usually bring their personal human relationship to firms as a potential source of competitive advantage (Aldrich et al. 1987). Social capital has been contemplated as a kind of asset stocks to measure the resource ability of one firm (Ahuja 2000). Therefore, human relationship is often utilized by executives to support their business achieves (BarNir and Smith 2002). Especially in the critical and emergent situations, senior executives tend to rely on personal level ties as the inter-organizational relationship (Bhide 2000). Based on these arguments, the proposed hypotheses suggest that human relationship is also important when firms are facing bankrupts in a trade environment.

The importance of human relationship has been indicated in different levels: from facilitative to substantive (Ahuja 2000). In the facilitative level, human relationship mainly provides the collaboration opportunities (Gulati 1999), while human relationship benefits more in exchanging resource and information in the substantive level (Bhide 2000). For example, executives communicate with each other and share their knowledge, which gives the partners access to extra information and resources (Hite and Hesterly 2001). Rather than marginal effect in facilitative level, this paper considers the substantive benefits of human relationship.

2.2 Practical Data Analysis

Real Japanese firms data is used to analyze the role of human relationship in both inter-firm trade network and bankrupted firms. The dataset is provided by the joint project of TDB (Teikoku Databank LTD) and Tokyo Institute of Technology, which includes detailed financial information of billions of Japanese firms from 2005 to 2015.

We found that human relationship is a very important property between trade firms. According to the data, about 8 millions trade links within Japanese firms are constructed from their historical trade records. In this trade network, there is a large amount of human ties, as over 20% senior executives are serving in more than one Japanese firms. By considering two firms sharing the same executive member, more than 2 millions inter-firm human links are generated among the firms and constructed as a whole of inter-firm human network.

In addition, the empirical analysis in bankrupted firms presents an obvious diversity in their human relationship. By collecting human links of bankrupted firms, the human degree distribution shows a power law feature: while most bankrupt companies do not have human partners in the industry, over 60% of bankrupt firms with human relationship have more than 10 human partners. The observation implies the different effects of human ties to bankruptcy. This has been motivating us to examine the internal human relationship impact in bankrupt diffusion by agent-based simulation.

3 AGENT-BASED MODEL

Based on the hypotheses, we present the agent-based model following the ODD (Overview, Design concepts, Details) protocol in this section (Grimm et al. 2010).

3.1 Purpose

In this work, the agent-based model is designed to investigate the role of human relationship in the bankrupt diffusion process of inter-firm trade network. There are two main questions to be examined: 1) whether human relationship affects the inter-firm bankrupt evolution; 2) does different human relationship have different influence on the process, and which kinds are more influential. By exploring these questions, we aim to understand the internal mechanism of inter-firm bankrupt propagation, then seek good features or strategies of human relationship, which can help firms to recover from near bankruptcy.

3.2 Entities, State Variables and Scales

In this model, three types of entities are presented from the real phenomenon. The inter-firm trade network is extracted as the market environment, and each firm is considered as an individual agent. Senior executives of the firm are conceptualized as manager entities of each agent to measure human relationship. Table 1 shows the description of entities and their state variables.

Table 1: Entities and state variables.

Entities	Description	State variables
Environment	Overall market environment	Agents ($agent_1 ... agent_n$), Trade relationships, Human relationships, Social aspiration level, Time stamp
Agent ($agent_i$)	Individual firm i	ID = i, Managers ($manager^i_1 ... manager^i_m$), Status, Performance, Internal fitness, External resource, Historical aspiration level
Manager ($manager^i_j$)	Senior executive j of firm i	ID = j, Knowledge vector, Fitness

Table 2: State variables in detail.

State variables	Description	Detail
Trade relationship	Supplier-customer tie between firms	R_t is directed
Human relationship	Executive-based tie among firms	R_h is undirected
Time stamp	Simulation time	$t \in [0, 20]$
Social aspiration level	Overall performance in the environment	$AS \in (0, 1)$
Status	Economy status of firm i	$S^i \in \{S_h, S_d, S_b\}$
Performance	Economy performance of firm i	$P^i \in (0, 1)$
Historical aspiration level	Performance history of firm i	$AH^i \in (0, 1)$
Internal fitness	Internal fitness of firm i	$IF^i \in (0, 1)$
External resource	External resource of firm i	$ER^i \in (0, 1)$
Knowledge vector	Knowledge content vector of manager j	$V^j = (0, 1, 1...)$
Fitness	Fitness of manager j	$F^j \in (0, 1)$

The detailed descriptions and scales of state variables are shown in Table 2. The environment contains both human (R_h) and trade relationship (R_t). Among them, trade links represent firm's trade records with directions, while human relationship is the undirected inter-firm human links from executive information of firms. In the environment, simulation time is defined as a time stamp variable t, which varies from 0 to 20 (as one time step represents half a year and simulations are run for 10 years), and the performance of all firms is defined as the social aspiration level (AS) (Greve 1998).

We define three statuses for agents (i.e. firms) healthy, distressed and bankrupt (Cybinski 2001). Healthy status (S_h) means the focal firm is successful and wants to persist its current trend. Distressed status (S_d) means the focal firm is currently facing an economic emergency and taking action to survive from near bankrupt. Bankrupt status (S_d) means the focal firm is completely failed. The performance of a focal agent i is defined as P^i, while its performance history is conceptualized as the historical aspiration level (AH^i) (Greve 1998). The agent's performance is weighted summation of two parts: internal fitness (IF^i) and external resource (ER^i), which represent two aspects of firm's economic situation. We model knowledge evolution of manager j of agent i as a binary vector (V^j). During the simulation, the vector is being updated and consequently results in updates of the manager's fitness (F^j).

3.3 Process Overview and Scheduling

This agent-based model simulates both agent's internal adaptation and interactions within the inter-firm environment. Figure 1 presents the overall simulation circle (left) and status transition flow of agents (right).

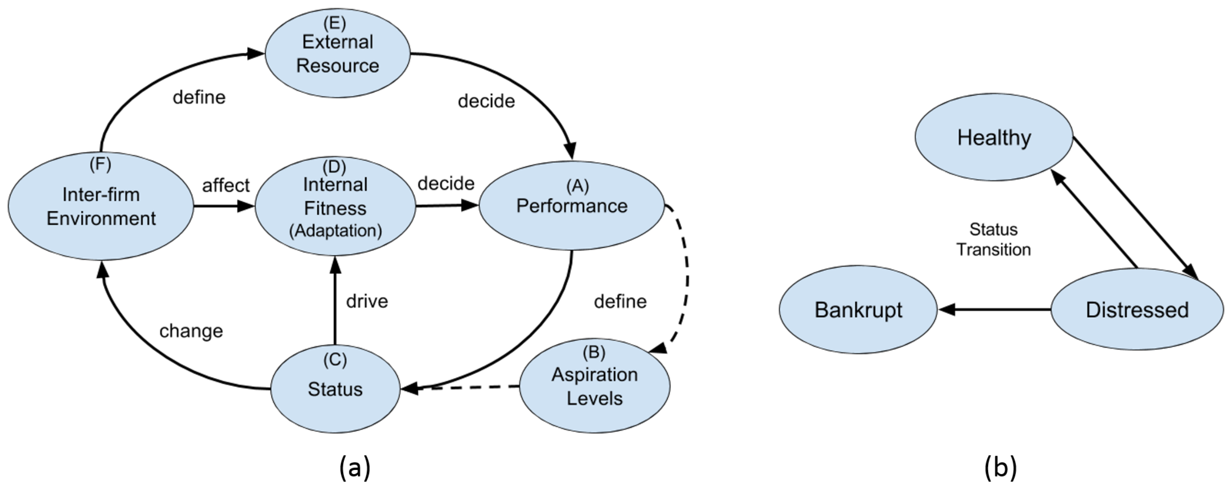

Figure 1: Overall simulation circle (a) and status transition flow (b) of the agent-based model.

In the Figure 1-(a), each agent holds a performance (A) at the current time step t. Considering its performance with aspiration levels (B), the agent has an economy status (C). Different statuses drive different adaptive behaviors, and also change the inter-firm environment (F). The agent updates the internal fitness (D) for the next time step by internal adaptation, while the market environment forms its external resource (E). Combing the internal and external economic situation, the agent has a new performance, which drives the adaptation of simulation time $t+1$. In this way, agents take actions to adjust and interact with the environmental over time. In particular, as shown in Figure 1-(b), agents cannot transfer back to either distressed or healthy status once they bankrupted.

3.4 Design Concepts

3.4.1 Basic Principles

In the model, as each agent represents one firm, the organization behavior theories are mainly employed as the basic design concepts. Overall, there are two kinds of principles, including the individual agent behavior and impact of inter-firm environment.

A common assumption in organization learning is that the firm tends to learn from its experience and take actions based on its performance (Huber 1991). To better understand current situation, the aspiration level is often used as *the borderline between perceived success and failure and starting point of doubt* (Lopes 1987). The model follows the well studied assumption and integrates two aspiration levels (social and historical) (Cyert and March 1963). The historical and social aspiration levels of focal agent i at time t are defined in equations (1) and (2) respectively (Greve 1998). In the equation (1), α is the weight factor of performance influence on historical aspiration (AH_t^i). Social aspiration level (AS_t) is the mean of performance of all firms in the inter-firm environment at time t.

$$AH_t^i = \alpha P_{t-1}^i + (1-\alpha) AH_{t-1}^i. \tag{1}$$

$$AS_t = \frac{1}{n} \sum_{i=1}^{n} P_{t-1}^i. \tag{2}$$

Therefore, the first principle of model behavior design is that a variety of agent statuses drive various agent behaviors, as the firm behaves differently based on whether the performance attains its goal (Cyert and March 1963). In particular, various agent statuses are determined by agent's performance relative to the aspiration levels. The statuses of agent i at time t are defined in equation (3). When the performance (P_t^i) is larger than both social (AS_t) and historical (AH_t^i) aspiration levels, agent i is healthy (S_h). In contrast, the agent goes bankrupt (S_b). If the performance is between two of them, agent i is distressed (S_d).

$$S_t^i = \begin{cases} S_h, & \text{if } P_t^i > Max(AH_t^i, AS_t); \\ S_d, & \text{if } Max(AH_t^i, AS_t) > P_t^i > Min(AH_t^i, AS_t); \\ S_b, & \text{if } P_t^i < Min(AH_t^i, AS_t). \end{cases} \tag{3}$$

At the same time, the inter-firm environment affects the agent's behavior through links between firms as well. In the model, both trade and human relationships constitute the environmental effect. Moreover, organizational theory suggests that the impacts from these two kinds of links are various, which is the second basic concept in the model design. In the organizational resource perspectives, inter-firm ties are forms of resource (Pfeffer and Salancik 2003), which provide value for related firms (Mahoney and Pandian 1992). Facing with emergency of trade partner's bankrupt, which is equivalent to alliance dissolution, the firm often takes action in response to the external resource challenge (Hite and Hesterly 2001). Thus, the trade link is conceptualized as the external resource-based factor. By contrast, inter-firm social ties play a more substantive role on partner firms (Hite and Hesterly 2001), as the executives are important inter-firm knowledge transfer (Malecki 1997). By carrying information across firms to overcome local search (Rosenkopf and Almeida 2003), human relationship affects the internal adaptation of organizations.

3.4.2 Objectives

One important objective in the model is performance, which measures the success of firm's economy and drives agent's behavior. The performance is defined in equation (4), where it combines both internal fitness (IF_t^i) and external resource (ER_t^i). Parameter ε is the adjustment factor that defines the weight of internal and external influences on performance.

$$P_t^i = \varepsilon IF_t^i + (1-\varepsilon) ER_t^i. \tag{4}$$

At the same time, as adaptive trait for each manager entity, the fitness of manager shows the overall operation situation at each time step. The internal fitness of a focal agent i at time t is conceptualized as the average fitness (F_t^j) of its managers in equation (5), where agent i has m managers in total.

$$IF_t^i = \frac{1}{m} \sum_{j=1}^{m} F_t^j \tag{5}$$

3.4.3 Adaptation

In the model, the adaption of an agent is executed by its managers. Each independent manager has a knowledge vector showing the current situation and obtains the fitness based on a function of knowledge vector in the NK model (Kauffman and Weinberger 1989). In each simulation time, the manager updates the knowledge vector to pursue a better fitness.

Figure 2 gives an example of the adaptation process. With the human relationship, a focal manager j not only searches locally by self experience, but also acquires knowledge from other human partners (Doz 1996). Such knowledge exchange behavior provides manager j more information to act and update the fitness for the next simulation time. Within many possible choices (from local search and all social partners), the manager generally has two kinds of behaviors: 1) filter the candidate situations with better fitness and select one based on the majority rule (Harris and Raviv 1988); 2) choose the update at random.

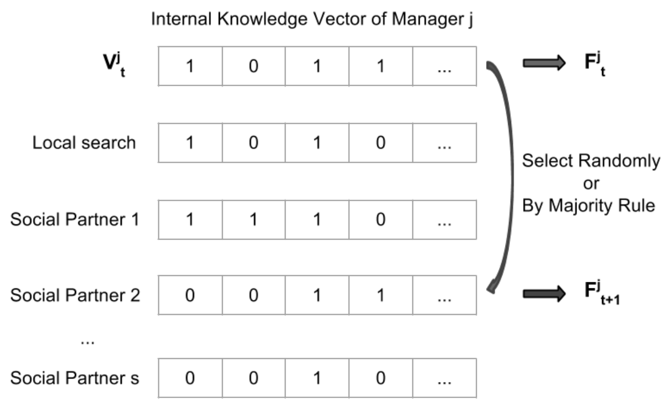

Figure 2: An example of internal adaptation.

In general, as the unhealthy status of agents restricts the energy of managers to behave actively, the status of manager's agent determines how it updates. In particular, the manager of agents in distressed selects from candidate updates randomly, while the healthy manager follows the majority rule and only chooses the knowledge vector that contributes to a better fitness.

3.4.4 Sensing

Agents are sensing the inter-firm trade network environment to define their external resource. The trade links of agent i generally build an ego economic environment, which brings the agent valuable resources. While the trade linkage equally affects the trade partner on both sides, the amount of transaction brings different resources (Gulati 1999). Thus, the weight of trade linkage between agent i and k is defined as W^i_k. Moreover, if the trade partners of agent i are in different statuses, the impact from them are also different. In particular, the effect factor of agent k (a trade partner of agent i) on agent i is defined in equation (6), where S^k_t is the status of agent k at time t.

$$f^k_t = \begin{cases} 1, & \text{as } S^k_t = S_h; \\ 0.5, & \text{as } S^k_t = S_d; \\ 0, & \text{as } S^k_t = S_b. \end{cases} \tag{6}$$

Equation (7) presents the external resource of a focal agent i with total p trade ties at time t. Within the two multiplying parts in equation (7), the right part implies the overall economic situation around agent i, which is conceptualized as the average internal fitness of all trade partners. The higher average internal fitness provides agent i more valuable resource. Moreover, the left part of equation (7) shapes a healthy ratio of economic environment around agent i. It presents the percentages of outside valuable resources that the agent can receive. When all trade partners of agent i are healthy, the ratio reaches the highest at 1, in contrast, the bankruptcy of all partners brings 0 resource to agent i.

$$ER_t^i = \frac{\sum_{k=1}^{p} W_k^i f_{t-1}^k}{\sum_{k=1}^{p} W_k^i} \times \frac{\sum_{k=1}^{p} IF_{t-1}^k}{k} \tag{7}$$

3.4.5 Emergency

Experiencing a severe performance failure, an agent goes bankrupt in the model, which not only makes itself inactive, but also creates new risk to related agents by deleting its human and trade ties. Such dissolution of linkages changes the inter-firm network environment in the consequent periods.

3.4.6 Observation

We collect macro level data from the agent-based model to understand the dynamic evolution of environment over time, including bankrupt records and social aspiration level. In micro level, temporal performance of focal agents are recorded to measure the internal expression facing with bankrupt emergency.

3.5 Initialization

At the initial state, the model first constructs the agents and environment from the given inter-firm trade network. Then, managers of each agent are randomly generated and linked together based on the given human-based ties. Within state variables, knowledge vector of each manager is a set of random binary bits, which contributes to a value of manager fitness. In addition, the initial ratio of three agent statuses in the environment is controlled, while the status of each agent is set up at random. Other initial variables of agent and environment are calculated automatically by the model equations (See Table 2 and equations).

3.6 Input Data

There are two input data in this work, including the inter-firm trade network and inter-firm human network, which are constructed by the inter-firm trade and human relationship respectively. The two artificial networks are generated based on the properties of extracted Japanese inter-firm networks.

4 SIMULATION SETUP

In each simulation run, given an inter-firm business environment, few agents are initialized with bankrupt status, which brings bankrupt emergency into the environment. Then, we simulate and observe the inter-firm trade network evolution in 20 simulation times to understand the human relationship impact. Overall, the simulation result is averaged over 50 runs in each experiment.

4.1 Network Generation

As in the model, the inter-firm trade and human network determine the initial environment of each simulation, the generated networks in this study are firstly introduced. Previous researches have well studied the Japanese inter-firm trade network and shown its scale-free property (Miura et al. 2012, Goto et al. 2015). In addition, analysis of human relationship in real data indicates that the inter-firm human network has an obvious modularity feature and power law distribution. Thus, the trade-based network and human-based network are generated by Barabási-Albert (BA) model (Albert and Barabási 2002) and Lancichinetti-Fortunato-Radicchi (LFR) benchmark (Lancichinetti et al. 2008) respectively. LFR benchmark is often utilized to generate artificial benchmark networks that resemble real-world networks with both wide community structure and power law degree distribution, like the inter-firm human network. Erdős-Rényi (ER) random network and regular network are also constructed for other experiments. The examples of used networks are in Figure 3. Among them, the size of each node in network 1 represents its degree value, combining both in degree and out degree.

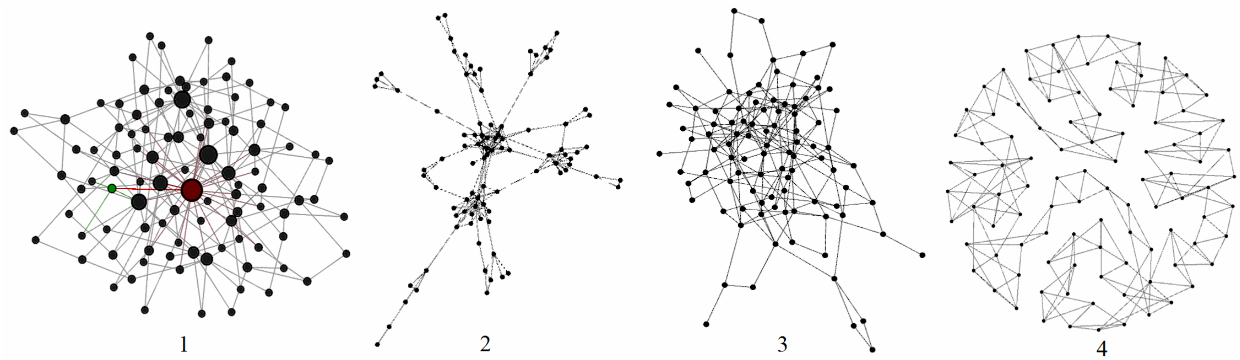

Figure 3: Examples of networks we use: 1) scale free 2) LFR benchmark 3) ER random 4) regular.

4.2 Parameter Setting

In each firm (i.e. agent), two senior executives (i.e. managers) are considered (i.e. $m = 2$). The settings of other parameters are presented in Table 3. We evaluate several groups of parameter settings and select the one with the most stable results. In NK model, the contribution and elements' relation table are both randomly generated at the beginning of each simulation. The initial ratio of three statuses in the environment is set up as 5% bankrupt, 25% distressed and 70% healthy agents. To include varying trade amounts in the trade network, the weight on every trade link is also selected randomly in set W.

Table 3: Parameter setting.

Parameter name	Setting
NK model	N = 10, K = 2
Initial agent status ratio	Bankrupt = 5%, Distressed = 25%, Healthy = 70%
Weight in equation (7)	$W_k^i \in W,$ where $W = \{1, 5, 10, 50\}$
Weight in equation (1)	$\alpha = 0.5$
Weight in equation (4)	$\varepsilon = 0.5$

5 EXPERIMENTS AND DISCUSSION

In this section, we describe features of the simulation experiments and discuss the results. Overall, three groups of experiments are conducted to evaluate: 1) evolutionary effects of human relationship; 2) evolutionary effects of different macro-level human relationship; 3) evolutionary effects of different micro-level human relationship.

5.1 Impact of Human Relationship

To study the effects of human relationship, in the first set of experiments, we simulate the inter-firm trade network evolving scenarios with and without inter-firm human network. In the scenario without human network, managers of the agent adapt the knowledge vector only by local search. In particular, healthy agents update only when local search contributes to a better fitness, while distressed agents update randomly.

The simulation results of the both scenarios are shown in Figure 4, which includes the temporal agent's bankrupt information (upper side) and social aspiration level (lower side) of three individual experiments. Simulations with 200, 300 and 500 agents are set up respectively with the same parameter setting as given in Table 3 and same network structures (See Figure 3-1 and 3-2 for trade and human network).

In Figure 4, we observe the similar results in three experiments with various number of agents. When bankrupt happens in the inter-firm trade network, the size of surviving agents follows a power law distribution, which matches the empirical evidence of firm size distribution (Hong et al. 2007). Comparing two scenarios,

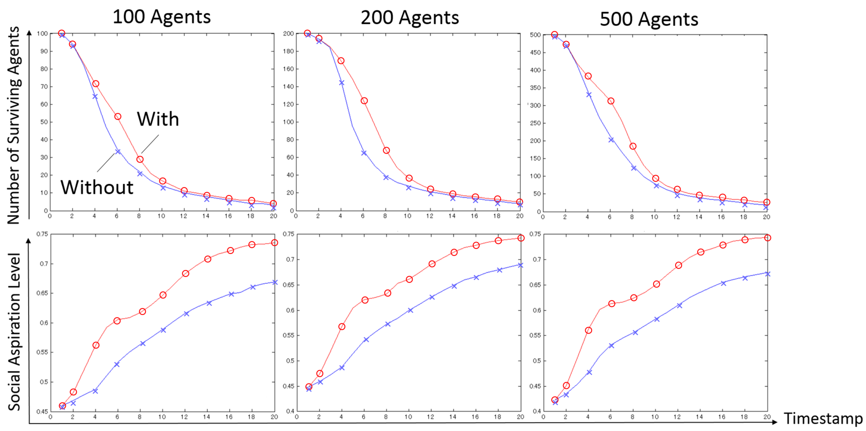

Figure 4: Temporal bankrupt and social aspiration level information with human relationship (○) and without human relationship (×).

the bankrupt diffusion of inter-firm trade network delays and the overall social aspiration level increases in the simulations with human relationship. This stable phenomenon indicates that human relationship is influential on inter-firm bankrupt transferring and promotes the average environmental performance.

5.2 Impact of Different Human Relationship

Having observed the effect of human relationship in the previous experiment, we seek to further understand the impact of different human relationship at both macro and micro levels.

5.2.1 Macro-level Human Relationship

To evaluate human relationship (i.e. inter-firm human network) with different macro-level network features, the same scale free trade network with different initial human networks are utilized. Two aspects of features, average degree and network structure, are examined in the experiments. First, the regular human network is used to control the network structure and analyze various average degree. Second, human networks with the same average degree but different structures are generated, including LFR benchmark, ER random and regular network (examples in Figure 3). In these experiments, each simulation has 100 agents and the same parameter setting as given in Table 3. The results of the two experiments are shown in Figure 5.

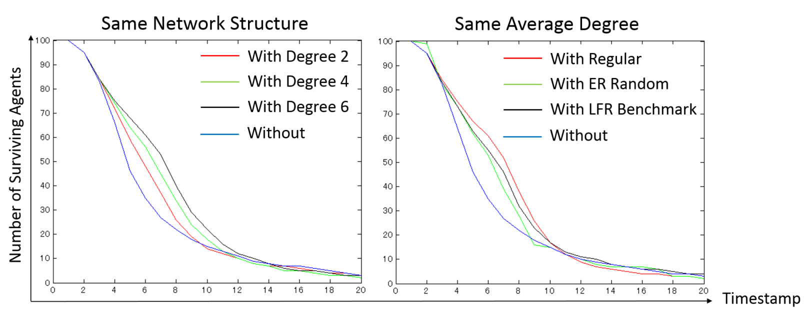

Figure 5: Temporal bankrupt information with various human networks.

The results indicate that different macro-level inter-firm human relationship have different effects on the bankrupt evolution. The left part of Figure 5 shows the influence of human network with various average degree: the firms receive more resource helps when they have more human partners. At the same time, different network structures also affect the evolution in different ways, but all benefits the bankrupt diffusion process. The social aspiration level results show the same phenomenon as the bankrupt information.

5.2.2 Micro-level Human Relationship

The local human structure of a focal agent is also studied to explore whether human relationship (i.e. inter-firm human network) with different micro features affects the agent to survive in the bankrupt risk. In particular, we focus on the influence of agent's individual human degree.

When one trade partner of the focal agent bankrupts, this agent is strongly affected and may go bankrupt as well (Gatti et al. 2009). Thus, we design the following general scenario in this experiment. One important trade agent b (the red node in Figure 3-1) is initialized as the bankrupt firm. While one of its trade partner agent f (the green node in Figure 3-1) has different number of human partners, its performance in the subsequent time periods are observed and analyzed. In the simulation, all trade and human networks have 100 agents and share the same network structure. In particular, to make sure the bankrupt agent b brings the same influence to agent f in each simulation, we set up the weight of trade link W_b^f as 1, instead of a random value in W. Figure 6 presents the average performance of the focal agent f with different human degree in 50 simulation runs.

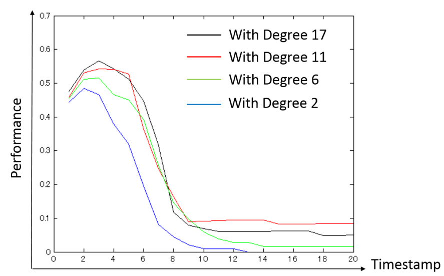

Figure 6: Temporal performance of focal agent f with various human degree.

The different effects of the local human relationship is found out in the above figure. In the early time after bankruptcy of the trade partner, higher human degree (i.e. more human partners) brings more benefits in the agent performance. In addition, while the agent with the fewest human ties (blue line in Figure 6) are most likely to bankrupt, agents with more human ties (red line in Figure 6) usually survive as bankrupt transferring. The result not only suggests that more human partners are more beneficial in bankrupt diffusion, but also shows that good human relationship (i.e. more human partners) can help the firm to recover from an urgent bankrupt impact.

At the same time, an interesting phenomenon is seen that agents with higher human degree not always result in a higher performance in the long term. Such phenomenon matches the data analysis result in Section 2.2 that firms with high human degree also go bankrupt. It shows a sign that degree is not the only influential factor of human relationship and provides a potential to explore other important ones.

6 CONCLUSION AND FUTURE WORK

In this paper, we study the impact of human relationship on the evolution of inter-firm trade network emerging from bankruptcy. In particular, an agent-based model is proposed using Japanese firm data analysis. Then, given initial bankrupt firms, the dynamic evolution of inter-firm trade network is simulated and observed in three experiments. With a validated distribution, the simulation results present the influential role of human relationship in bankrupt diffusion that more human partners generally bring more positive effect to firms in the trade business environment. From the micro level scenario, good individual human relationship also benefits the firm to survive in the bankrupt emergency.

Similar to any other study, this paper has some limitations that can be potential directions for future research. First, the model in this paper is driven by patterns from Japanese firm data, which is limited to properties of interconnectivity in particular country and business context. Thus, as our model is conceptually designed from general organization theory, we conjecture that the model can be extended for other business environments by feeding extracted features in different data. Second, other potential significant factors (e.g. betweenness and closeness) in inter-firm human network can be explored to understand the importance of human relationship. Finally, we need to use historical real data to further validate our model.

ACKNOWLEDGMENTS

The research is partially supported by the Center for TDB Advanced Data Analysis and Modeling in Tokyo Institute of Technology and JSPS KAKENHI (Grant Number 25240048). We also thank Suenaga for the network generation tool.

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