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Knowledge sharing in an organization

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Abstract

Managers are always seeking effective policies that encourage employees to share their knowledge with others in an organization. The appropriate organizational incentives are difficult to investigate due to human factors and other institutional complexities affecting sharing behaviors of individuals. Conducting laboratory or field experiments to evaluate the effectiveness of various organizational incentive policies is unrealistic. This work proposes a novel agent-based modeling approach to simulate the actions of knowledge sharing between actors in an organization. Several human and institutional factors in this artificial world were manipulated to understand knowledge sharing. The simulation results produce the following interesting findings. (1) The initial state of actors' action affects the knowledge-sharing action regardless of the adopted strategy. (2) Poorer collective capability among the population lowers the knowledge sharing behaviors. (3) The incentive policy has restricted effects for increasing the sharing action. Rewarding each knowledge-sharing action is more effective than the periodic organizational incentives to encourage actors' knowledge sharing behaviors.

Keywords: Knowledge sharing; Agent-based modelling; Organizational behaviour; Organizational incentive policy

1. Introduction

Knowledge plays a significant role in many organizations. Managers have perceived the competitive advantages resulting from knowledge for the last several decades. To maintain and acquire sustained competitive edge or power, many companies devote mass organizational resources to construct

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knowledge management systems and promote knowledge sharing in their organizations. However, many knowledge management systems have failed to facilitate knowledge sharing. One possible reason for this problem is as follows. If special knowledge is a competitive advantage and strategic resource for an organization, then clearly it is also a source of power and advantage for people who own it in the organization. People owning specific knowledge could enjoy some benefits and unique positions. People who share their knowledge with others would lose their unique positions in organizations. Therefore, the issue of sharing knowledge in an organization involves a “social dilemma”, and complex interactions between individuals and organization policy.

This work investigates the influence of the human behaviors based on self-interests (called as “the principal of maximizing their utility”), and different organizational incentives to promote knowledge sharing in an organization. In the past, empirical research and conceptual modeling have been widely undertaken, but presented difficulties in analytical reasoning. The complex social interaction cannot easily be formulated using mathematical functions. Moreover, different people have different capabilities, making knowledge sharing in an organization hard to analyze. Therefore, this investigation applies an agent-based modeling scheme to study the knowledge sharing phenomena by simulating the complex interactions between individuals, and assuming different organizational incentive policies. Through such simulations, managers can understand the complex knowledge sharing phenomena and measure the effectiveness of organizational incentive policies.

The rest of this paper is organized as follows. Section 2 discusses the attributes of knowledge and knowledge sharing issues. Section 3 then introduces social dilemmas, referring to conflicts between people and organizations. Knowledge sharing between people can be treated in game theory as a “prisoner’s dilemma” like game. Next, Section 4 presents the designs of different incentive policies in an organization. Section 5 introduces the agent based modeling strategy. Section 6 then discusses the simulation framework. Section 7 describes the experimental design. Section 8 summarizes the simulation results. Conclusions are finally drawn in Section 9, along with recommendations for future research.

2. Knowledge sharing in knowledge management

In the last decade, there has been a dramatic increase in the number of publications on knowledge management. Researchers and practitioners have widely investigated the characteristics and classification of knowledge, the concept models or frameworks of knowledge management, the methods or impact factors of transferring different knowledge, and the information technology supporting systems. These researches have now given us useful information and understanding for knowledge management theories and practices. Grant [1] conceptualized the “knowledge-based firm”, in which knowledge would be considered as important input elements and outcomes in production processes. The capability of integrating knowledge in a firm is an important key for success [1–4]. Therefore, the firms were considered as the institution for integrating knowledge or the distributed knowledge system [1,5]. Based on resource-based view or knowledge-based view, knowledge has been regarded as an important strategic agenda and resource, which is called “intellectual capital” [6,7].

Therefore, knowledge produces a strong competitive advantage when managing rapidly changing external environment [8]. Due to some properties of knowledge, which is tacit, dynamic, irreducible and extensible, enterprises can create an obstacle to their opponents, and perform organizational innovation on operation, service and products [9–13]. Additionally, the competitive advantage caused by knowledge is difficult for opponents to imitate [9–11]. Hence, knowledge management becomes a significant management topic in modern business.

In spite that knowledge plays an essential role in competition, the nature and definition of knowledge have been debated for decades by scholars. The characteristics of knowledge have been discussed widely in the literature. It is not easy to delineate clearly the properties of knowledge that involves different perspectives from philosophy, cognitive science, information science, organizational science, communication, *etc*. The claims from many aspects of knowledge might be different, even contradictory. Knowledge is considered as belief in mind, or a particular matter which could be managed as object and process [14]. The nature of knowledge is recognized widely as dynamics and exhibits a duality [15,16]. In general, knowledge could be classified as explicit or tacit knowledge according to the degree whether people could share easily with another [10,11,17,18]. Explicit knowledge typically refers to the knowledge that could be easily expressed by words or documents. In contrast, tacit knowledge is obscure and not easily or fully expressed. Polanyi [17] stated tacit knowledge, that "we can know more than we can tell".

Nevertheless, Nonaka and Takeuchi [11] suggest that total split into tacit-explicit should be an imperfect division of knowledge. That is, tacit and explicit knowledge are not independent but mutually complementary entities. It is helpful to understand the nature of knowledge to expound the process of knowledge conversion between individuals and organizations. The conversion processes is comprised of four stages: socialization, externalization, combination, and internalization. The conversion processes is triggered spirally, called "knowledge spiral", and knowledge creation and sharing become part of the culture of an organization. One of these stages, called socialization, the sharing of tacit knowledge, which is regarded as personal behavior and activities in mind, is a key. For sharing tacit knowledge, the interactions between individuals, e.g., joint activities, face-to-face discussion, are emphasized in this stage.

One of main goals of knowledge management initiatives is to improve or enable knowledge sharing or transferring across units for organizations [19]. If employees can utilize and share their individual knowledge of working, then both the organization and individuals can grow up. If knowledge cannot be effectively shared in an organization, then it is likely to fade away [20–23]. However, there are various factors that should be identified to foster knowledge sharing. In short, these factors can be categorized into three dimensions: organizational, individual, and knowledge level [24]. Separately, the complications on organizational level have been depicted including culture, power [25], technology [26], organizational capability [1,2,21,27–29], organizational climate [30,31] and social structure [3,29,32–34]. The factors on individual level are motivation [31,35], trust [36], social capital [37], self-efficacy [36,38], outcome expectation [36,37] and absorptive capability [29,39], etc. On the knowledge level, the characteristics of knowledge would influence the outcome of knowledge sharing [11]. As to knowledge level, it is interesting to find that little studies conduct the viewpoint, economic value of individual knowledge, to explore knowledge sharing in an organization. Most studies focus on the sharing or transferring of tacit knowledge.

Based on the economics theory, scarcity of knowledge decides its economic value, but not whether knowledge is tacit or explicit. It is concerned with the cost of transferring knowledge. The scarcer the knowledge needed by an organization is, the higher the economic value of knowledge for an organization is. If people could own the knowledge that is scarce and important, they would acquire great benefit from the organization. That is, once if they share their scarce knowledge, their knowledge advantage would be lost and benefit would also be damaged. In this case, why would people share their specific knowledge with others? About this question, little is known.

According to the above discussion, the classification of knowledge by its economic value is necessary for exploring knowledge sharing. Becerra-Fernandez et. al. [26] proposed an appropriate framework that can be used to clarify the economic value of knowledge. According to them, knowledge can be distinguished into general knowledge and specific knowledge. General knowledge is held by a large number of individuals and can easily be transferred across individuals. For example, the standard operation procedures may be considered as general knowledge. In contrast, specific knowledge is possessed by a very limited numbers of individuals and is not easily transferred. Specific knowledge may be technical or contextual. Technically specific knowledge is deep knowledge about a specific area. It includes the knowledge of tool and techniques for addressing problems in that area such as physicians, engineering. Contextually specific knowledge involves the knowledge of particular circumstances of time and place in which work is to be performed.

Besides, "localness of knowledge" [9] is an important characteristic of knowledge sharing across individuals. People usually share their knowledge with their organizational neighbours. Especially to specific knowledge, the transaction of the knowledge more depends on the mutual trust because of its potential risk. Individuals generally trust the persons whom they know. So, it could be expected that individual's knowledge sharing would be limited by their interactive networks that are composed of different social relationships including formal and informal relationships.

Many practitioners have recently attempted to manage individual and group knowledge in their organizations by developing efficient knowledge management systems and utilizing information communication techniques. However, but most of these projects have failed. The critical issue in knowledge management is knowledge sharing. Even though the best management systems are instituted, and information communication techniques are put in use, related working knowledge might still not be shared and infused into the right people. The knowledge management project might ultimately not improve the organization's competitive advantage, but instead bring overhead.

3. Social dilemma and prisoner's dilemma

The motivation of individual behaviour must be considered first. Sharing knowledge is a personal behaviour. In the past investigations, different kinds of motivation about knowledge sharing were discussed. Based on different motivations such as competition, reciprocity, reputation, ego satisfaction, organizational climate and so on [6,7,9,10,31,35], people might share knowledge with others. This study only considered economic motivation. In economics, the primary motivation of personal behaviours is self-interest. People would do their best to maximize individual utility. If knowledge owned by people is valuable to themselves, they are unlikely to share it with others [40–42].

Successfully knowledge sharing or knowledge transferring relies on neither document nor information techniques. Knowledge sharing in an organization involves interactions between people [9,11]. Under these conditions, an individual would consider the trade off between individual and organizational interests when making decision to share knowledge with others.

Since knowledge is powerful and scarce resource in a knowledge-intense firm, people possessing the important knowledge about an organization occupy a strong position and acquire some benefits in an organization. If people share their knowledge with others, their current advantages might suffer, or even be transferred to others. A rational individual would not easily share knowledge with others in these circumstances. However, an organization could consolidate its competitiveness by instigating innovation processes in which people share their knowledge unselfishly, so that knowledge can be utilized effectively. The context could be viewed as a "social dilemma", in which individual rationality results in collective irrationality [43,44].

Additionally, the conflict of interest between people also arises when people attempt to share their knowledge with their colleagues. This situation could be by analogy with the "prisoner's dilemma" [44–47].

The decision of whether to share knowledge influences individual profits. However, individual behaviour also affects the utility of opponents.

4. The organizational incentives policies

Assume that people are driven by the motivation of self-interests. In this assumption, people are likely to share their knowledge with others in an organization if they can gain additional payoff through doing so. People potentially benefit when they share knowledge with each other, by gaining or creating new specific knowledge, thus increasing the exclusive benefit in an organization. Due to the possibility of obtaining additional payoff, people are driven to share their valuable specific knowledge, even if there is a potential risk of losing their own knowledge advantages.

Therefore, managers could give employees extrinsic or natural rewards to encourage them to share knowledge in an organization. From the operant conditioning perspective, the reinforcement process would be activated, in which the expected behaviour, such as knowledge sharing, would be stimulated because it could lead to a positive outcome [48]. Knowledge sharing involves a conflict of interest between individual and group. A proper incentive policy is required to coordinate the conflict of interest among different stakeholders, and encourage knowledge sharing in an organization. Nevertheless, very few studies have been conducted on the design of knowledge sharing incentive policy, and its impact on the behaviour of individuals and an organization in short or long term.

Since the quality of shared knowledge is hard to measure, employees are in practice given rewards based on the frequencies of occurrence of sharing behaviour. Hence, managers could review regularly or irregularly the frequencies of knowledge sharing, and decide how much incentive should be provided. The reward offered by the organization should offset individual potential loss. Under this circumstance, different incentive policy designs might influence individual behaviour, enabling people might adapt their behaviours to interact with their external environments [49–51].

5. Agent-based modeling approach as a research strategy

The available analysis of knowledge sharing present some underlying analytical difficulties when attempting to explore the tendency of sharing knowledge among individuals and its effect on organizations and individuals, owing to the emergence of global characteristics that are not predictable from local interactions. Computer simulation seems to be appropriate for investigating these complex phenomena [52–54].

The effect of knowledge sharing in an organization is not a simple causality, but rather is involved in the interaction between individuals and organizational units. The phenomena cannot be treated simply as a linear system where individuals in an organization can spontaneously demand and supply different knowledge. Individuals would take actions and apply some strategies to maximize the utility of knowledge [55].

To explore the interaction among individuals and the effect of knowledge-sharing in an organization, agent-based modelling (ABM) is a good strategy for studying such complex systems. It is a simulation method and bottom-up strategy [44,45,52,54]. ABM can be utilized to create, observe, analyze and experiment with artificial world populated by agents that interact in non-trivial ways. The artificial systems constructed with ABM exhibit the following two properties: (1) they comprise interacting agents; and (2) they exhibit attributes arising from the interactions among agents that cannot be discovered simply by aggregating the characteristics of the agents. It is necessary to keep in mind that agent's rules of behaviour are appropriately simplified according to theories, literatures and research questions, compared with real life. Nevertheless, ABM can help researchers to explore the complex social phenomena.

6. The framework of simulation

This section discusses objectives and features of the proposed agent-based simulation model.

6.1. Research questions as simulation goals

The Repast toolkit [56] is adopted as the agent-based simulation framework to develop and implement the model in Java. Repast was selected due to its widespread use and openness. Repast is also supported by a strong community of users. Models created by Repast could be easily understandable by other researchers.

This work attempts to establish an agent-based simulation model to describe (1) the human behaviour rules, (2) payoffs of knowledge sharing among people, (3) individual capability of knowledge sharing and absorption, and (4) the incentive policy of organization. Although there are probably lots of factors, which govern behaviour, e.g., place, time, social relationship, intention, culture, position, etc., it is necessary to keep in mind that simulation is necessarily a simplification. In any event, this is a good start.

Therefore, in principle, the emergent phenomena are sought at the macro level from the interactions of simple agents described in the model, and the following issues are addressed:

1. How the combination of strategies, which could be adopted by people in an organization, affects the organizational behaviour, climate, and performance without organizational intervention, considering the different payoff matrices of knowledge sharing.
2. How different organizational incentive policies influence the organizational behaviour, climate and performance throughout given payoff matrices of knowledge sharing?

Organization behavior refers to collective behavior within an organization. In this model, the organizational behavior is observed by obtaining the frequency of actions involving members sharing their knowledge in an organization under different given conditions, including the combinations of strategies applied by people, and incentive policies.

The organizational climate refers to the contextual situation at a point in time, and its link to thoughts, feeling and the behaviors of organizational members [31,50,57]. Therefore, in the artificial world, the tendency of the organizational climate can be built from the frequencies of the actors' strategies at a point in time. In the model, the actors' strategies, which are exogenous factors identified by investigators, are individual attitudes in response to another behavior. By observing the diversification of strategies at a point in time, the organizational climate can be employed to justify the organizational intervention, depending on whether people are encouraged to share their knowledge.

The following issues are investigated at the micro level.

(1) How does the effect of knowledge sharing influence the agents' behaviour because of the characteristics of knowledge?
(2) How do the organizational incentive policies influence the agents' behaviour?
(3) How do the different capabilities of sharing and absorbing knowledge influence the agents' behaviour?

Knowledge sharing can be regarded as a process of interactions among people. Assuming that knowledge sharing is not an obligation, the prisoner's dilemma is to decide whether to share knowledge with others. The model includes three utility payoff matrices, based on the differentiation of knowledge shared in an organization, to explore the effect on agents' behavior combined with different strategies.

Assuming that agents would maximize their utilities that are perceived by people, the next step is to discover the strategies that reach a goal. Agents need to maximize their perceived utilities through learning, imitation and adaptation of strategy based on different utility payoff matrices of knowledge. Additionally, people can acquire additional or synergetic values due to the integration of different knowledge through sharing. That is, people might be stimulated into generating additional valuable knowledge, which could raise their utilities [30,31]. Five kinds of deterministic strategies are described to examine their model effects. Furthermore, the effect of organizational incentive policies, and the collective capabilities of sharing and absorbing knowledge on the strategies adopted by agents, is also addressed.

6.2. Payoff deriving from knowledge sharing

Assuming that each piece of knowledge has equal value or utility, and that any player has some knowledge that others have not, the effect of sharing knowledge on any individual agent consists of the following three components:

1. the basic value of knowledge for receivers, denoted by R, where $R \geqq 0$;
2. the synergetic value describing the degree to which each agent gains because of the mutual knowledge sharing, represented by S, where $S \geqq 0$;
3. the perceived utility loss describing the degree to which each agent perceives the negative utility from the knowledge sharing activity due to the transfer of monopolistic knowledge, denoted by $-L_A$, which is player A's perceived loss when player A share knowledge with player B; or denoted by $-L_B$, which is player B's perceived loss when player B share knowledge with player A and $L_A, L_B \geqq 0$;

Considering that each agent has equal capability of knowledge transferring or absorption, the degree of utility gained by each agent from the interaction of knowledge sharing depends on the opponent's behavior. For instance, if players *A* and *B* mutually share their knowledge, then each agent could increase its utility obtained from the basic value of knowledge ("*R*"), and gain the synergetic value ("*S*") because of

Table 1
Payoff matrix if agents' capabilities are equivalent

		Player A	
		Sharing knowledge	Not sharing knowledge
Player B	Sharing knowledge	$R+S-L_A$	R
		$R+S-L_B$	$-L_B$
	Not sharing knowledge	$-L_A$	0
		R	0

Legend
R: basic value of knowledge from the opponent, where $R \geqq 0$.
S: synergetic value gaining from mutual sharing knowledge, where $S \geqq 0$.
$-L_A$: perceived loss of Player A's utility because monopolistic knowledge was transferred, where $0 \leqq L_A \leqq R$.
$-L_B$: perceived loss of Player B's utility because monopolistic knowledge was transferred, where $0 \leqq L_B \leqq R$.

Table 2
Payoff matrix if agents' capabilities are equivalent while offering organizational incentive

		Player A	
		Sharing knowledge	Not sharing knowledge
Player B	Sharing knowledge	$R+S-L_A+I$ $R+S-L_B+I$	R $-L_B+I$
	Not sharing knowledge	$-L_A+I$ R	0 0

Legend
R: basic value of knowledge from the opponent, where $R \geqq 0$.
S: synergetic value gaining from mutual sharing knowledge, where $S \geqq 0$.
I: added utility gaining from organizational incentive, where $I \geqq 0$.
$-L_A$: perceived loss of Player A's utility because monopolistic knowledge was transferred, where $0 \leqq L_A \leqq R$.
$-L_B$: perceived loss of Player B's utility because monopolistic knowledge was transferred, where $0 \leqq L_B \leqq R$.

mutual knowledge sharing, but both agents also suffer some utility loss ("$-L_A$" or "$-L_B$") from knowledge sharing. Conversely, if neither agents share knowledge with each other, then the payoff of each agent is zero. If one agent shares knowledge with the other, but the other does not, then the knowledge receiver would increase its utility obtained from the basic value of knowledge ("R"), and the giver suffers utility loss ("$-L_A$" or "$-L_B$") from the interaction. Table 1 presents the payoff matrix.

Another payoff matrix (as Table 2) is then calculated given that an organization would offer a positive incentive, denoted by I, for employees who have exhibited sharing knowledge behavior, and assuming that the utility of the incentive is equal for all employees. The positive incentive might make up the individual perceived utility loss.

Finally, Table 3 shows the payoff resulting from the knowledge sharing when addressing the variation of personal capabilities of knowledge sharing and absorption. The capabilities of knowledge sharing (C_s) and absorption (C_a) indicate the imperfect aspects of knowledge delivering and receiving, respectively. The

Table 3
Payoff matrix if agents' capabilities are different while offering organizational incentive

		Player A	
		Sharing knowledge	Not sharing knowledge
Player B	Sharing knowledge	$R*Cs_B*Ca_A+S+I$ $-L_A*Cs_A*Ca_B$ $R*Cs_A*Ca_B+S+I$ $-L_B*Cs_B*Ca_A$	$R*Cs_B*Ca_A$ $-L_B*Cs_B*Ca_A+I$
	Not sharing knowledge	$-L_A*Cs_A*Ca_B+I$ $R*Cs_A*Ca_B$	0 0

Legend:
R: basic value of knowledge from the opponent, where $R \geqq 0$.
S: synergetic value gaining from mutual sharing knowledge, where $S \geqq 0$.
I: added utility gaining from organizational incentive, where $I \geqq 0$.
$-L_A$: perceived loss of Player A's utility because monopolistic knowledge was transferred, where $0 \leqq L_A \leqq R$.
$-L_B$: perceived loss of Player B's utility because monopolistic knowledge was transferred, where $0 \leqq L_B \leqq R$.
Cs_A, Cs_B: the player A's or player B's capability of sharing knowledge out, where $0 \leqq Cs_A$, $Cs_B \leqq 1$.
Ca_A, Ca_B: the player A's or player B's capability of absorbing others' knowledge, where $0 \leqq Ca_A$, $Ca_B \leqq 1$.

Table 4
Type I payoff matrix

		Player A	
		Sharing knowledge	Not sharing knowledge
Player B	Sharing knowledge	*3*	*5*
		3	*−2*
	Not sharing knowledge	*−2*	*0*
		5	*0*

phenomena usually happen in a real life. Someone might own a lot of knowledge; however, he (she) is not a good teacher to deliver his (her) knowledge to others. Someone might be eager to obtain new knowledge; however, he (she) is not a good student to learn knowledge from others. The capability of knowledge sharing (as a teacher) and absorption (as a student) would moderate the effect of knowledge sharing.

7. Experiment design

7.1. Payoff matrix implementation

Tables 4, 5 and 6 show several implementations for the above payoff matrices. Consider the matrix in Table 1. Three sets of parameter values were implemented as follows.

Type I payoff matrix (Table 4): $R=5, L=2$, and $S=0$. In other words, first assume no synergy effect on knowledge sharing.
Type II payoff matrix (Table 5): $R=5, L=0$, and $S=0$. Restated, assume no synergy effect on knowledge sharing, and no potential utility loss.
Type III payoff matrix (Table 6): $R=5, L=2$, and $S=5$. That is, the knowledge sharing might spark some new knowledge, producing the synergy effect.

Table 5
Type II payoff matrix

		Player A	
		Sharing knowledge	Not sharing knowledge
Player B	Sharing knowledge	*5*	*5*
		5	*0*
	Not sharing knowledge	*0*	*0*
		5	*0*

Table 6
Type III payoff matrix

		Player A	
		Sharing knowledge	Not sharing knowledge
Player B	Sharing knowledge	*8*	*5*
		8	*−2*
	Not sharing knowledge	*−2*	*0*
		5	*0*

7.2. Agent strategies

In the simulation, an agent adopts a strategy, which includes the rules responding to the opponent behaviors. The time series of different strategies applied by the persons in the whole organization can be adopted to predict whether an organization climate involves trust. Referring to the literature [44,45,58,59], five strategies (named as cooperative, tit-for-tat, bullying, uncooperative, and mistrustful in the following) were adopted in this experiment to investigate the effects on the individual behavior and performance of organizational knowledge sharing.

1. Cooperative: people always share their knowledge with their opponents, regardless of the actions adopted by the opponents.
2. Tit-for-tat: people initially share their knowledge with their opponents, and later follow the action of their opponents.
3. Bullying: people initially do not share their knowledge with their opponents, and later adopt the opposite action to their opponents (i.e., not sharing if the other sharing; sharing if the other not sharing).
4. Uncooperative: people never share their knowledge with their opponents, irrespective of the actions adopted by opponents.
5. Mistrustful: people initially do not share their knowledge with their opponents, and later follow the action of opponents.

Assuming that each agent has a memory of only one round memory, that is, it can only remember its opponent's behavior in the previous interaction, individual action strategies can be denoted as a set of discrete probability variables represented as follows [58]:

$$\text{Strategy Space} \equiv S(i, p, q) \quad i, p, q \in \{0, 1\}$$

i Probability of sharing knowledge in the first interaction
p Probability of sharing knowledge if opponent shared their knowledge in last interaction
q Probability of sharing knowledge if opponent did not share their knowledge in last interaction

Table 7 presents the strategy space of these five strategies.

In the experiments, different combinations of strategies were designed to simulate the tendency of mutual trust among people. Four combinations of strategies, (cooperative, tit-for-tat, bullying, uncooperative), (cooperative, tit-for-tat, bullying, uncooperative, mistrustful), (tit-for-tat, bullying, uncooperative,

Table 7
Strategy space and strategy types

	i	p	q
Cooperative	1	1	1
Tit-for-tat	1	1	0
Bullying	0	0	1
Uncooperative	0	0	0
Mistrustful	0	1	0

mistrustful) and (cooperative, bullying, uncooperative, mistrustful), were applied. In first run of simulation, the strategies were assigned randomly and distributed in equal proportion to agents. The strategies separately indicate different levels of mutual trust among people.

7.3. The capability of sharing and absorbing knowledge

The capabilities of knowledge sharing and absorption affect the individual payoff of knowledge sharing, and might influence individual behaviors. In the experiments, capabilities of employees in an organization were used as probability distribution functions. The following four organizational capabilities were investigated in the experiment.

1. Uniformly intelligent: each agent can completely share and absorb knowledge.
2. Smart distribution: the capabilities of organizational members have a Beta probability distribution with $\alpha=5$ and $\beta=2$. It is a left-skewed distribution with mainly smart members.
3. Normal distribution: the capabilities of organizational members is assumed to be a normal probability distribution with μ(mean)$=0.5$ and σ^2(variance)$=0.16$.
4. Stupid distribution: the capabilities of organizational members would be assumed as Beta probability distribution with $\alpha=2$ and $\beta=4$. It is a right-skewed distribution with mainly stupid members.

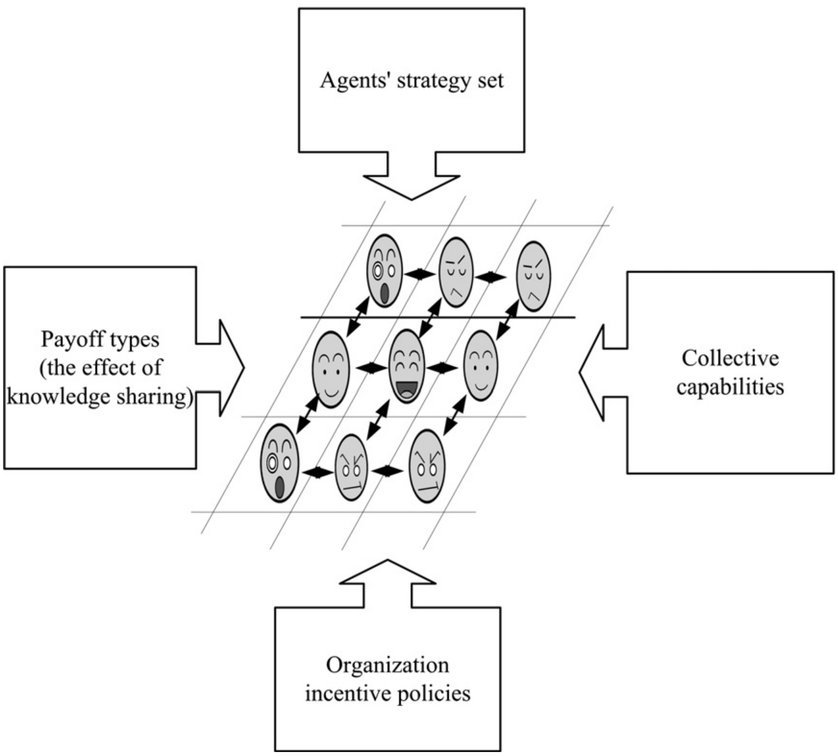
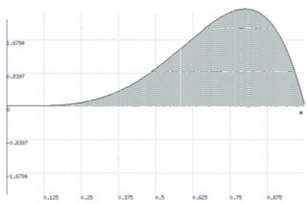
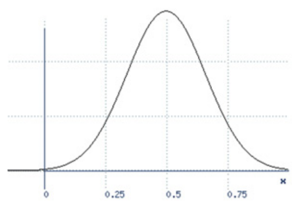
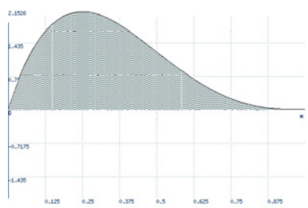


Fig. 1. The sets of simulation parameter configurations.

Table 8
A summary of parameter configurations of simulations

Simulation parameters	Configurations	Descriptions
Payoff types (the effect of knowledge sharing)	Type I payoff	No synergy with loss
	Type II payoff	No synergy, and no loss
	Type III payoff	With synergy and loss
Agents' strategy sets	Set 1	Cooperative, tit-for-tat, bullying, uncooperative
	Set 2	Cooperative, tit-for-tat, bullying, uncooperative, mistrustful
	Set 3	Cooperative, bullying, uncooperative, mistrustful
	Set 4	Tit-for-tat, bullying, uncooperative, mistrustful
Collective capabilities	Intelligent	Each agent can fully deliver knowledge to others and receive knowledge from others
	Smart	Collective capabilities is shown as Beta distribution with $\alpha=5$ and $\beta=2$. 
	Normal	Collective capabilities is shown as Normal distribution with $\mu=0.5$ and $\sigma^2=0.16$. 
	Stupid	Collective capabilities is shown as Beta distribution with $\alpha=2$ and $\beta=4$. 
Organization incentive policies	No rewards	No any incentive given whether agents share their knowledge or not
	Incentive for each knowledge sharing action	Incentive values were given between 0 and 2
		Incentive values were given between 2 and 5
	Periodic rewards	Incentive values were included 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100

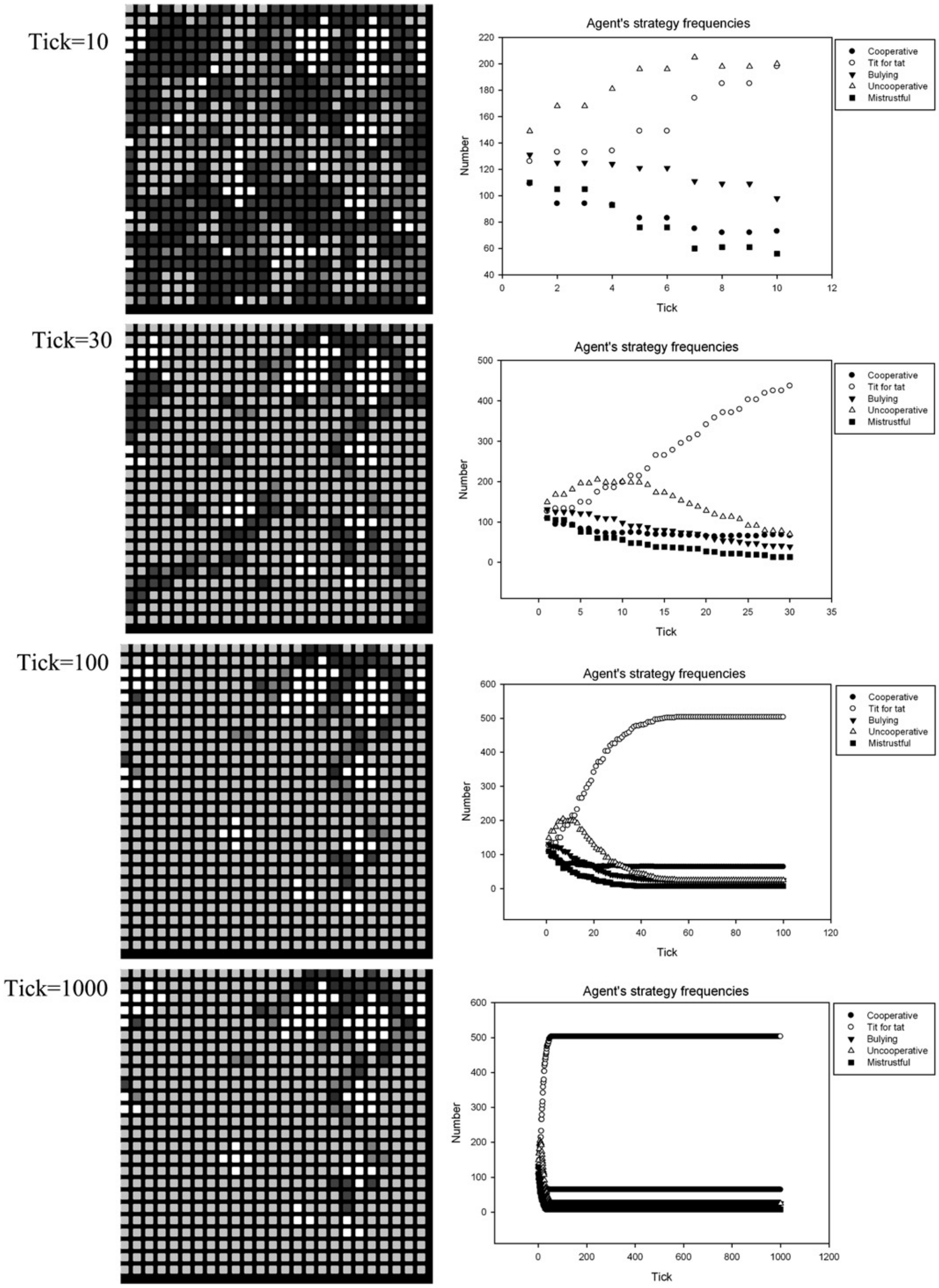


Fig. 2. Simulation dynamics. (The parameters of the above run are set as follows: Payoff type I: no synergy with loss; Agents' strategy set: {cooperative, tit-for-tat, bullying, uncooperative, and mistrustful}; Collective capabilities: smart distribution; No any organization incentive).

7.4. Organizational incentive policies

The following three incentive policies were designed to explore the effectiveness of incentive policies on knowledge sharing in the short and long terms. The degrees of incentives are implicitly degrees of risk premium for knowledge sharing by actors.

(1) No rewards: no organizational incentive is provided for individual knowledge sharing.
(2) Rewards to each action of knowledge sharing: if an individual shares his (her) knowledge, he (she) obtains a reward immediately. Two types of gain are assumed. The first is to assume that the organization partly compensates for an agent's perceived loss due to sharing knowledge with others, based on an algorithm that randomly assigns a floating-point number between 0 and 2 (depicted as [0, 2]) when an agent shares knowledge. The second is to assume that organizational fully compensates for the agent's perceived loss, but the compensation is fewer than knowledge basic value which s(he) shares, by an algorithm that randomly assign a floating-point number between 2 and 5 (depicted as [2, 5]) when agent shares knowledge with another.
(3) Periodic rewards: if the ratio of sharing knowledge actions of an individual exceeds 50% within a period, then the individual is rewarded. The rewarded value is fixed in a simulation. The experiment was performed with payoffs of 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100.

Table 9
Average frequencies of knowledge sharing under different payoff types if tit-for-tat could be chosen

Behaviour / Payoff matrix types	Sharing	Not-sharing
Type I (no synergy with loss)	19855.2	144.8
Type II (no synergy, no loss)	20000	0
Type III (with synergy and loss)	20000	0

Table 10
Average frequencies of knowledge sharing under different payoff types if tit-for-tat could not be chosen

Behaviour / Payoff matrix types	Sharing	Not sharing
Type I (no synergy with loss)	212.6	19787.4
Type II (no synergy, no loss)	11312.4	8687.6
Type III (with synergy and loss)	20000	0

Table 11
Average frequencies of strategies adopted by agents under different payoff types if tit-for-tat could be chosen

Strategy / Payoff matrix types	Cooperative	Tit-for-tat	Bullying	Uncooperative
Type I (no synergy with loss)	7.8	613.8	0	3.4
Type II (no synergy, no loss)	126.4	498.6	0	0
Type III (with synergy and loss)	169.5	455.5	0	0

Table 12
Average frequencies of strategies adopted by agents under different payoff types if tit-for-tat could not be chosen

Strategy / Payoff matrix types	Cooperative	Bullying	Uncooperative	Mistrustful
Type I (no synergy with loss)	6.1	0.4	576	42.5
Type II (no synergy, no loss)	301.7	118.6	203.2	1.5
Type III (with synergy and loss)	625	0	0	0

Table 13
The expected payoff of different strategies in a tick stage (4 times interactions)

	Type I payoff	Type II payoff	Type III payoff
Cooperative	3	11	14
Tit-for-tat	6.8	12	15.8
Bullying	6.4	10	12.8
Uncooperative	8	8	8
Mistrustful	5.2	6	9.2

7.5. Mechanism of learning and adaptation

Given that all agents could observe the strategies and average payoff of their opponents after a period of time, agents might adapt their strategies by comparing the total payoffs with their opponents. If one agent gains the largest average payoff, then other agents might, but not necessarily (with the assigned probability 20%), learn the winner's strategy. Agents would imitate the best-performing strategy among their opponents in the experiment.

7.6. Simulation runs

A population of 625 (25×25) individuals was experimented in a grid space. Each individual could interact with four opponents (left, right, top, and down). Considering knowledge sharing payoff matrices, the combination of behavioral strategies, collective capabilities, and incentive policies, 624 (3×4×4×13) parameter configurations were simulated. Fig. 1 is illustrated the parameter configurations of simulations. The summary of parameter configurations is listed in Table 8. Each parameter configuration was simulated repeatedly for 10 runs for taking up noises as possible, due to the differentiation of random exogenous parameters. In each run, the model was run for 1000 periods

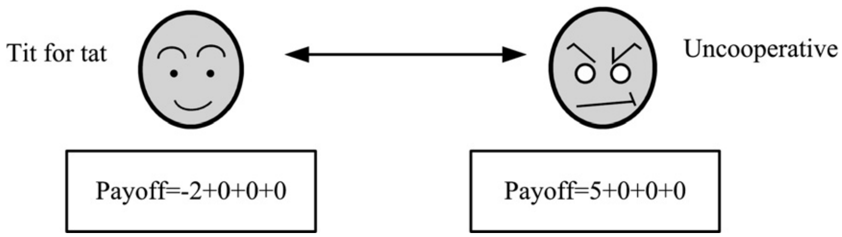


Fig. 3. The separate payoffs that tit-for-tat and uncooperative agents obtain from neighbours.

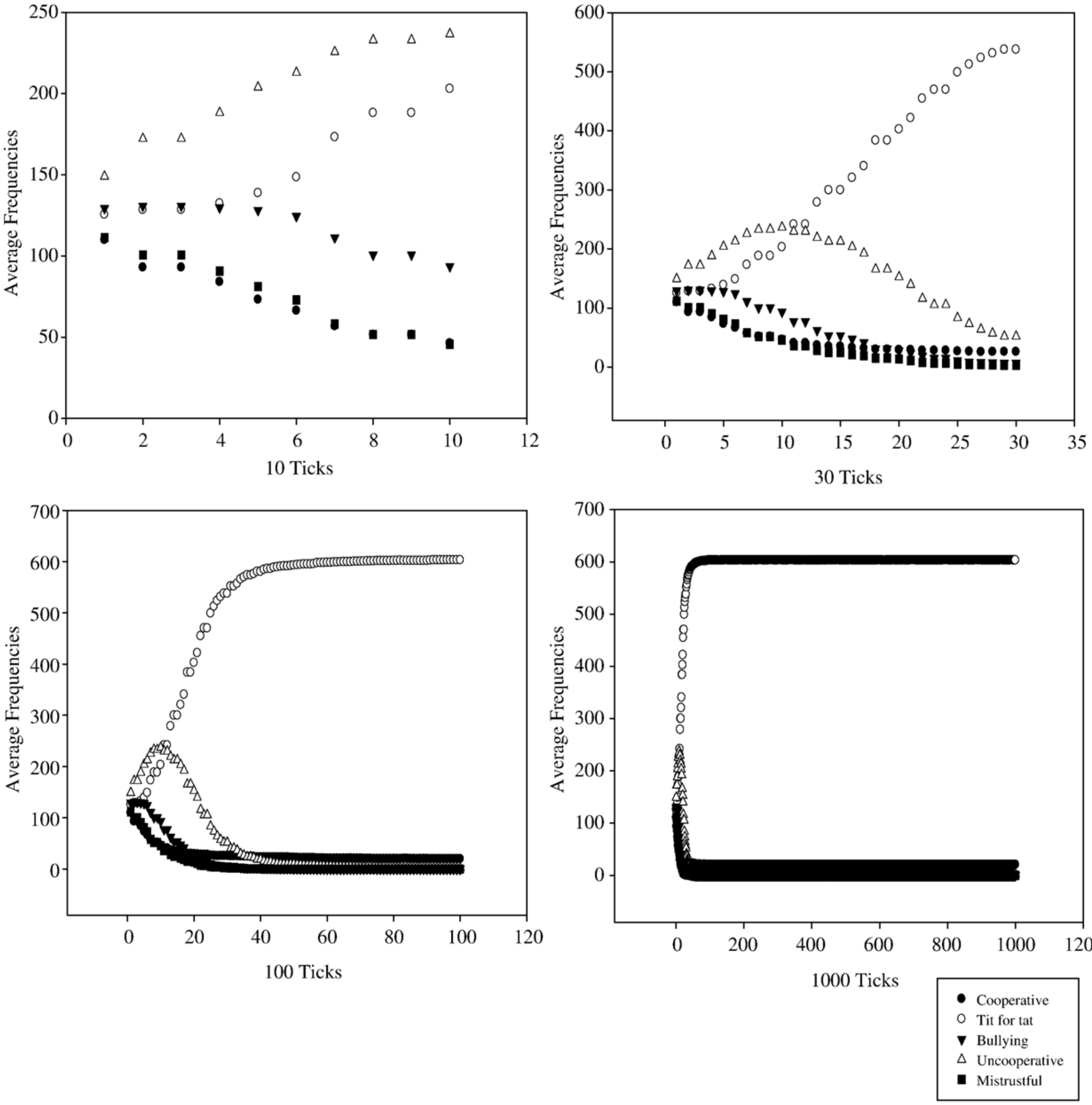


Fig. 4. Average frequencies of different strategy types in the tick series of knowledge sharing according to the results of ten runs. (The above is set the following parameters: Type I payoff: no synergy with loss; Agents' strategy set: {Cooperative, Tit-for-tat, Bullying, Uncooperative, Mistrustful}; Collective capabilities: Intelligent; No any organization incentive).

(called as "ticks" in the Repast toolkit), and each individual would meet each opponent 4 times in each tick. Individuals could recognize previous interactions, and remembered some aspects of previous outcomes, when interacting with opponents. Individuals would eventually adapt their own strategies for comparing average payoff with their opponents. The frequencies of individual actions, strategies, and payoff were collected for each period. Finally, the average values of these variables were obtained

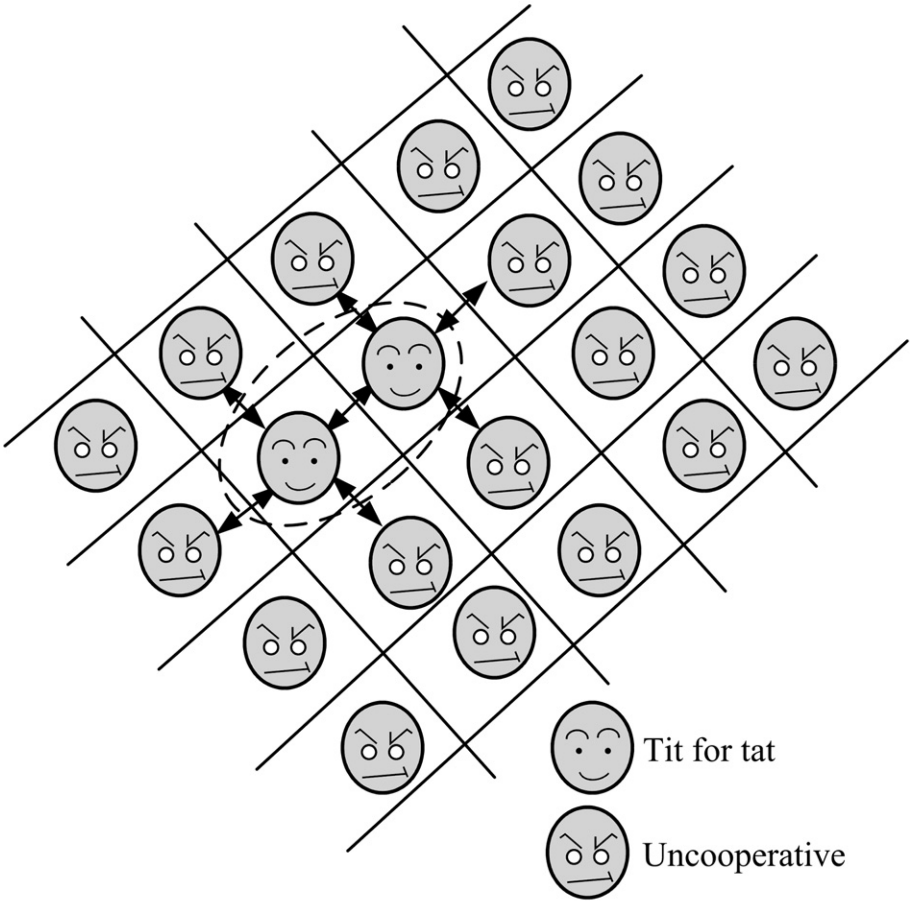


Fig. 5. Group effect illustration. (If two tit-for-tat agents or more meet together, they could invade uncooperative agents around).

for each parameter configuration. The simulation dynamics of one set of parameters are illustrated in Fig. 2.

8. Findings and discussions

This study produced three main findings, which are summarized below.

8.1. Knowledge sharing spontaneously

The model produced three interesting results.

(1) As demonstrated in Table 9, knowledge sharing occurs spontaneously in most conditions, without considering the variation in personal capability (i.e., assuming they are all intelligent) and organizational incentive. However, if tit-for-tat cannot be adopted by agents facing a Type I payoff, then the non-sharing behaviours would rise, as revealed in Table 10.

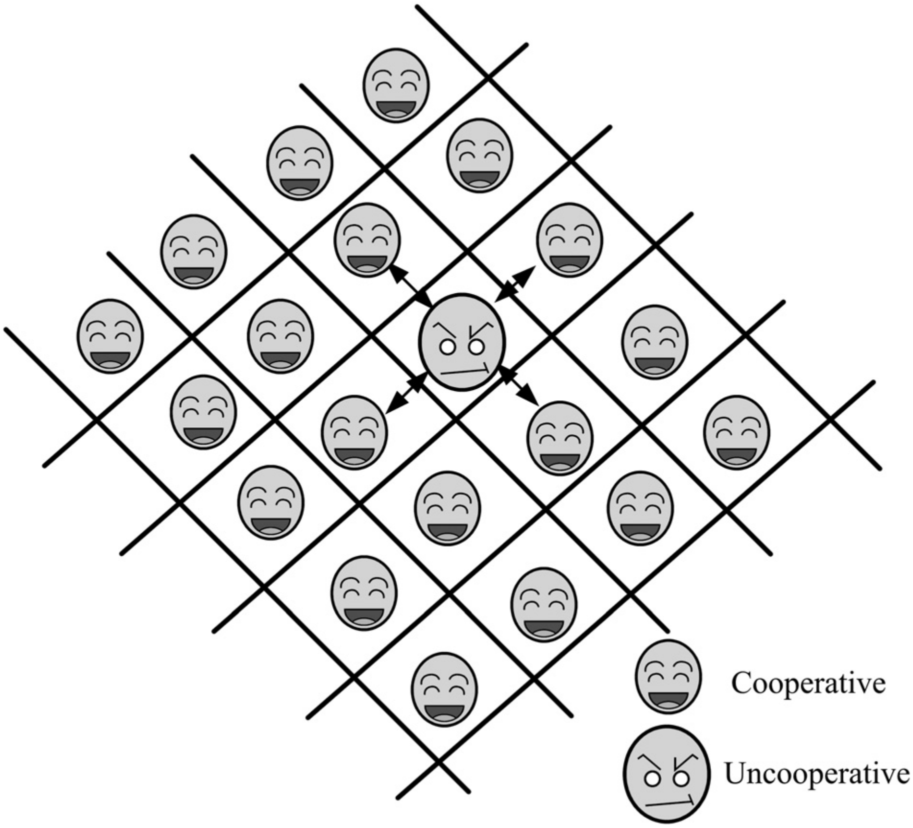


Fig. 6. A single uncooperative agent would invade easily the cooperative agents.

(2) As indicated in Table 11, tit-for-tat strategy would dominate in the population. However, as shown in Table 12, if tit-for-tat is not allowed to be adopted by agents, then uncooperative dominates in the population under Type I payoff, while cooperative dominates under Type III payoff (a synergy effect is present).
(3) If knowledge sharing raises the payoff (synergy effect), then more agents adopt the cooperative strategy, but its growth is still limited.

According to the effects of knowledge sharing, which are denoted as types of payoff, the expected payoff of strategy types can be estimated (shown in Table 13), when an agent doesn't identify the strategy type of his opponent in a tick stage. Tit-for-tat strategy usually performs better than other strategies. There is an exception to this rule. That is, when the effect of knowledge sharing is no synergy with loss (Type I payoff), uncooperative can perform better than others strategies in a tick stage. Fig. 3 indicates the separate payoffs that tit-for-tat and uncooperative agents would obtain from their neighbors, when they are in a tick stage. Uncooperative strategy performs better than tit-for-tat. In a long run, however, it was found from experiment results that tit-for-tat always dominate other strategies. The results are illustrated in Fig. 4. In initial stages, the frequencies of uncooperative agents increased fast more than tit-for-tat.

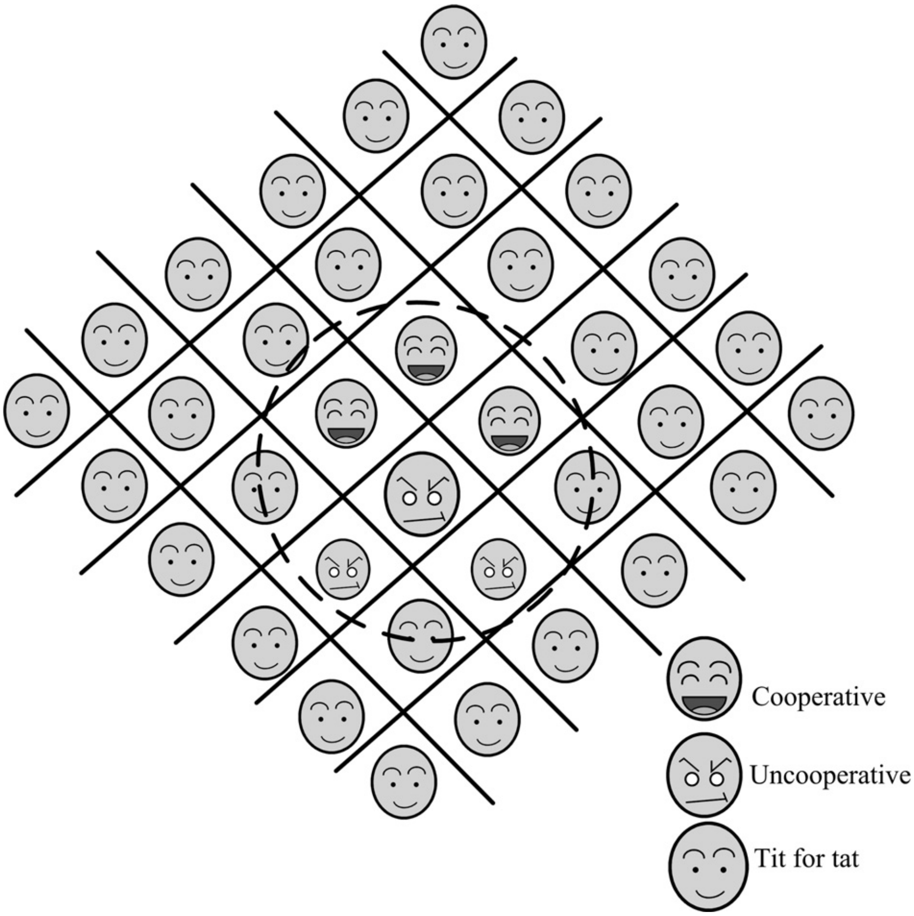


Fig. 7. A pattern of remaining uncooperative agents in the model.

Latter, uncooperative agents, however, decreased gradually and tit-for-tat agents kept increasing. Finally, tit-for-tat agents dominated in the space.

The domination of tit-for-tat strategy can be explained as follows. When agents are in a peer-to-peer game which is Type I payoff (no synergy with loss), the observed interchange gains in Fig. 3 demonstrate that uncooperative agents gained the most in a tick stage. Therefore, uncooperative agents could "invade" cooperative, tit-for-tat, bullying and mistrustful agents. The "invasion" implies that strategies of other agents would be influenced and adapted, causing them to imitate the uncooperative strategy to maximize their payoffs. Therefore, uncooperative agents would spread fast in the beginning. However, two uncooperative agents did not gain from each other. In that case, their payoffs were nothing. On the other hand, tit-for-tat clusters generate a better "group effect" than uncooperative. That is, when tit-for-tat agents grouped together, in a long run, they could increase their payoff compared with uncooperative groups. Moreover, tit-for-tat group could invade uncooperative agents around (illustrated with Fig. 5). In these circumstances, the uncooperative group could not easily invade the overall system. Instead, tit-for-tat agents dominated other strategies.

Table 14
Average frequencies of different strategy agents under different payoff types without organizational reward

Capability Level	Payoff	Cooperative	Tit-for-tat	Bullying	Uncooperative	Mistrustful
Uniformly intelligent	Type I	20	602.6	0	2.4	0
	Type II	174.7	450.3	0	0	0
	Type III	268.2	356.8	0	0	0
Smart distribution	Type I	63.4	489.2	23	43.7	5.7
	Type II	201.9	402.7	13.9	5.2	1.3
	Type III	236.2	384.1	2.7	0.2	1.8
Normal distribution	Type I	74.5	393.1	55.2	88.2	14
	Type II	196.1	392.6	23.8	8.7	3.8
	Type III	232.7	364	21.4	2.8	4.1
Stupid distribution	Type I	118.2	288.6	95.5	91	31.7
	Type II	180.1	344.3	67.9	24.5	8.2
	Type III	199.7	345.7	57.3	8.6	13.7

Note: Each average frequency means the average number of agents adopting different strategies. It was calculated according to the results of ten runs corresponding to a parameter configuration. For example, the parameter configuration of the first row is that payoff type is "Type I", collective capabilities are "uniformly intelligent", the agents' strategy are {cooperative, tit-for-tat, bullying, uncooperative, mistrustful}, respectively, and organization incentive policy is "no rewards".

Cooperative agents also exhibited the same "group effect" as tit-for-tat. Therefore, when cooperative and tit-for-tat groups met, they remained relatively stable, and did not invade each other. However, cooperative did not dominate in the model, since it was fragile and easily despoiled by other strategies, especially uncooperative (illustrated in Fig. 6). The cooperative agents had the lowest expected payoff (shown in Table 13). Under the Type 2 payoff (knowledge sharing without loss and synergy) or Type 3 payoff (with synergy and loss), the expected payoff of cooperative agent increased, and agents also

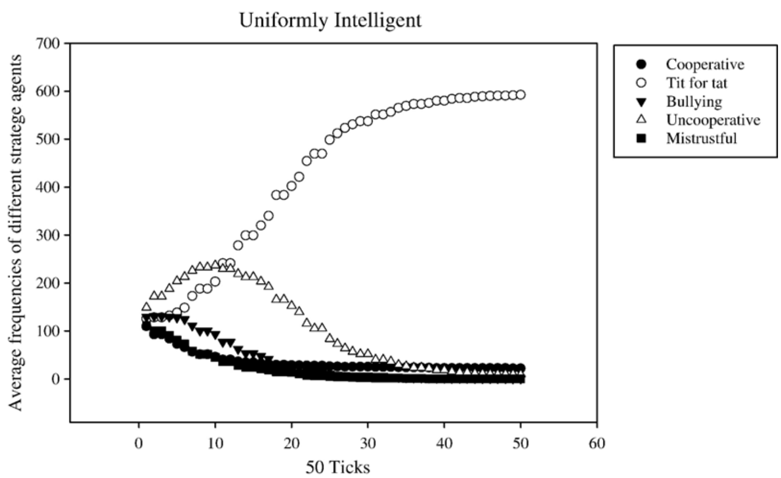


Fig. 8. Dynamics about agents' strategy change with uniformly intelligent capabilities of agents. (The parameter configuration: that payoff type is "Type I", the agents' strategy set is {cooperative, tit-for-tat, bullying, uncooperative, mistrustful}, and organization incentive policy is "no rewards").

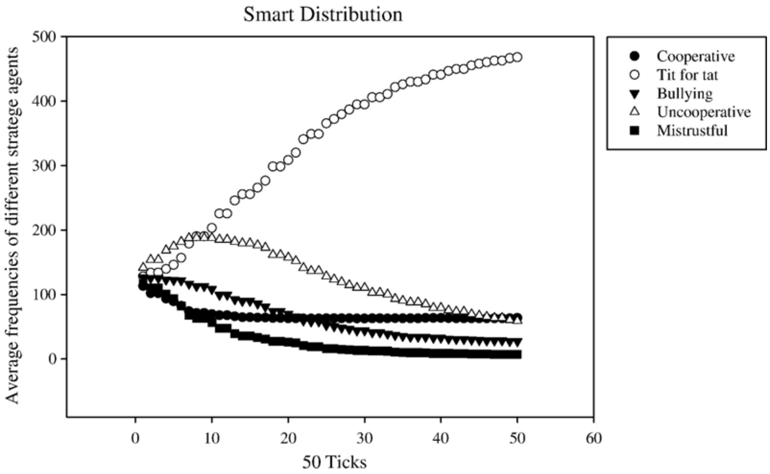


Fig. 9. Dynamics about agents' strategy change with smart distribution collective capabilities. (The parameter configuration: Payoff type is "Type I", the agents' strategy set is {cooperative, tit-for-tat, bullying, uncooperative, mistrustful}, and organization incentive policy is "no rewards").

increasingly adopted cooperative. However, cooperative still did not dominate other strategies. Because it does not punish hostile opponents, the cooperative group was difficult to invade into other population. But, cooperative was easily invaded by uncooperative group. By contrast, tit-for-tat group easily suppressed uncooperative by the "group effect". Consequently, tit-for-tat always dominated the population in a long run, and most agents exhibited knowledge sharing behavior. In spite that most agents extrinsically showed knowledge sharing, they most finally adopted the tit-for-tat strategy to interact with opponents. The analysis implies that the organization climate seem to be tending towards self-defense and less trustable under tit-for-tat domination.

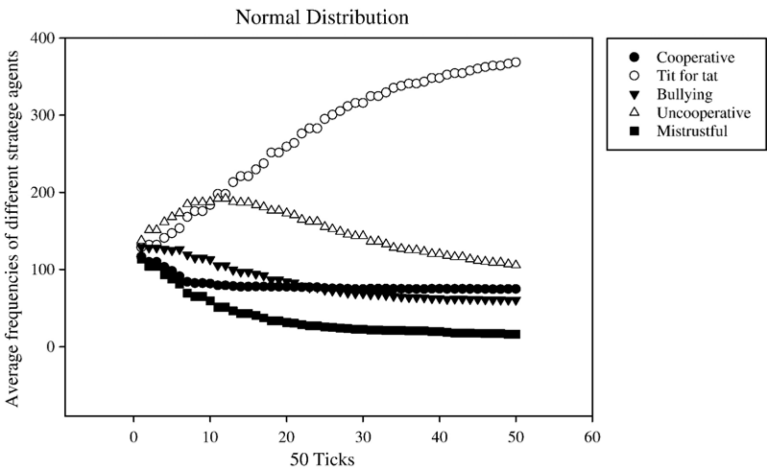


Fig. 10. Dynamics about agents' strategy change with normal distribution collective capabilities. (The parameter configuration: payoff type is "Type I", the agents' strategy set is {cooperative, tit-for-tat, bullying, uncooperative, mistrustful}, and organization incentive policy is "no rewards").

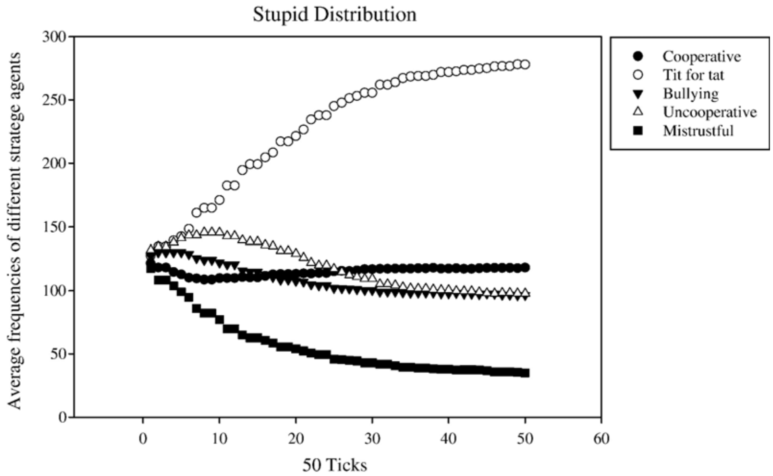


Fig. 11. Dynamics about agents' strategy change with stupid distribution collective capabilities. (The parameter configuration: payoff type is "Type I", the agents' strategy set is {cooperative, tit-for-tat, bullying, uncooperative, mistrustful}, and organization incentive policy is "no rewards").

Some simulations runs indicated few agents adopting uncooperative strategy at the end of simulation runs. Why didn't these uncooperative agents fully disappear in the model? An interesting pattern was discovered from these runs. One of uncooperative agents existing surrounded half of its neighbours adopting cooperative strategy and the other half adopting uncooperative would exist stably in the model, but could not expand (illustrated in Fig. 7). This finding implies that the connection structure might affect the knowledge sharing behaviours and strategies adopted by agents.

Table 15
Average frequencies of knowledge sharing under different payoff types and collective capabilities distribution without organizational reward

Capability level	Payoff type	Sharing	Not-sharing
Uniformly intelligent	Type I	19,896.8	103.2
	Type II	20,000	0
	Type III	20,000	0
Smart distribution	Type I	17,531.4	2468.6
	Type II	19,406.2	593.8
	Type III	19,884.8	115.2
Normal distribution	Type I	15,063	4937
	Type II	18,983.8	1016.2
	Type III	19,292.6	707.4
Stupid distribution	Type I	13,823.4	6176.6
	Type II	17,385.8	2614.2
	Type III	18,030.8	1969.2

Note: Each average frequency means the average times of sharing and not-sharing actions adopted by agents. It was calculated according to the results of ten runs corresponding to a parameter configuration. For example, the parameter configuration of the first row is that payoff type is "Type I", collective capabilities are "uniformly intelligent", the agents' strategies are {cooperative, tit-for-tat, bullying, uncooperative, mistrustful}, respectively, and organization incentive policy is "no rewards".

Table 16
The effect of different organizational incentive policies

Payoff types	Rewards	Strategies					Behaviour		Performance evaluation	
		Cooperative	Tit-for-tat	Bullying	Uncooperative	Mistrustful	Sharing	Not sharing	Organizational knowledge accumulation	Rewards given by the organization
Type I	No reward	20	602.6	0	2.4	0	19,896.8	103.2	59,690.4	0
	[0,2]	91.9	533.1	0	0	0	20,000	0	60,000	19,968.9344
	[2,5]	448.9	176.1	0	0	0	20,000	0	60,000	70,000.45852
	10	50	544.4	5.6	24.8	0.2	18,822	1178	56,466	10,187
	20	76.5	488	12.4	48.1	0	17,792.6	2207.4	53,377.8	18,464
	30	203.1	313.8	16.4	91.4	0.3	16,231	3769	48,693	24,960
	40	304.7	167.8	27	125.3	0.2	15,108.4	4891.6	45,325.2	33,156
	50	352.6	155.7	19.1	97.5	0.1	16,272.2	3727.8	48,816.6	44,610
	60	389.5	115.9	17.7	101.9	0	16,172.6	3827.4	48,517.8	52,224
	70	488	85.2	18.5	33.3	0	18,370.2	1629.8	55,110.6	71,533
	80	511.3	86.4	7.8	19.5	0	19,126.4	873.6	57,379.2	86,448
	90	510.8	87.3	7.5	19.4	0	19,138.6	861.4	57,415.8	102,222
	100	514.2	85.9	9.6	15.3	0	19,203.2	796.8	57,609.6	113,380
Type II	No reward	174.7	450.3	0	0	0	20,000	0	100,000	0
	[0,2]	291.5	333.5	0	0	0	20,000	0	100,000	19,986.26176
	[2,5]	460.8	164.2	0	0	0	20,000	0	100,000	70,004.14164
	10	267.5	355.2	1.2	1	0.1	19,928.2	71.8	99,641	11,246
	20	344.2	276.4	2.9	1.4	0.1	19,864	136	99,320	23,470
	30	437.5	180.3	3.6	3.6	0	19,769.6	230.4	98,848	32,040
	40	452.1	163.5	4.7	4.7	0	19,699.2	300.8	98,496	44,600
	50	492	133	0	0	0	20,000	0	100,000	58,410

	60	509.7	115.3	0	0	0	20,000	0	100,000	65,178
	70	505.2	119.8	0	0	0	20,000	0	100,000	73,395
	80	518.1	106.9	0	0	0	20,000	0	100,000	89,208
	90	516.6	108.4	0	0	0	20,000	0	100,000	105,381
	100	515.1	109.9	0	0	0	20,000	0	100,000	113,490
Type III	No reward	268.2	356.8	0	0	0	20,000	0	160,000	0
	[0,2]	282.2	342.8	0	0	0	20,000	0	160,000	20,030.38136
	[2,5]	365.9	259.1	0	0	0	20,000	0	160,000	70,000.42454
	10	294.6	330.4	0	0	0	20,000	0	160,000	10,998
	20	337.7	287.3	0	0	0	20,000	0	160,000	22,914
	30	364.5	260.5	0	0	0	20,000	0	160,000	33,237
	40	396.9	228.1	0	0	0	20,000	0	160,000	48,096
	50	439.8	185.2	0	0	0	20,000	0	160,000	55,935
	60	455.6	169.4	0	0	0	20,000	0	160,000	64,692
	70	473.6	151.4	0	0	0	20,000	0	160,000	76,104
	80	468.8	156.2	0	0	0	20,000	0	160,000	87,192
	90	468.2	156.8	0	0	0	20,000	0	160,000	97,281
	100	491.7	133.3	0	0	0	20,000	0	160,000	117,090

Note: (1) Each average frequency in the "Strategies" column means an average value of different strategy agents at the end of ten runs; (2) Each average frequency in the "Behaviour" column means an average value of sharing and not-sharing actions of ten runs; (3) values in the "Performance Evaluation" column means respectively general averages of utility of ten runs, in which the first value was the accumulation of knowledge because of knowledge sharing and the other was the rewards paid for encouraging knowledge sharing. (4) the parameter configuration: agents' strategy set is {cooperative, tit-for-tat, bullying, uncooperative, mistrustful} and collective capabilities is uniformly intelligent.

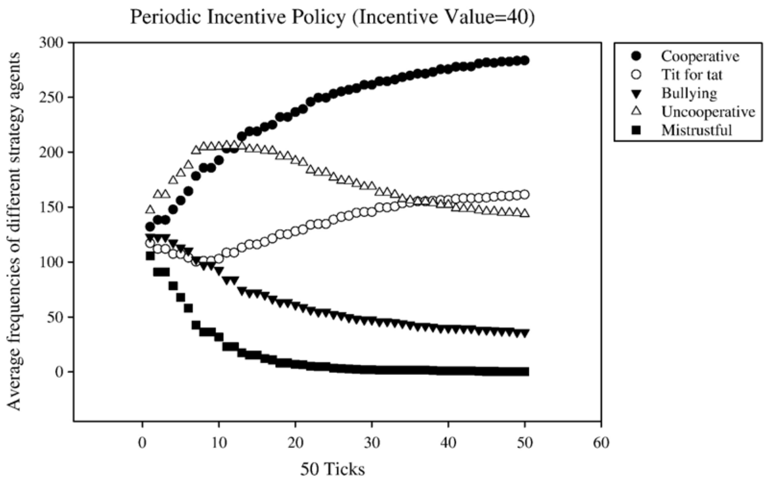


Fig. 12. Dynamics about agents' strategy change with periodic organizational incentive policy. (The parameter configuration: Payoff type is Type I, the agents' strategy set is {cooperative, tit-for-tat, bullying, uncooperative, mistrustful}, collective capabilities is uniformly intelligent, and organization incentive policy is periodic).

8.2. Different personal capabilities

Three interesting observations on the variations of personal capabilities were found.

(1) An agent with better capabilities is less easily able to modify its initial strategy.
(2) Agents with better capabilities can locally attract their neighboring opponents to imitate their strategies.
(3) A population with worse collective capabilities is less likely to partake in knowledge sharing.

The differentiation of personal capabilities of sharing and absorbing knowledge reveals that an interesting effect, called the "local attraction effect", affects the strategy adoption and the behaviours of agents. As demonstrated in Table 14, worse collective capabilities lead to greater diversity of strategies, and thus weaker tit-for-tat dominance. This phenomenon can be explained by examining the system dynamics (illustrated with Figs. 8, 9, 10, 11). The numbers of both tit-for-tat and uncooperative agents rose initially, but uncooperative soon began to fall owing to the lack of group effect. However, agents with other strategies did not disappear as long as their capabilities were better than the surrounding neighbours. The agents with better capabilities even encouraged their neighbours with worse capabilities to adopt the same strategy. The attraction was purely local, since the attracted agents generally had worse capabilities, and could not further affect others. This phenomenon is called the local attraction effect. Such effects are mitigated if the knowledge sharing does not harm the monopolistic profit of agents (Type II payoff), or produces the synergy effect (Type III payoff).

Additionally, due to the local attraction effect, agents with better capabilities would not easily change their initial strategy, or even attract locally other agents with worse capabilities to follow their behaviours. Hence, contrasting with the cases in which all players were with intelligent capabilities, less knowledge sharing occurred in these cases, as demonstrated in Table 15.

8.3. Organizational incentive

The following interesting outcomes were observed when only considering the intelligent capabilities, after manipulating different incentive policies and degrees of rewards.

(1) As revealed in Table 16, incentive for each action increased the adoption of cooperative strategy and knowledge sharing in the population, despite partial ([0, 2]) or full ([2, 5]) compensation for agents. This finding indicates that the incentive policy could enhance the organization climate and trust in the environment. The incentive policy is less sensitive to knowledge sharing under Type II (no monopolistic loss) or III (the synergy effect) than under Type 1. However, the increase of knowledge sharing actions is not large even under Type I payoff. Restated, the incentive policy is not cost-effective, since agents would spontaneously share their knowledge even without incentives as mentioned before. But, it is worthy to notice that organizational incentive policy might lead cooperative strategy to dominate other strategies in the population. The "Performance Evaluation" in Table 16 column demonstrates that the organizational knowledge accumulation is not much greater even when rewards are given. The organizational knowledge accumulation is defined as the sum of the payoffs of all agents in the population.
(2) Incentive for each action is more effective than a periodic fixed reward.
(3) Under Type I payoff, the periodic fixed incentive policy might not suppress the number of agents with bullying and uncooperative strategies, compared to no organizational rewards.

If an organization wishes to encourage agents to share their knowledge, then the best incentive policy is to reward each action of knowledge sharing. Under Type I payoff, if organizational rewards are periodic and fixed, then an "opportunistic effect" might be induced by agents not sharing knowledge to maximize their profits. The shaded rows in Table 16 indicate that not-sharing actions were increasing relative to the condition of no organizational rewards. Although the incentive policy could stimulate the adoption of the cooperative strategy, it would not also suppress the adoption of uncooperative and bullying strategies. Fig. 12 indicates the dynamics about agents' strategy change in which organizational incentive policy is periodic and value is 40. Examining the system dynamics demonstrates that bullying, tit-for-tat, and mistrustful fell initially and then tit-for-tat rose little by little; cooperative and uncooperative agents rose simultaneously, and then uncooperative then fell. Finally, cooperative agents would be the majority. Compared with no organizational rewards, however, the quantity of uncooperative and bullying agents were relatively more in the population. The increased number of uncooperative agents was probably due to more cooperative agents induced by incentive policy. As discussed before, an uncooperative agent can exist in the population when half of its neighbors are cooperative agents. Comparing two pairs of interchanged gains while the agents meet each other, bullying to cooperative, and uncooperative to cooperative, the bullying agent was found to as much as the uncooperative agent. Some bullying agents might thus remain in the population with appropriate organizational incentive.

9. Conclusions

The phenomenon of knowledge sharing in an organization is not easy to understand due to the complexity of interaction between people and organizations. People decide whether to share knowledge according to the knowledge value. People may obtain monopolistic value from the knowledge, so need an incentive to share it. Conversely, people might not gain knowledge from others without sharing their own knowledge. In the interactions of knowledge sharing, the payoff depends on mutual actions. This investigation presents an agent-based modeling approach to study related issues of knowledge sharing in an organization. The following variables are considered: knowledge sharing payoff, behavioral strategy, incentive policies and collective capabilities. An artificial world is built by computer technology. The variables in the artificial world are manipulated to examine their effects on knowledge sharing behavior in an organization.

This investigation has produced some interesting outcomes. The model shows that people will share their knowledge automatically if the payoff of knowledge sharing is sufficiently high. However, if agents were restrained from tit-for-tat strategy, most agents would not share their knowledge automatically in the population. Uncooperative strategy would dominate other strategies. Additionally, a higher payoff from knowledge sharing demonstrates that the organizational climate seem to be more trustworthy for the population because cooperative strategy dominated in the population.

Considering the variations of individual capabilities, agents with better capabilities can locally encourage their neighbors with worse capabilities to adopt the same strategy. This phenomenon is called the “local attraction effect”. It results in different strategies forming their clusters separately, but cooperative and tit-for-tat groups still dominate in the population.

Finally, considering the effects of incentive policy, this work indicates that the incentives have limited effects to encourage knowledge sharing. Furthermore, a reward for each action is more effective than periodic fixed rewards. Periodic fixed rewards might result in opportunistic behavior among agents, and reduce the knowledge sharing behavior.

This study still has certain limitations. (1) An agent cannot reject any interaction and choose his opponents freely. As also mentioned, the connection structure might influence the behavior of agents. Therefore, future works might consider the mechanism of connection among agents. (2) Strategies are simply assigned to agents. The model lacks the mechanism of strategy evolution. Some effective strategies might emerge from evolution. (3) Agent’s traits are assumed that the stock of individual knowledge is unlimited, and that the utility of any knowledge is fixed and unchangeable. Future research might design a knowledge pricing mechanism for realizing the knowledge market in an organization. (4) An agent is assumed to have an overpowering thirst for knowledge. However, in real life, if agent’s knowledge have progressed and grown, his (her) intention of absorbing knowledge might be mitigated. Also, this study only considered agent’s capabilities of knowledge sharing and absorption. However, other characteristics of agents, e.g., enthusiasm, role, and social position, might influence the effect of knowledge sharing. Future research might consider more agents’ characteristics. (5) An agent’s memory is assumed one round memory. The agent’s limited memory might influence agent’s behaviors. Future work might release the constraint to explore the impact on agents’ knowledge sharing. (6) The agent’s motivation for knowledge sharing is assumed based on economic motivation. In real life, the motivations of sharing knowledge might be derived from need for competition, ego satisfaction, or reciprocity, etc.

Acknowledgment

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