Theoretical Analysis and Simulation to Investigate the Fundamental Rules of Trust Signaling Games in Network-based Transactions

So Young Kim, Junseok Hwang
Technology Management, Economics and Policy Program
Seoul National University
Seoul, Republic of Korea
none8171@snu.ac.kr, junhwang@snu.ac.kr

***Abstract*—Online network-based transactions are widespread forms of transactions in e-commerce markets such as peer-to-peer markets or smart media markets. In these markets, the participants need criteria to search, select and manage their partners. One of the most important criteria is the trustworthiness of the partner. The participants aim to enhance the probability of being selected by their opponents through signaling their trustworthiness levels to their opponents. Simultaneously, the opponents adjust their beliefs on the trustworthiness of other participants based on observation of signals. This paper describes this situation using a signaling game in which the seller sends a signal of his/her trust level and the buyer decides his/her payment schedule for the presented signal. The results of the equilibrium analyses suggest criteria for the signaling of the cost structures of participants and the market environment. Additionally, the results of the simulations validate the results of the equilibrium analyses.**

Keywords-trust; signaling game; equilibrium; agent-based simulation

I. INTRODUCTION

Autonomous agents in the network-based transaction market need criteria to search for other participants, select partners and manage relationships. One of the most important criteria is the trustworthiness of the partner. Network-based transaction markets such as e-commerce, peer-to-peer markets, business-to-customer markets, and business-to-business markets often only provide information goods [1]. Information goods have the characteristics of experience goods, whose quality is difficult to observe in advance, but can be ascertained with experience [2]. Therefore, information asymmetry is one of the main focuses of many studies that deal with information goods.

Many studies have attempted to mitigate the negative effects of information asymmetry. Researchers have investigated various mechanisms that evaluate the level of trustworthiness of an agent in the network, such as reputation, recommendation and third party authorization [3]. For example, web recommendation systems [4] and trust certification stamp systems [5] are kinds of mechanisms that have been developed to manage trust among a number of unspecified agents in the internet. These previous efforts, however, have focused more on enhancing the accuracy of prediction by developing sophisticated prediction mechanisms. The signal resulting from these mechanisms is also asymmetric, so that an agent has to adjust his/her belief about the trustworthiness of the opponent based on the results of observation.

This paper describes this situation as a signaling game in which the seller (or the sender) sends the signal of his/her trust level and the buyer (or the receiver) decides his/her payment schedule for the presented signal. This paper also presents the criteria of the signaling cost structures of participants and the market environment. Satisfying these criteria ensures the effectiveness of signals in distinguishing each type of participant and the stability of the separating equilibrium. Through these processes, this paper also investigates fundamental rules of trust signaling games in network-based market transactions. Additionally, it also uses an agent-based simulation to validate whether these rules are effective in the market for agents that mimic bounded-rational human behavior.

The remainder of the paper is organized as follows. The next section reviews the related literature. Section 3 proposes the trust signaling model. Section 4 conducts an equilibrium analysis of the trust signaling game. Section 5 validates the theoretical model using an agent-based simulation. Finally, Section 6 provides a discussion and conclusion.

II. LITERATURE REVIEW

Akerlof [6] discussed the problem of information asymmetry and quality uncertainty in the market for used cars. Spence [7] also considered the issue of information asymmetry between employers and employees in his pioneering work. He suggested that the employers use employees' education levels as signals and offer wage schedules on the basis of their beliefs about labor productivity. Spence's model offers a theoretical framework that can describe many kinds of signaling games. This model could be used to describe social relationships based on the trustworthiness signal.

Several recent studies have focused on interactions between autonomous agents in the network using game theory, particularly signaling games. One of these studies applied game theory to detect intrusion by malicious nodes in a mobile ad hoc network without

Copyright (c) IARIA, 2011. ISBN: 978-1-61208-154-0

centralized control [8]. This study provides insights regarding the attacker in the network and the intrusion detection system by modeling the interaction between normal nodes and attackers as a basic Bayesian game. Another study of mobile ad hoc networks focused on the best strategies that normal nodes and malicious nodes can select in a dynamic Bayesian signaling game. It validated the superiority of the suggested strategy and concluded that restricting the opportunity for malicious nodes to flee from detection is important [9].

The mechanisms supporting the decision making about whether one can trust an opponent in network transactions have been considered in various studies over a long period of time. Reputation mechanisms have become a fairly common framework since several pioneering studies [10] [11] and subsequent studies [12]. One subsequent study suggested that the reputation mechanism of the previous opponents of a player offers feedback information about previous transactions; the autonomous system aggregates these feedback with proper weights and then the system offers more accurate evaluation of the opponents' trustworthiness [13].

Another study compared simulation analysis and theoretical analysis. It suggested that while game theory can analyze the behavior of rational agents, agent-based simulations can analyze the behavior of software agents that mimic real-life decision makers [14].

III. MODEL DESCRIPTION

In the simplest signaling game, there are two players—the sender and the receiver—in the set I. The sender can be either malicious type (M type) or normal type (N type). The receiver can only be regular type (R type). The set of types is denoted by T: $T=T_S\times T_R$, $T_S=\{M,N\}$, $T_R=\{R\}$. The type of sender is chosen by nature and is the private information of the sender. Each player has a strategy set A and a utility set u. Therefore, the structure of the game is simply denoted by: $G=\{I,T_i\}_{i\in I},\{P(\cdot|\cdot)\}_{i\in I},\{A_i\}_{i\in I},\{u_i\}_{i\in I}\}$

The prior probability that the sender is M type or N type is $\pi(Malicioius)=\pi_M$ or $\pi(Normal)=1-\pi_M$. The sender of a particular type sends a message m $(m:T\rightarrow M)$ about his/her level of trustworthiness to a receiver. The message is drawn from the set $M=\{e,0\}$. The receiver receives this signal, and then takes an action drawn from a set A. This action a $(a:M\rightarrow A)$ indicates the value that the receiver is willing to pay to sender, w. The values of w forms the strategy set $A=\{w|w\in R^+\}$. The payoff of player i is given by the function $u_i:T\times M\times A\rightarrow R$. This means that the payoff of a player is decided by the player type, the message of a sender and the action of a receiver.

In our example, M type and N type senders receive the payoffs $v+L$ and v (v, $L\geq 0$) when the transaction is successful. The receiver receives payoffs of $-(v+L)$ if he/she transacts with an M type sender and v if he/she transacts with an N type sender.

The receiver cannot observe the type of transacting sender; therefore, the sender uses a certain form of signal to increase the probability that the receiver chooses him/her as a partner or increase the payoff from a successful transaction. The signal can take various forms such as the disclosure of a transaction history, presentation of a certification from a third party authority, or advertising. Most of these signals involve a cost. For example, if a sender wants to signal by disclosing a transacting history, he/she cannot violate the transaction rules for a given period even if he/she is the M type sender. One can easily imagine that this form of signal costs more for the M type sender than for the N type sender. Some forms of signal may involve an equal cost for the M xtype and the N type senders. However, it is likely that the receiver will be unable to distinguish one type from another if the signal costs of obtaining the same level of trustworthiness for two types of senders are the same. Therefore, we assume that the cost of an M type sender is relatively higher than that of an N type sender.

The sender advertises his/her own type honestly or deceitfully by sending a certain level of message $e\in[0,\infty)$ that appears to represent the trustworthy level. The message e costs $c_M(e)$ for the M type sender and $c_N(e)$ for the N type sender. Then the receiver suggests the fee schedule $w(e)$ that the receiver wants to pay to ensure a trust-based transaction with the sender. Therefore, the expected payoff of the M type sender is $u_M(e)=v+L+w(e)-c_M(e)$ and $u_N(e)=v+w(e)-c_N(e)$ for the N type sender when the transaction is successful.

The potential receivers are assumed to be sufficiently many and to be risk neutral so that they suggest a wage schedule that has the same value of expected profit for a transaction and satisfies the zero profit condition of the competitive market providers [15]. Therefore, the receiver suggests the fee $w(\mu_e)=v-\mu_e(2v+L)$ to ensure a trust-based transaction when he/she has observed the message e from the sender and has the belief μ_e that the sender is an M type. Of course, the receiver does not participate unless $\mu_e<v/(2v+L)$.

IV. EQUILIBRIUM ANALYSIS

A. Separating Equilibrium

Proposition 1. When the level of trustworthiness of a participant is used as the signal, the signal can be effective in distinguishing one sender from another if the cost of trust level signaling is sufficiently distinct.

Proposition 1 indicates that the presented signal gives perfect information of the type of sender if the two sender types select distinct levels of trustworthiness as their signals in the equilibrium. When e_M and e_N are the selected signals in the equilibrium of the M type sender and the N type sender, $c_M(e_M)=e_M$ and $c_N(e_N)=\gamma e_N$ are the cost of signaling of each type of sender (where $0<\gamma<1$), and $w(e_M)$ and $w(e_N)$ are the fee schedules, and the separating signaling equilibrium exists and satisfies the following conditions.

$$w(e_M) = 0 \\ w(e_N) = v \tag{1}$$

$$w(e_M) - e_M \geq w(e_N) - e_N \\ w(e_N) - \gamma e_N \geq w(e_M) - \gamma e_M \tag{2}$$

The fee schedule $w(e)$ that satisfies the following satisfies conditions 1) and 2).

$$w(e) = \begin{cases} v & \text{for } e \geq e^* \\ 0 & \text{for } e < e^* \end{cases} \tag{3}$$

Finally, the optimal level of signal e^* must satisfy the following simple condition.

$$v \leq e^* \leq \frac{v}{\gamma} \tag{4}$$

For the above conditions, in the separating equilibrium, the receiver believes that the sender is M type (or N type) with probability one when he/she observes the signal e_M (or e_N). Therefore, the values of $w(eM)$ and $w(e_N)$ are 0 and v in accordance with the assumption of zero profit. Furthermore, the expected payoff of the M type sender is $v+L-e_M^*$ and for the N type sender it is $2v-\gamma e_N^*$. It is clear that $e_M^*=0$ is the best choice of the M type sender. For the N type sender, $e=0$ is the best choice and the payoff is only equal to v if he/she selects e satisfying $e \neq e_N^*$ and the receiver has belief $\mu_e=1$ for all e other than e^*. Therefore, the N type sender does not have an incentive to leave the separating equilibrium when the following condition is satisfied: $2v-\gamma e_N^* \geq v$, that is, $e_N^* \leq v/\gamma$.

If the M type sender wants to leave the separating equilibrium, selecting e_N^* as the signal is the best choice. However, the receiver's belief is $\mu_{eN^*}=0$ in this situation so that the receiver offers only the value v as the fee for the trust-based transaction and the M type sender obtains the payoff $2v+L-e_N^*$. Therefore, the M type sender does not have an incentive to leave the equilibrium when the following condition is satisfied: $2v+L-e_N^* \leq v+L$, that is, $e_N^* \geq v$.

The meaning of condition (4) is clear. To ensure the existence of the separating equilibrium in which the M type sender does not send any signal and the N type sender sends a positive signal, e_N^* has to be sufficiently high so that the M type sender cannot pretend to be the N type sender and coincidently cannot to be so high that the N type sender cannot afford the signaling cost. In the separating equilibrium, the utility-maximizing N type sender selects $e_N^*=v$ as the best choice.

What one has to focus on is that the signaling cost structures of the two types of senders have to be distinct. However, one has to consider that not every form of signal ensures a distinct cost structure for the two types of senders.

B. Pooling Equilibrium

Proposition 2. The pooling equilibrium in which the two types of senders select the same trustworthy level as a signal is not stable if the signaling cost structure is distinct.

If the sender cannot send any signal, the receiver believes that the probability that the sender is the M type sender is prior probability π_M. The receiver participates in the transaction and suggests the fee for a trust-based transaction of $\pi_M<v/(2v+L)$ so that all types of senders take w as the fee. Similarly, if the two types of senders select the same signal e^* as their trustworthiness level, the receiver cannot obtain any information regarding the type of sender. In this situation, the belief of the receiver is the same as the prior probability that the sender is the M type sender. Furthermore, the signal e, other than e^*, must satisfy the following conditions.

$$w(e^*) = v - \pi_M(2v+L) \\ w(e\ ) = v - \mu_M(2v+L) \tag{5}$$

$$w(e^*) - e^* \geq w(e) - e \\ w(e^*) - \gamma e^* \geq w(e) - \gamma e \tag{6}$$

Therefore, the receiver suggests the fee schedule $w^*=v-\pi_M(2v+L)$ when he/she observes e^*. The M type sender receives the payoff $u_M(e,w)=2v+L-\pi_M(2v+L)-e^*$ and the N type sender receives the payoff $u_N(e,w)=2v-\pi_M(2v+L)-\gamma e^*$. To ensure the pooling equilibrium in which the two types of senders select the same signal, the payoff from selecting e must not be higher than the payoff that resulted from selecting e^*. Therefore, the following two inequalities have to be satisfied: $(2v+L)(1-\pi_M)-e^* \geq (2v+L)(1-\mu_e)-e$ as the payoff condition of the M type sender, and $2v(1-\pi_M)-\pi_M L-\gamma e^* \geq 2v(1-\mu_e)-\mu_e L-\gamma e$ as the payoff condition of the N type sender.

The M type sender has an incentive to leave the pooling equilibrium if the belief of the receiver is $\mu_e \leq v/(2v+L)$ and the condition $(2v+L)(1-\pi_M)-e^*<v+L-e$ is satisfied. The N type sender has a similar incentive.

In the pooling equilibrium, the receiver always has the belief $\mu_e=v/(2v+L)$, so that $e=0$ is the best choice for the any type of sender if the sender leaves the pooling equilibrium. The M type and N type senders take $v+L$ and v as their payoff from the transaction. Therefore, all types of senders do not have an incentive to leave the

Copyright (c) IARIA, 2011.

equilibrium if the following two inequalities are satisfied: $(2v+L)(1-\pi_M)-e^* \geq v+L$ and $2v(1-\pi_M)-\pi_M L-\gamma e^* \geq v$.

Therefore, the pooling equilibrium is where the two types of senders select the same signal, e^* for all e^* that satisfy $e^* \leq v-\pi_M(2v+L)$. The receiver believes that the sender is the M type with probability one when he/she observes a lower signal than e^* and expects the type of the sender in accordance with the prior probability when he/she observes a higher signal than e^*.

However, this situation is not rational because the two types of senders obtain $(1-\pi_M)(2v+L)$ and $2v-\pi_M(2v+L)$ when they do not send any signal and the equilibrium payoffs are less than the no-signal payoffs. Therefore, the pooling equilibrium is not stable.

Figure 1 illustrates how the optimal choice of a sender changes by comparing the fees and the costs of trustworthy transactions by the level of signals.

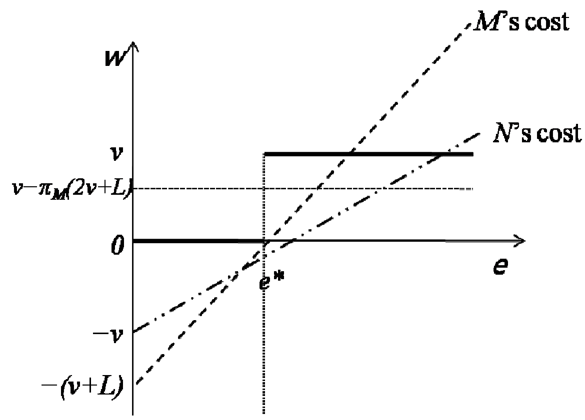

Figure 1. The fees of trustworthy transactions and costs by the level of signals.

C. The Existence Condition of the Equilibrium

Proposition 3. The effectiveness of the trustworthiness level signaling depends on the proportion of malicious type participants in the market.

When the two types of sender cannot send any signals, they obtain $(1-\pi_M)(2v+L)$ and $2v-\pi_M(2v+L)$ for each type of sender. For the N type sender, the strategy that he/she sends the equilibrium signal gives a better payoff than the strategy that he/she does not send any signal if the following inequality is satisfied: $2v-\gamma e_N^* > 2v-\pi_M(2v+L)$, that is, $\pi_M > e_N^*/(2v+L)$. This condition becomes $\pi_M > \gamma v/(2v+L)$ in accordance with the separating equilibrium condition. This means that the proportion of M type senders must be higher than a certain level so that N type senders do not achieve a better outcome when they are treated as average senders including M type senders. Additionally, the receiver wants to transact with the sender if the condition $\pi_M < v/(2v+L)$ is satisfied.

Therefore, the existence condition of equilibrium is the following inequality.

$$\gamma \frac{v}{2v+L} < \pi_M < \frac{v}{2v+L} \qquad (7)$$

The most important factor in equation (7) is gamma. Gamma is the signaling cost ratio of the N type sender to the M type sender. The range of the proportion of the M type senders in the market increases as gamma increases.

For example, if the value obtained from a trust-ensured transaction, v, is equal to one for the receiver and equal to one for the N type sender and the value extorted from a deceitful transaction, $v+L$ is two (one plus one), then the equilibrium can exist when the proportion of M type senders is less than 1/3. Furthermore, if there exists a third party authority and it charges the M type sender twice the higher cost for certification of the same level of trustworthiness, the trust signaling can be effective when the proportion of M type senders is greater than 1/6.

V. Agent-Based Simulation and Results

A. The Simulation Description

This section validates the results of the equilibrium analysis. While the theoretical analysis assumes rational agents, the agent-based simulation assumes that agents have bounded rationality, which helps us understand the behaviors of real-life decision makers.

The agents that participate in the virtual market are bounded-rational receivers and senders. The signal senders are sellers that have perfect information of their own goods and their types. The signal receivers are buyers and they do not have sufficient information about the goods and the sellers' types. While there are numerous senders and receivers in the virtual market, their searching and comparing capabilities are also bounded so that they can search and compare only a few opponents. Every agent has his/her own type, selects a strategy by simple heuristics, and amends the previous strategy by evaluating the payoff resulting from the previous transaction. This is a process with behavioral elements similar to that suggested by some studies analyzing artificial intelligence.

The senders are one of two types as in the equilibrium analysis. The N type senders prefer to maintain the rules of the transaction and the M type senders prefer not to keep the rules. These senders want to increase the probability that they are selected as a partner of the receiver by sending a proper signal. The senders use the derivative follower algorithm that an agent changes their strategy based on the presented profit. This algorithm has been often used as the pricing algorithm of producers in the analysis of artificial intelligence or electronic commerce [15]. Specifically, the sender changes the signal in the same direction until the current profit drops below the profit observed in the previous period and the previous profit also drops below the profit observed in the period before previous period. With these basic heuristics, the senders use additional algorithms. One of them is that although the net profit tends to increase, the agent may decrease the signal when one expects the additional profit to decrease with the signal. The signal cannot be negative.

In the simulation, the receivers are of two types. The first type of receiver prefers to transact with the sender who sends the highest signal among those agents searched by the receiver. The second type of receiver prefers to minimize the fee cost of ensuring a trustworthy transaction.

The first type of receiver thinks that the sender who has the highest signal is the N type sender, so that he/she pays the expected value that can be obtained from the transaction with the N type sender as the fee for the trustworthy transaction. If the searched signals are all of similar magnitudes, the receiver pays the expected value that can be obtained from the transaction with the average sender using the prior probability that the sender is an M type sender. These two types of receivers make decisions based on the presented signals and the transaction value *v*. Additionally, the receiver cannot punish the malicious agent.

Each run of simulation has 200 iterations. The population proportion of malicious senders in the entire population of senders varies from 0.05 to 1 for comparing the utility changes and checking simulation sensitivity. The population proportion of cost minimizing receivers in the entire receivers is set to 0.5. The gamma which means the ratio of signaling costs of two types of senders is set to 1/3 and one. The value of a good and the benefit of a sender by extortion from receiver are normalized to one. The simulation parameters are described in Table 1.

TABLE I. SIMULATION PARAMETERS

Parameters	Value
Iteration	200
Senders	
Number of senders	100
Proportion of malicious senders	Various
v (value of goods)	1
L (additional extortion)	1
Signaling decision algorithm	Change signal by step size
Step size	0.1*v
e_M (Signals of malicious senders)	80% of N(0,0.025*v) and 20% of N(1,0,025*v)
e_N (Signals of normal senders)	80% of N(1,0.025*v) and 20% of N(0,0,025*v)
γ, gamma	1/3, 1
Receivers	
Number of receivers	100
Proportion of cost-minimizing receivers	0.5

While the base value of malicious sender's signal is zero, 20% of malicious senders are set the initial values of signals to one in order to pretend to be normal senders as shown in Table 1. Oppositely, 20% of normal receivers are set their initial signals to zero in order to minimize their signaling costs while other receivers are set their initial signal to one. The signals are normally distributed with a mean of one or zero and a standard deviation of 0.025 to distinguish each individual signal. The signals vary stepwise with the derivative follower algorithm; the size of the step is 0.1. This value means 10 % of initial value of normal sender's signal.

B. *The Simulation Results*

Figure 2 illustrates the simulation results of the signal changes of two types of senders for various periods. The signals of the two types seem to converge before the 20^{th} period; however, they finally diverge to around 1 and below 0.2 and become stabile.

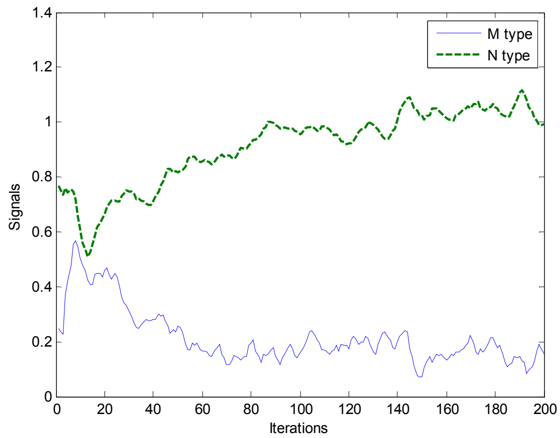

Figure 2. Signal changes of the two types of senders

From equation (7), we expect that the separating equilibrium such as in Figure 2 exists in the range from 1/9 to 1/3 for the given parameters in this simulation.

The simulation results of Table 2 indicate that if M type senders increase to 40 percent of total senders, over 80 percent of receivers take losses.

TABLE II. UTILITY CHANGE OF THE RECEIVERS

Proportion of M type senders	0.1	0.2	0.3	0.4
Average utility of receivers	0.79	0.45	–0.73	–1.30
Number of receivers having positive utility	50	36	25	16

The simulation results of Table 3 indicate that if the M type senders are less than 1/9 of total senders, the total sum of utilities in this situation is less than in the no-signaling situation.

Copyright (c) IARIA, 2011. ISBN: 978-1-61208-154-0

TABLE III. COMPARISON OF THE SUM OF UTILITIES

Proportion of M type senders		0.05	0.1
Signaling	*M type*	2.72	3.11
	N type	2.86	2.87
	All types	2.85	2.89
No-signaling	*M type*	4.04	4.40
	N type	7.89	7.99
	All types	4.00	4.00

Finally, if the signaling costs of the two types of senders cannot be distinguished from each other, that is, gamma equals 1, the results of the simulation suggest that the M type senders increase their signal more than the N type senders, as indicated in Figure 3.

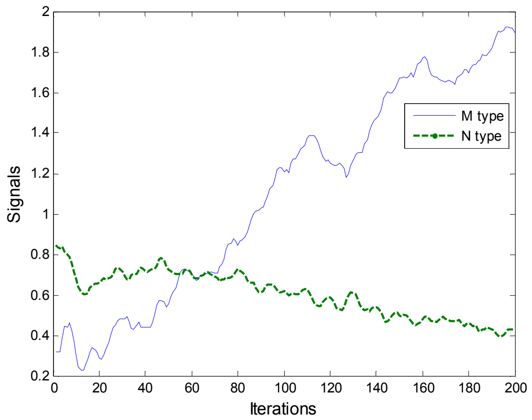

Figure 3. Signal changes of the two types of senders (when gamma equals one)

C. *The Comparison with Equilibrium Analysis*

Satisfying the criteria suggested by the results of the equilibrium analysis ensures the effectiveness of signals in distinguishing each type of participant and the stability of the separating equilibrium. First, to distinguish each type of participant on the basis of their signal, the signaling cost has to be distinct for each type to a certain extent. Second, the equilibrium that all types of participants select the same level of trust as their signal is not stable. Third, the effectiveness of distinction on the basis of the signal is affected by the revealed proportions of sender types.

The results of the simulation analysis validate the results of the equilibrium analysis and ascertain that the fundamental rules of the theoretical analysis are generally observed in the agent-based simulation in which bounded-rational agents interact with each other.

VI. CONCLUSION

This paper described the situation in which agents search, transact and manage their partners in network-based transactions based on trustworthiness signals and tried to formalize the fundamental rules of this situation using game theory, particularly the signaling game. In the situation described in this paper, the seller sends a signal of his/her trust level and the buyer decides his/her payment schedule for the presented signal. The results of the equilibrium analyses suggest the criteria of the signaling cost structures of participants and the market environment. Additionally, the results of the simulations validate the results of the equilibrium analyses.

However, this paper has the limitation as it only tried to find several fundamental rules. It only ascertained that the trust signaling cost structures of the different types of agents have to be distinguished from each other and did not suggest specific mechanisms. Therefore, future research should focus on specific mechanisms such as certification of third party authority and suggest an extended signaling game in which various types of agents interact with each other.

ACKNOWLEDGMENT

This research was supported by the KCC (Korea Communications Commission), Korea, under the CPRC (Communications Policy Research Center) support program supervised by the KCA (Korea Communications Agency). (KCA-2011-(11-941-1-005))

REFERENCES

[1] E. Chang, T. Dillon, and F. Hussain, "Trust and Reputation for Service Oriented Environment". John Wiley and Sons, 2005.

[2] C. Shapiro and H. Varian, Information Rules: A Strategic Guide to the Network Economy. Boston: Harvard Business School Press, 1999.

[3] A. Jøsang, R. Ismail, and C. Boyd, A survey of trust and reputation systems for online service provision, Decis. Support Syst. vol. 43, 2007, pp. 618–644.

[4] C. Shahabi, F.B. Kashani, Y.S. Chen and D. McLeod, Yoda: An accurate and scalable web-based recommendation system, Proceedings of the 9th International Conference on Cooperative Information Systems, 2001, pp. 418–432.

[5] M. Head, and K. Hassanein, "Trust in e-Commerce: Evaluating the Impact of Third-Party Seals", Quarterly Journal of Electronic Commerce, vol. 3, no. 3, 2002, pp. 307–325.

[6] G. A. Akerlof, "The market for "lemons": Quality uncertainty and the market mechanism," The Quarterly Journal of Economics, vol. 84, no. 3, 1970, pp. 488–500.

[7] A. M. Spence, "Job market signaling," Quarterly Journal of Economics, vol. 87, no. 3, 1973, pp. 355–374.

[8] A. Patcha and J. Park, "A Game Theoretic Formulation for Intrusion Detection in Mobile Ad Hoc Networks, " International Journal of Network Security, vol. 2, no. 2, 2006, pp. 131–137.

[9] F. Li and J. Wu "Hit and run: A Bayesian game between malicious and regular nodes in mobile networks", Proc. IEEE SECON, 2008, pp. 432–440.

[10] R. Axelrod, The Evolution of Cooperation, Basic Books: New York, 1984.

[11] M. A. Nowak and K. Sigmund, "Evolution of indirect reciprocity by image scoring", Nature, vol. 393, 1998, pp. 573–577.

[12] B. Johnson, J. Grossklags, N. Christin and J. Chuang, “Are Security Experts Useful? Bayesian Nash Equilibria for Network Security Games with Limited Information,” Proceedings of ESORICS'2010, 2010. pp. 588–606.

[13] J. Hwang, S. Kim, H. Kim and J. Park, “An optimal trust management method to protect privacy and strengthen objectivity in utility computing services,” International Journal of Information Technology & Decision Making, vol. 10, issue 02, 2011, pp. 287-308.

[14] A. Lopez-Paredes, M. Posada, C. Hernandez, and J. Pajares, “Agent based experimental economics in signaling games in Complexity and artificial markets,” Lecture Notes in Economics and Mathematical Systems, vol. 614, S. Klaus and H. Florian, Eds. Springer Verlag berlin Heidelberg, 2008, pp. 121–129.

[15] A. Greenwald and J. Kephart, “Shopbots and Pricebots,” Sixteenth International Joint Conference on Artificial Intelligence, August, 1999, pp. 506-511.