Social Network as Double-Edged Sword to Exchange: Frictions and the Emerging of Intellectual Intermediary Service

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Abstract. The value of complex social network and the optimization of it are determined by the structure and nodes' characteristics. Direct friction and indirect friction are defined to describe the possible exchange difficulty each node meets with its neighbors in exchange network. Exogenous intermediary and endogenous intermediary can decrease these frictions by adding links. Agent-based Simulating results show that both frictions and the optimization of them are influenced by demander and supplier rate, the exchange network structure as well as the environment constrains and exogenous intermediation acts better than endogenous intermediation in decreasing both frictions. While assists exchange, the results of this paper also implies social network as origin of impefect market.

Keywords: Complex Social network, Exchange network, Direct friction, Indirect friction, Intellectual Intermediary service.

1 Introduction

The relationship between structure and dynamics such as robustness, fragibility, diffusion and spreading of complex network has been discussed by many literatures of complex networks. It is essential for a deeper understanding of the development and self-optimization of the society as a whole [1]. There are four kinds of optimization at the leading edge of the current research on network optimization [2]. The optimization of social network is also an aspect of this field. Intermediation plays a key role as an optimizer of our society. To understand the role and function of the intermediation along the developing process of social network is crucial to our comprehension of the formation and optimization of complex social network.

Exchange network which possesses two kinds of nodes is common in complex social network. In marrige, labor market as well as business dealings, a node realizes its value no other than he meet other side and exchange successfully. These relationship could be abstracted to two complementary services exists in

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exchange network, two sides yield value only by cooperation. The value of holistic exchange network is to facilitate trades among the nodes. Analogizing with friction in mechanics, frictions to exchange refer to the forces blocking the realization of nodes' value. The preference of demander [3], prices two sides willing to accept [4] and other factors can be the source of frictions. Besides information, time [5] and price concession [4][6] are identifiers to describe the frictions to exchange. Frictions to exchange network should involve network structure as substrate of these factors, the relation between nodes as well as the attributs of nodes. Typically, there exists two kinds of intermediary to coordinate trade of exchange network. One is exogenous intermediary such as govornment. The other is endogenous intermediary emerging from the nodes of exchange network, such as banks, brokers and so on. There are two ways for intermediary to optimize exchange network. One is to link nodes and get the optimal outcome [7][8]. The other is to link nodes and decrease the frictions to exchange. Traditional economics literatures discussed the exist of intermediation at different situation [9]–[11]. Coase's traditional analysis model [12] is used to explain the presence of intermediaries between demand and supply sides. Information is a main topic in the function of intermediation [13]–[17]. Watanabe [18] has promoted a uniform framework to analyze the function of intermediation.

Related with intermediation in complex social networks, key nodes and crucial links such as structure holes, weak ties and strong ties prompt concern of sociologists [19][20][21]. Efficiency and stability can coexist in a network with intermediation by defining critical link and intermediary position [22]. How brokers gain competitive advantage in a certain network [23], endogenous and exogenous intermediations in complex social networks are discussed. For example, Based on Banknet developed by Askenazi [24], banking activity emerges from the interaction of a continuum series of financial transactions between heterogeneous economics agents [25]. Total payoff contributed by intermediation as a whole with different match mechanisms is discussed [7]. Goyal et al. [8] studies a model of network formation where agents provided ability to block bilateral interaction between two players and to be intermediations.

Based on general exchange network generated from a social network with certain structure, exchange network frictions are considered to measure the difficulty nodes trade to each other. The influences that nodes' attributes and the exchange network structure bring to these frictions are discussed in section 2. In section 3 and section 4, the optimization of exogenous and endogenous intermediary are investigated respectively. Section 5 is conclusions and section 6 is acknowledgement.

2 Frictions of Exchange Network

In social network G with $|G|$ nodes such as figure 1(a), nodes refer to individuals or organizations and links present their relationship. With trust $b(b \in [0,1])$ between two nodes and time limit $T(T > 0)$, exchange network K^T is generated from G by the communication between linked nodes with time T, see figure 1(b).

Denotes average degree of G and K^T as $\langle G\rangle$ and $\langle K^T\rangle$. With probability ρ and $1-\rho$, nodes in K^T are divided into two parts: suppliers and demanders who provide complementary services. Either side supplies homogenous service and achieves his goals only by coorperating with complementary side. The value of exchange network is to assist all nodes achieve their objectives. But the structure of exchange network may block exchange while assist it. For example, a man only knows men and his goal is to get merried on one hand. A demander's objective can't obtained if he meet none supplier(woman) within any T and b. On the other hand, if a man meet some women but these women know more other men at the same time, then the chance to success of his merriage will be small than these women only know him. Phenomenons like this are far-ranging in the social and natural world. Merriage, kindney exchange, labor market, risk investment and trade are involved here. Like fiction which block objects moving in classical mechanics, frictions of exchange network are defined as the strenth or probability to obstruct exchange.

2.1 Direct and Indirect Friction of Exchange Network

Just like the difficulty the man who want to get merried can meets, frictions of exchange network are rooted in two aspects: one is how many agents an agent meet can't be partners and the other is how many corrivals it has. The first illustrates the probability agents can't meet trade partner and the second accounts for the probability they meet corrivals. Average frictions present the holistic friction level of exchange network and the standard deviations indicate the discrepancy or heterogeneity among nodes.

Definition 1. Direct friction (DF) at time t defined as

$$F_i^t = \begin{cases} 1 & |D_i^t| = 0 \\ \frac{|S_i^t|}{|D_i^t|} & |D_i^t| > 0 \end{cases} \tag{1}$$

Definition 2. Indirect friction (IDF) at time t defined as

$$I_i^t = \begin{cases} 1 & F_i^t = 1 \\ 0 & \exists j \in N_i^t \quad and \quad |D_j^t| = 1 \\ \frac{\sum\limits_{j\in N_i^t} (|N_j^t|-1)/|D_j^t|}{|N_i^t|} & Otherwise \end{cases} \tag{2}$$

Definition 3. Average direct friction(ADF) of K at time t defined as

$$A_F^t = \frac{\sum\limits_{i=1}^{|K^t|} F_i^t}{|K^t|} \tag{3}$$

Definition 4. Average indirected friction($AIDF$) of K at time t defined as

$$A_I^t = \frac{\sum\limits_{i=1}^{|K^t|} I_i^t}{|K^t|} \tag{4}$$

Where S_i^t denoted the set of i's neighbors in K^t which possess same attribute–supply or demand to i and N_i^t denoted the set of i's neighbors in K^t which possess different attribute to i. $D_i^t = S_i^t \cup N_i^t$ is the set of i's neighbors. $|D_i^t|$ denoted the degree of node i and $|D_i^t| = |S_i^t| + |N_i^t|$. Define $A_F^t = 0$ and $A_I^t = 0$ where $|K^t| = 0$ or $|K^t| = 1$. The standard deviations of F_i^t and I_i^t which shows the equality or discrepancy of nodes are S_F and S_I. As shown in figure 1(b), frictions of nodes and network can be computed according to formula (1)-(4)($\langle G\rangle = 1.25$, $\langle K^t\rangle = 0.875$, $\rho = 3/8$, each pair of numbers present F_i^t and I_i^t of a node, $A_F^t = 0.29$, $A_I^t = 0.38$, $S_F^t = 0.341$, $S_I^t = 0.324$).

Two nodes linked by an link with probability $\rho^2 + (1-\rho)^2$ possess same attribute. Assume the probability of node i with degree d is $f(d) = Prob(|D_i^t| = d)$, $E[F_i^t] = f(0) + [1-f(0)](2\rho^2 - 2\rho + 1) = 1 + 2(\rho^2 - \rho)[1-f(0)]$ where there are some isolated nodes and $f(0) \neq 0$. $\frac{\partial E[F_i^t]}{\partial \rho} = 2[1-f(0)](2\rho - 1)$ and the minimum A_F is $A_F^{min} = f(0) + \frac{1}{2}[1-f(0)]$ at $\rho = \frac{1}{2}$. If there is no isolated node in K^t and $f(0) = 0$, then expected F_i of K^t is $E[F_i^t] = 2\rho^2 - 2\rho + 1$ and the minimum A_F is $A_F^{min}(\frac{1}{2}) = \frac{1}{2}$ at $\rho = \frac{1}{2}$. A_F is only related to the probability of isolated nodes instead of the distribution of degree of K^t. If K^t is random network with connected probability p, $E[F_i^t] = (1-p)^{|K^t|-1} + [1-(1-p)^{|K^t|-1}](2\rho^2 - 2\rho + 1)$, $A_F^{min} = (1-p)^{|K^t|-1} + \frac{1}{2}[1-(1-p)^{|K^t|-1}]$ at $\rho = \frac{1}{2}$.

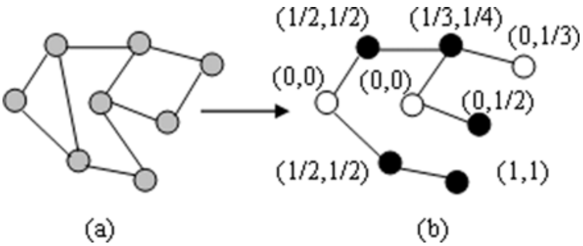

Fig. 1. Exchange network Generated from Social Network

2.2 Features of Average Frictions in Exchange Network

Frictions are influenced by the features of the nodes ρ, the enviornment constrain T and the relationship of pairs of nodes b. T, b and G determine the average degree $\langle K^T\rangle$. Lower $\langle K^T\rangle$ means more probability with isolated nodes and higher A_F^T and A_I^T with same ρ.

Simulated with 500 networks with $|G| = 2 - 500(b = 0 - 1,\ T = 1 - 30,\ \rho \in (0,1))$ in order to investigate how frictions influenced by ρ and $\langle K^T\rangle$. Respectively, figure 2(a) and figure 2(b) show A_F^T, A_I^T, S_F^T and S_I^T changed with ρ. A_F^T and A_I^T are almost same at lower connectivity($\langle K^T\rangle = 0.2$). But A_F is higher than A_I at medium connectivity($\langle K^T\rangle = 2.0$) and the disparity shrinked at higher connectivity($\langle K^T\rangle = 29.1$). The relations between S_F^T, S_I^T and $\rho(\rho < 0.5)$ are concave. S_F^T and S_I^T are increased with $\rho(\rho < 0.5)$ at

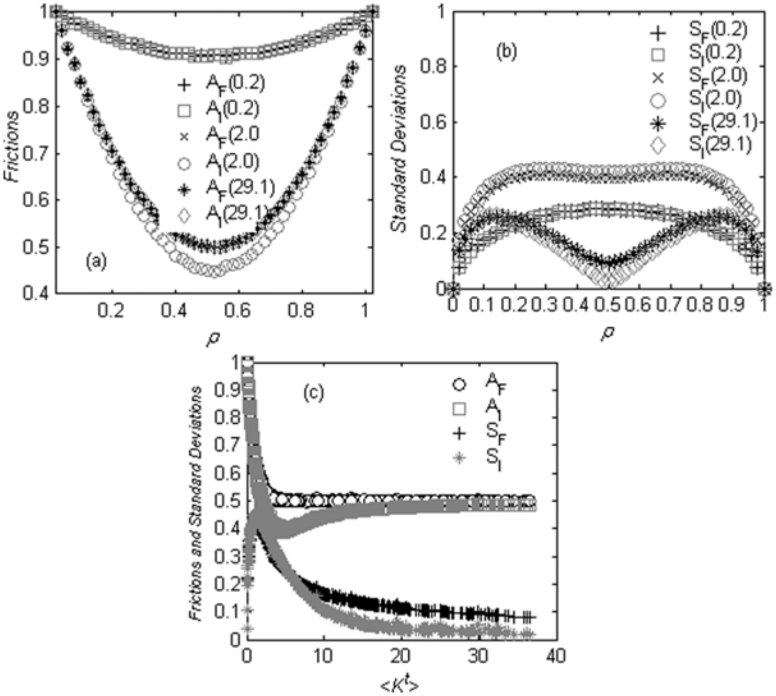

Fig. 2. Frctions and Standard Deviations of Networks

lower($\langle K^T \rangle = 0.2$) and medium($\langle K^T \rangle < \langle K^{T*} \rangle$, $\langle K^{T*} \rangle \approx 1.98$) connectivity. S_F^T is more gentle than S_I^T at high connectivity. The maximum S_F^T and S_I^T are reached where $\rho = 0.5$ at lower connectivity. But they are reached where $\rho \neq 0.5$ at medium($\langle K^T \rangle > \langle K^{T*} \rangle$) and higher connectivity($\langle K^T \rangle = 29.1$). Figure 2(c) shows A_F^T, A_I^T, S_F^T and S_D^T influenced by $\langle K^T \rangle$ at $\rho = 0.5$. $A_F^T(0.5)$ converged to 0.5 where $\langle K^T \rangle > 5$ for there is not any isolated nodes in K^T. $A_I^T(0.5)$ declines to 0.4 where $\langle K^T \rangle > 5$ then goes up to 0.5 where go up $\langle K^T \rangle > 30$. The maximum S_F^T and S_I^T are obtained about $\langle K^T \rangle \approx 2$.

Microscopically, frictions a node meet come from its neighbors and its neighbor's neighbors. Macroscopically, A_F^T are influenced mainly by the proportion of demanders and suppliers as well as the probability of isolated nodes in the network. A_I^T and A_F^T varied in different pattern where $\langle K^T \rangle = 5 - 15$, A_I converged to A_F^T while K^T increased.

3 The Optimization of Exogenous Intermediary Service

3.1 Optimization Algorithm

Assume there is an exogenous intermediary such as labor broker, government, e-commerce web site who know the globe information of K^T and his function is to decrease the frictions of K^T. The intermediary may not be located in the network and add links to the nodes possessing different attributes where there still has no link in K^T. The new link may not exists in G.

Added link to node i and j can influence both direct friction and indirect friction of them and indirect friction of there neighbors which possess different attribute to them. There are two alternatives for exogenous intermediation to decreasing the A_F^t or A_I^t of $K^t(t \geq T)$ by adding links. Firstly, both frictions will be reduced if the objective of exogenous intermediation is to reduce A_I^t by adding links to two nodes with different attributes. Adding a link to two arbitrary nodes i and j with different attributes can reduce A_F^t. An optimization algorithm(IRA) for exogenous intermediation is developed to decrease frictions as follows. The added link must reduce the maximum average friction of K^t.

Indirect friction reducing algorithm(IRA):

Step 0: t=T;

Step 1: Calculate friction of network K^t.

Step 2: Find each pair of nodes i and j with opposite attributes have no link in K^t. If there are no such nodes, step 5.

Step 3: To all pair of nodes not linked in K^t, calculate ΔI_i^t, ΔI_j^t, ΔI_k^t, ΔI_l^t), and ΔA_I^{ijt}. Where $k \in D_i^t$ and $l \in D_j^t$.

Step 4: Find $\{i^*, j^*\} = min_{\Delta A_I^t}\{i, j|\Delta A_I^{ijt} < 0\}$ and add a link between i^* and j^*. $t = t + 1$. If there is no such $\{i^*, j^*\}$, step 5.

Step 5: End optimization.

Secondly, if the objective of exogenous intermediary is to reduce A_F^t, he can simply adds links to all nodes with opposite attributes. To reduce A_I^{ijt} can decrease of both $F_i(t)$ and $I_i(t)$ but to reduce A_F^t is not always true. If $|D_i^t| = 0$ or $|D_j^t| = 0$ before the link added, I_i^t or I_j^t can be reduced by the added link between them. But if $N_i^t > 0$ or $N_j^t > 0$, the indirect friction of nodes in N_i^t or N_j^t can be increased. So if the objective of exogenous intermediary is just adding links to reduce direct friction of nodes, the link-adding process will be terminated once additional added link may make A_I^t increased. Another algorithm called direct friction reducing algorithm(DRA) which changed $min\{\Delta A_I^t\}$ to $min\{\Delta A_F^t\}$ is different to IRA at step 3 and 4. The links will be added to the nodes with $D_i^t = 0$ or $N_i^t = 0$ where $F_i^t = 1$ and $I_i^t = 1$firstly to make $\Delta F_i^t < 0$. If there is no such nodes, the network can not be optimized.

Step 3(a): To all pair of nodes not linked in K^t, calculate ΔI_i^t, ΔI_j^t, ΔI_k^t, ΔI_l^t, and ΔA_I^{ijt}. Calculate ΔF_i^t, ΔF_j^t, ΔF_k^t, ΔF_l^t, and ΔA_F^{ijt} at the same time. Where $k \in D_i^t$ and $l \in D_j^t$.

Step 4(a): Find $\{i^*, j^*\} = min_{\Delta A_F^t}\{i, j|\Delta A_F^{ijt} < 0\}$, if $\Delta A_I^{i^* j^* t} < 0$ then add a link between i^* and j^*, $t = t + 1$; else step 5.

The least links can be added to K^T to get a bipartite graph if $\langle K^T \rangle = 0$. Figure 3(a) and (b) shows the results of DRA and IRA where $\langle K^T \rangle = 0$. Figure 3(a) shows there are 4 suppliers and 4 demanders. With DRA or IRA, exogenous intermediary links them to pairs to make $A_F^{(T+4)} = 0$ and $A_I^{(T+4)} = 0$. Another

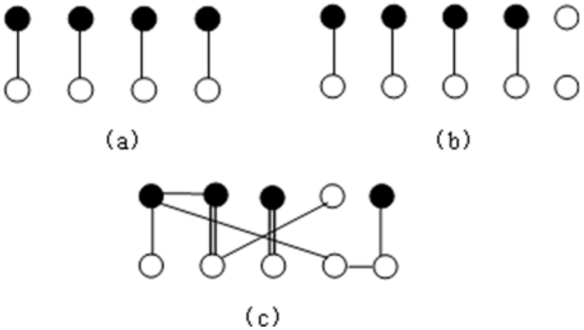

Fig. 3. Optimized network where $\langle K^T \rangle = 0$

Table 1. Different networks between DRA and IRA of 1000 samples

	Result network	Amount of links added	A_F	A_I
max	74	41	57	63
min	28	10	21	23
mean	49.054	24.158	37.271	40.146
SD	7.1305	4.7922	6.0713	6.3824

circumstance is that their are 4 suppliers and 6 demanders. Optimized result with DRA or IRA form 4 links and 2 isolated nodes and $A_F^{(T+4)} = 0.1$ and $A_I^{(T+4)} = 0.1$, as shown in figure 3(b). Figure 3(a) may match along with perfect market and figure 3(b) implies one kind of imperfect market [29]. Figure 3(c) shows the optimization result of $\langle K^T \rangle = 1.2$. Two double lines are links added by IRA and DRA. Here $A_F^{(T)} = 0.6333$ and $A_I^{(T)} = 0.5667$, $A_F^{(T+2)} = 0.3333$ and $A_I^{(T+2)} = 0.1667$. The result network is more complex than figure 3(a) and (b). That means more negotiation and decision will be taken to realize the exchange. It is interesting that monogamy as evolving institute practiced by many nations, will be explained to reduce frictions of family. But to find partner in exchange network is a frictional task.

DRA and IRA play same roles where K^T is empty and complete graph. To compare the effects of these 2 optimization mechanics where K^T is arbitrary network. Simulated with 1000 networks with 1000 times($|K^T| = 2-500, b = 0-1, T = 1-30, \rho \in (0,1)$), the number of different result networks are shown in table 1. There is positive probability that DRA and IRA create same result network as well as different result networks to any network. The probability to same result is obviously higher than that of different results according to the simulation results. Most networks can be optimized by DRA and IRA without differency. But it is remarkable that even the numbers of links added are same by DRA and IRA, these links added to different pairs of nodes and result to different result networks. Some pairs of different result networks have same A_F^T and A_I^T. Result networks of a certain original network with different A_I^T may not possess different A_F^T at the same time. A_F^T and A_I^T of DRA and IRA are statistically indifference with t-test($\alpha = 0.01$, $p^F = 0.0578$, $p^I = 0.4367$).

3.2 Optimization Results Analysis

Figure 4 shows the optimization rate influenced by the connectivity of K^T. In figure 4(a), average degree of K^T influenced by the number of the nodes in K^T where T is bigger($T = 5$). It is obvious the optimization rate(rate of optimized networks from 500 networks) decreased with the increase of T and decreace of ρ, see figure 4(b). In figure 4(c) the optimization rate decreased with the increasing of network density $\langle K^T \rangle / (|K^T| - 1)$. Even if at same density, the optimization rate is much higher at small $T(T = 1)$ than bigger $T(T = 5)$ because bigger T leads to higher $\langle K^T \rangle$.

Figure 5 indicates the optimization efficiency decreasing with the increasing of $\langle K^T \rangle$. There are several measures be defined to describe the efficiency of the optimization on figure 5. The first is the proportion of networks can be optimized(network rate) and the second is the decreasing rate of $A_F^T (\Delta A_F / A_F)$

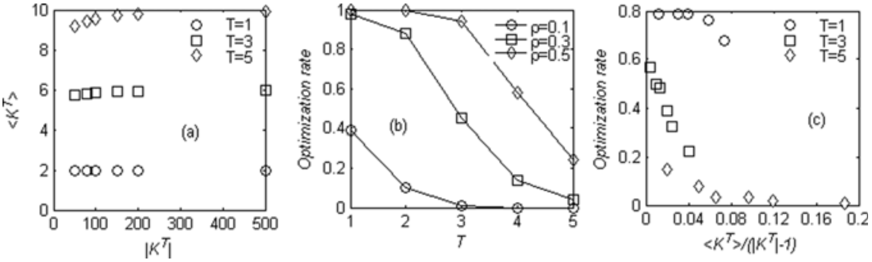

Fig. 4. Optimization Effect of Exogenous Intermediary Services

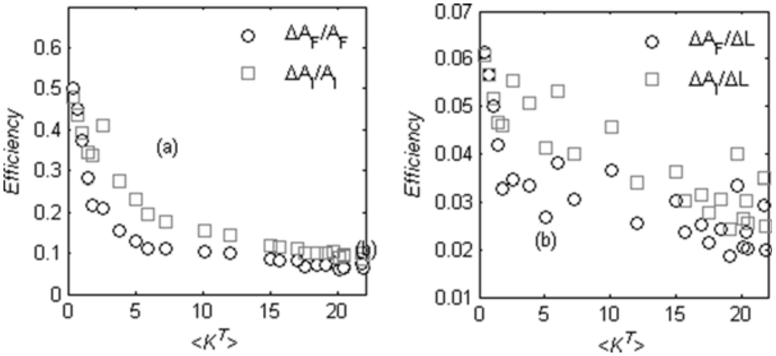

Fig. 5. Optimization Efficiency of Exogenous Intermediary Services

and $A_I^T(\Delta A_I/A_I)$. The second is the decreasing of A_F^T and A_I^T by each added link and indicates the contribution of intermediation($\Delta A_F/\Delta L$ and $\Delta A_I/\Delta L$). Both indexes are decreased with the increasing of $\langle K^T \rangle$.

4 The Optimization of Endogenous Intermediary Service

4.1 Probability of Endogenous Intermediary Service

A node may be an exogenous intermediary while considering his all neighbors as G and he will act on the sub-network consisted of his neighbors. But he may be endogenous intermediary while considering a more extensive network including him. If there exists nodes i in K^T that $S_i^T > 0$ and $N_i^T > 0$, he will be potential intermediary. Compared with exogenous intermediary, endogenous intermediary is embedded into K^T and only has local information of his neighbors. So what can he do is just link nodes remained unkown in K^T and reduce directed friction of K^T. A_F^T and A_I^T will be influenced if a node acts as endogenous intermediary and linked his neighbors with different attributes. In view of the direct friction and indirect friction, define two kinds of intermediary probability of node i as follows:

$$P_i^{Ft} = \frac{\sum\limits_{j \in D_i^t} F_j}{D_i^t - ||N_i^t| - |S_i^t||} \tag{5}$$

$$P_i^{It} = \frac{\sum\limits_{j \in D_i^t} I_j}{D_i^t - ||N_i^t| - |S_i^t||} \tag{6}$$

Simulated with 500 random network($|K^T| = 500$), figure 6(a) and figure 6(b) separately shows the rate of potential intermediary nodes according to $P_F(R_F^B$ is the rate before optimization by DRA and R_F^A means the rate after optimization) and $P_I(R_I^B$ is the rate before optimization by DRA and R_I^A means the rate after

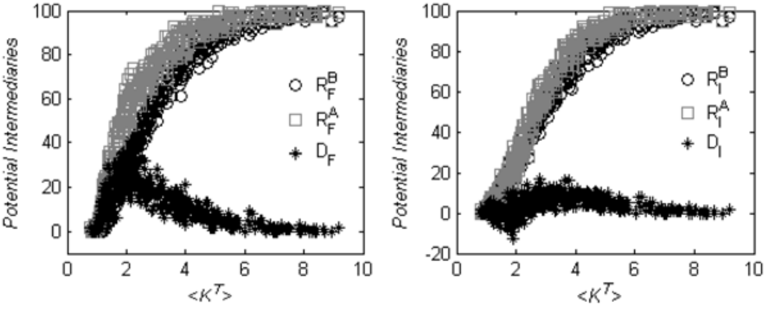

Fig. 6. Probability of Endogenous Intermediary Service

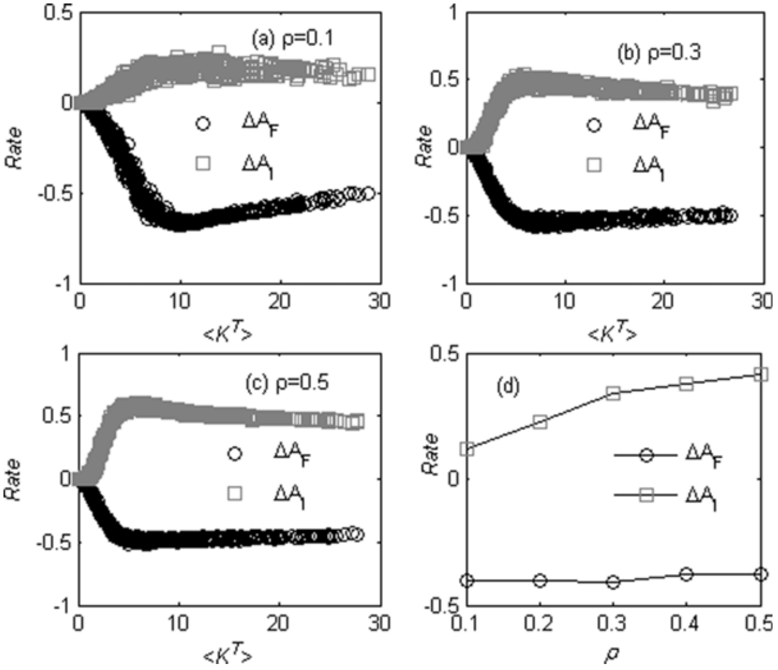

Fig. 7. Optimization Effects of Endogenous Intermediary Service

optimization) varies with the increase of $\langle K^T \rangle$. Both are increased with $\langle K^T \rangle$ increasing. But that of the optimized network is increased faster than the original network. D_F and D_I mean the rate balances between optimized networks and oringinal networks. The maximum difference between optimized network and original network can be obtained at $\langle K^T \rangle = (2 - 3)$. There also exist some networks that their rates reduced after optimization.

4.2 Optimization Results Analysis

Can K^T be optimized if node i can link his neighbors with different attributes? It is obvious that linked nodes with degree 0 or 1 can reduce both frictions. But the information of i's neighbors may be private to i. He links nodes as possible as he can to ensure his intermediary income. Simulated with 1000 networks of different ρ, Figure 7 shows the optimization efficiency influenced by ρ and $\langle K^T \rangle$. In figure 7(a)($\rho = 0.1$), the maximum decreased direct friction(ΔA_F) and the maximum increased indirect friction(ΔA_I) reached their peak value at $\langle K^T \rangle = 8$. ΔA_F is at about $\langle K^T \rangle = 5$ and ΔA_I is at about $\langle K^t \rangle = 8$ while ρ increased. Figure 7(b) shows the average level of 1000 networks. The average ΔA_F is practically not changed with ρ increased.

5 Conclusion

The value to all agents on the network is propitious to trade. The opposite side of it is to block trade. For example, electronic marketplaces as intermediary can improved meeting probability between buyers and salers, but it also raised the indirect friction. Although search costs of buyers will be reduced by electronic marketplaces, buyers and salers as well as intermediary may "wait and see" to learn from others' experiences [26]. Instead of qualitative analysis, this paper puts forward quantitative measurements to measure how much the network blocks exchange and give algorithms to reduce the blocks. This can help to decide intermediary service what to do, how to do and how well he can do. Frictions are defined to measure the hindrance of a network in which the nodes have two different complementary attributes. Exogenous intermediary can optimize exchange network by adding links to reduced A_F and A_I. Endogenous intermediay usually can only reduce A_F but increase A_I. Both effect and efficiency of optimization are influenced by network structure as well as the characteristics of nodes. As direct influence factors to structure, the time limit to form K as environmental factor and the relationship between nodes b effect frictions and the optimization of them.

The results of this paper can explain we need intermediation very much, but the effect of intermediary service is limited. How well that market as invisible hand [27] and government as the visible hand [28] coordinate with complex social network at least depend on the network structure and the characteristics of agents in it. That means bounded rationality which leads to imperfect market [29] is rooted the embededness of social and exchange networks as well as it is regarded as the origin of the social and exchange networks.

It is reflects embededness of social networks [30][31] and ecology networks that exchange network K is generated from existing network G. To map, diagnose and improve the network consisted of individuals, brokers of social network are crucial to the performance of the network [32]. The nodes of the network mentioned here is not only individuals but also organizations or subnetworks can be regarded as systems. The links could be explained as the supply and demand of both material product and intellectual products. Cooperation for ecological and organization networks [33][34] are the examples of such bipartite relation discussed in this paper. By abstracting general attributes of two side exchange, our results implies that as fundus of nodes' dynamics occuring on, network structure is a double-edged sword to agents to achieve their utilities. To close to real social and ecology systems, homogenous services discussed here is not enough. Future research will be penetrated deeply in heterogeneous services and the dynamics of nodes besides more dynamics of ndogenous intermediary.

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