Chaos, Solitons and Fractals xxx (xxxx) xxx

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

Frontiers

Promoting knowledge sharing in the workplace: Punishment v. reward

Zaisheng Zhang[a], Fang Song[a,*], Zongbin Song[b]

[a] College of Management and Economics, Tianjin University, 92, Weijin Road, Nankai District, Tianjin, PR China
[b] China Satellite Navigation and Communications Co. Ltd., Shenyang, PR China

ARTICLE INFO

Article history:
Received 23 February 2019
Revised 25 September 2019
Accepted 8 November 2019
Available online xxx

Keywords:
Knowledge sharing
Punishment
Reward
Public goods game
Simulation

ABSTRACT

Previous studies have noted that both punishment and reward can improve knowledge sharing to some extent; however, which one better promotes knowledge sharing remains debatable. Furthermore, it has yet to be thoroughly investigated whether a higher fine or a higher bonus precipitates better knowledge sharing performance. Here, we analyze knowledge sharing behavior by introducing four models of the public goods game (PGG) with the following incentive mechanisms: no incentive, a reward, a punishment, and a mix of reward and punishment, to determine which mechanism best promotes knowledge sharing in the workplace. Each model is then used to simultaneously consider difficult pressures and coworkers' attitudes in a work environment. A simulation was conducted using the Java programming language, the results of which revealed the following: (1) Both punishment and reward can promote knowledge sharing behavior, but punishment is more effective than reward for sustaining knowledge contribution. Contrary to what was expected, the mixed mechanism is not as efficient as punishment or reward in facilitating knowledge sharing. (2) The amount of the fine/bonus is nonlinearly related to the quality of the knowledge shared. Thus, we suggest that the moderate fine/bonus is a satisfactory choice for organizations to promote knowledge sharing. (3) Peer pressure, time pressure, and coworkers' attitudes all contribute crucially to the equilibrium of the PGG. (4) It is easier to improve and maintain knowledge contribution when the facilitating influences, e.g. peer pressure, from the work environment are stronger than the inhibiting ones, e.g. time pressure. Our research not only promotes an understanding of the influences of incentive mechanisms and the effects of pressures and team atmospheres on knowledge sharing, but also provides practical implications for organizations and leaders.

1. Introduction

Knowledge sharing refers to the provision of task information and know-how to help others and collaborate with others to solve problems, develop new ideas, or implement policies or procedures [1]. Knowledge sharing has received considerable attention [2], as it is vital to the development of an organization's competitive advantage. Additionally, knowledge sharing is integral to knowledge management [3]. However, sharing personal knowledge with coworkers does not come naturally to most individuals [4]; knowledge can be considered as an individual's intellectual property, an intangible private asset, and power. Accordingly, individuals tend to hoard rather than share knowledge, as the knowledge contributors may fear that diminishing their internal competition makes them expendable, and thus puts their job at risk [5–11]. Scholars have conducted research of knowledge sharing in two primary ways. The first involves identifying important factors that affect knowledge sharing behavior. These include (a) the properties of the environment, including macro-level and micro-level environmental factors, (b) the properties of management and managerial actions, (c) the properties of the individuals, and (d) the properties of the knowledge itself [12]. In real life, decision-making is influenced by external environmental conditions and an individual's abilities based on bounded rationality [13]. Therefore, the individual's willingness to share knowledge is inevitably affected by the organizational environment. Contemporary employees are facing multiple pressures from the organizational environment, such as time pressure and peer pressure; they are busier than ever and require more cooperation than ever before. Some scholars have analyzed the influence of time pressure and peer pressure on knowledge sharing; however, these have all comprised empirical research. That is, there is no study regarding those pressures and their relation to knowledge sharing involving the public goods game (PGG) method and simulation. The second approach to investigations of knowledge sharing involves providing effective incentives for knowledge sharing. As many researchers have suggested, it is difficult to form cooperative relationships in the system when everyone makes de-

* Corresponding author.
E-mail address: fangsong@tju.edu.cn (F. Song).

https://doi.org/10.1016/j.chaos.2019.109518
0960-0779/

cisions in pursuit of maximizing their own payoffs [14]. However, both punishment and reward can improve knowledge sharing to some extent; but which one encourages better knowledge sharing is debatable. Furthermore, a research gap remains regarding whether a higher fine or a higher bonus leads to better knowledge sharing performance. Here, we analyze knowledge sharing behavior by introducing four models of the PGG followed by four incentive mechanisms: no incentive, a reward, a punishment, and a mixed reward and punishment. Each model is then used to simultaneously consider difficult pressures and coworkers' attitudes in a work environment. With Java programming language simulation, the following issues are investigated: (1) Punishment or reward, which on is better in promoting knowledge sharing? What happens if we adopt the mixed incentive mechanism? (2) Does the higher fine or higher bonus better encourage efficiency in facilitating knowledge contribution? (3) How do time pressure, peer pressure, and coworkers' attitudes influence knowledge sharing?

1.1. PGG and knowledge sharing

While previous works regarding knowledge sharing have contributed to an improved understanding of knowledge sharing, most have been empirical. Thus, these studies involve several limitations, such as the use of variables based on a questionnaire completed by a single source at one time period [1]. Alternatively, some scholars have investigated knowledge sharing from the perspective of social dilemmas existing in realistic organizations. The frameworks presented in these studies, borrowed from sociological research on cooperation, inform the socio-psychological processes governing exchanges among employees. Cabrera & Cabrera suggest that shared knowledge becomes a public good from which interdependent members of an organization can benefit directly, whether or not they have contributed; this may lead to opportunistic behavior and free riding [15]. Additionally, personal behaviors are primarily motivated by self-interest, from an economic perspective; people therefore tend to do their best to maximize individual utility [10,11]. This implies that knowledge sharing is a phenomenon with the potential to evoke feelings of conflict of interest among the individuals involved [16,17]. As a result of this, free riding is often the personal strategy that yields the best outcome for employees. Accordingly, such free riding resulting from maximizing one's own utility creates a public goods social dilemma, i.e. situations arise in which individuals' rational actions performed in an attempt to maximize their personal benefits damage the collective [18,19]. Evolutionary game theory has become one of the most prevalent methods to solve social dilemma situations [20], various approaches for promoting cooperation have been discussed including coevolution [21,22], reputation-based popularity [23], and independent networks [24]. Meanwhile, PGG also provides a reasonable explanation for group interactions among multiple players [25]. The knowledge sharing dilemma with the PGG model requires further investigation; thus far, this application of the PGG model has attracted a reasonable degree of supporting evidence from other disciplines which study human social behavior [15].

1.2. Incentive mechanisms and knowledge sharing

Promoting knowledge sharing is a difficult task as hoarding and guardedly considering knowledge are natural human tendencies [26]. Consequently, the willingness of an individual to share is one of the central barriers to knowledge sharing [27]. Research through the lens of providing effective incentives for knowledge sharing has thus attracted considerable attention. Their results show that knowledge sharing cannot be forced or mandated but can be encouraged and facilitated [28,29], as knowledge sharing is most likely to occur when employees perceive that incentives exceed costs [30]. Negative incentive, or punishment is used to reduce the free-rider's payoff, and positive incentive, or reward, can be utilized to increase the contributor's welfare [31]. Confrontation with the threat of punishment or the promise of reward can effectively induce individuals to contribute in the PGG, but considerations of which is more effective have historically returned different results. Some researchers believe that punishment is traditionally considered to be more successful than reward since it can have a stabilizing effect on cooperation [32,33]; however, another study shows that costly punishment is surprisingly ineffective in promoting cooperation [34]. Other scholars suggest that reward is preferred as the main catalyst behind collaborative efforts, a reward has several advantages over punishment [35–37]. Furthermore, there is still a research gap in this area: does a higher fine or a higher bonus instigate higher knowledge contribution? Inspired by these past works and continuing questions, we compare the knowledge sharing behavior by introducing four models of the PGG followed by no incentive, a reward, a punishment, and a mixed incentive mechanisms. Then, with a Java programming language simulation, we investigate the effects of fines and bonuses on knowledge sharing as well as the relationship between the frequency of punishment and knowledge sharing.

1.3. Time pressure, peer pressure, and knowledge sharing

Time pressure occurs when the environment creates a perception of limited time to complete a task, resulting in feelings of stress and the need to cope with the limited time constraint [38]. Today, time is a scarce resource in the workplace, and each activity requires some amount of time [39]. Accordingly, employees are unlikely to engage in sharing if they are fully utilized by their regular tasks at work. Significantly, employees' responses to time pressure reduce the amount of trust and quality of communication had between each other [40,41], which can affect an individual's attitude toward knowledge sharing [16,42,43]. Resultingly, the sharing behavior becomes discontinued [8,12]. In addition to time pressure, peer pressure contributes to the extent to which knowledge is shared. Peer pressure can be defined as pressure from peers to do something or to keep from doing something else, no matter if one personally wants to do it or not [44]; the existence of peer pressure leads to the belief that the peer group demands conformity to its norms [45]. The notion that peer pressure can be an effective motivator is not new [46]. It plays a critical role in promoting biological cooperation and is often invoked to explain why group-based incentives are surprisingly successful despite the incentive to free ride [47]. Furthermore, knowledge sharing occurs through peer interaction [48]. Employees may choose to share knowledge as a way to help develop personal relationships with peers or to simply manage their impression on others [1]. Prior research also shows that perceived coworker support has a strong positive relationship with knowledge sharing [49]. Therefore, peer pressure in a public institution results in a higher propensity of knowledge sharing among colleagues and peers [50]. These studies inform the relationships between various pressures and knowledge sharing behavior; however, they are all empirical investigations. As there is currently no study regarding the relationships between work pressures and knowledge sharing that utilizes the methods of the PGG and an ensuing simulation, we aim to provide such through this work.

The remainder of this paper is organized as follows. The spatial PGG models are elaborated upon in Section 2. The corresponding simulation results are provided in Section 3. Lastly, conclusions are given in Section 4.

2. Models

Spatial PGG models are presented to analyze the knowledge sharing behavior by introducing four models followed by no incentive, a reward, a punishment, and a mixed incentive mechanisms, respectively. Each model is then used to simultaneously consider difficult pressures and coworkers' attitudes in a work environment. For these four models, all assumptions and whole frames are the same; the only difference is the payoff.

All of the PGG models are run with a large network size to obtain stable results; in our models, PGG is staged on networks including 1000 players, wherein each person has a different number of neighbors (κ). That is, each player participates in $\kappa + 1$ PGG groups, where one group is centered on themselves and other κ groups focus on their neighbors. The per capita number of neighbors is a_{vn}, which is set as $a_{vn} = 36$; the largest number of neighbors is 100. The neighbors are created randomly, which means some players have many neighbors while others have few. This is acceptable as long as a player has one neighbor in the network, which is in line with reality.

There are three types of player in our models, denoted as *CA, CT*, and *HO: CA* is a knowledge contributor with an altruistic intention, *CT* is a knowledge contributor, and *HO* is a player who chooses to hoard knowledge. For the convenience of presentation, each type of player, *CA, CT*, and *HO*, is set to account for a different proportion of the total number of people, represented as ρ_1, ρ_2, and ρ_3, respectively. It is assumed that the *CA* player always chooses the sharing strategy, because people with altruistic intentions are typically enthusiastic to help others. Additionally, the *CA* player gets along with others in pleasant, satisfying relationships, in which knowledge sharing is directly engaged [51]. The original value of ρ_1 is defined as $\rho_1 > 0$, as this conforms better to reality [52]. Initially, all the players are distributed randomly on the network. For players who are not a *CA*, they are randomly assigned to be a contributor or a free-rider, with the equal probability. Additionally, $\rho_1 + \rho_2 = \rho_3 = 50\%$ is set as the starting values, such that half of the players choose the sharing strategy while the other half choose hoarding in the initial state. This also means that *CA* players are derived from CT_s, i.e., all of the CA_s are CT_s, but not all of the CT_s are CA_s.

2.1. Model 1: no incentive mechanism

Players choose to share or to hoard knowledge both simultaneously and independently. Each individual contributes one unit ($C = 1$) to the public pool if the player adopts the strategy of knowledge sharing; conversely, a free-rider individual contributes nothing, but exploits from the public pool if the individual chooses to hoard. The sum of contributions within a group is multiplied by a synergy factor ($r > 1$), such that the value of r needs to be less than the number of players in the group to ensure the existence of the social dilemma [35–53]. Next, the total contributions is distributed among all group members equally, such that everyone in the group can enjoy the public goods fairly. I.e., a free-rider can also benefit from public goods without contribution. Thus, the payoff obtained by each player can be calculated as follows:

$$\pi_i = \sum_{j \in \Omega_i} \left(r \frac{\sum_{m \in j} C_m}{k_j + 1} - C_i \right) \quad (1)$$

In Formula (1), players are numbered by parameter i, where π_i represents the payoff of player i. Ω_i denotes the set of PGG groups in which player i participates, and group j is one of the sets of Ω_i. k_j denotes the number of neighbors to player i in group *j; m* is one element of group j, correspondingly; C_m indicates the contribution of one player in group *j;* C_i indicates the contributions of player i ($C_i = 0$ if player i is a free-rider, $C_i = 1$ if a knowledge contributor).

In real life, players make decisions within a given work environment. Accordingly, propensities of knowledge sharing are affected by the situation in an organization. In our models, parameter E is used to represent the propensity of knowledge sharing for each player, wherein E is related to several work conditions: time pressure, peer pressure, and coworkers' attitudes towards knowledge sharing. Only a few previous studies have considered the role of individual personality or disposition in knowledge sharing [51], even though it has been confirmed that an individual's disposition has a significant impact on work attitudes and behaviors [54,55]. To account for individual personality and disposition, in our models, N_a is defined as the number of the players who exhibit openness, agreeableness, and conscientiousness as personality traits. These relate positively to higher work group and individual attitudes towards knowledge sharing [51,56,57]. N_b is defined as the number of the players who have greater self-interest, which relates negatively to the individual's attitude towards knowledge sharing [58]. The percentage ratios for N_a and N_b among all the players are $\emptyset_a$ and $\emptyset_b$, respectively. Additionally, P_a and P_b denote the influence coefficients of N_a and N_b, respectively, which either facilitate or inhibit knowledge sharing. Accordingly, the propensity of knowledge sharing is summed as follows:

$$E(t+1) = E(t) + P_p - P_t + N_a P_a - N_b P_b \quad (2)$$

where P_p and P_t denote peer pressure and time pressure, respectively. $N_a P_a$ and $N_b P_b$ are the positive and negative influences of coworkers' attitudes towards knowledge sharing, respectively. Lastly, t represents the time step. Since the entire evolution process is a dynamic repeat-play, E changes with time. In the real-world system, people cannot be expected to share their ideas and insights simply because it is the right thing to do [59]; e.g., potential knowledge contributors may refrain from a knowledge exchange if they feel they can better benefit by hoarding rather than by sharing [26]. Therefore, T_r [1] is used as a threshold, indicating the critical value at which the player would like to share knowledge with others. When $E > T_r$, the player makes the decision to share knowledge, otherwise, the player is considered to be profit-driven. Consequently, the player pursues the maximized profit by imitating a neighbor. For example, player i chooses to update its strategy S_i by learning the strategy S_j from the neighbor j, who is chosen randomly, with a probability given by the following Fermi rule [60]:

$$W\left(S_i \leftarrow S_j\right) = \frac{1}{1 + exp\left(\frac{\pi_i - \pi_j}{\mu}\right)} \quad (3)$$

where μ characterizes the bounded rationality or uncertainty of the player during the course of making the decision. $\mu \to 0$ ($\mu \to \infty$) denotes the completely deterministic (random) learning. Here, $\mu = 0.1$ is set as in Ref. [60]. Additionally, $\pi_i - \pi_j$ represents the difference of payoffs between player i and player j. Notably, these two players acquire payoffs in the same way.

2.2. Model 2: reward mechanism

Rewards may vary and can be used at all levels of human organizations to enhance cooperation, from gift giving to teamwork rewarding, and from community to international organizations [31]. Accordingly, in Model 2, a sum of bonuses is offered to the player

[1] For each type of the players, the initial values of T_r are set as this: for player *CA*, we assume his propensity $E > T_r$, since he seeks cooperation rather than competition [61]; for player *CT*, we let his propensity $E = T_r$, as cooperative behavior always emerges in PGG although defection is an optimal strategy [62]; and for player *HO*, we set his propensity $E < T_r$, given free riding is the personal strategy that yields the best outcome for employee [19].

when the player shares knowledge with others for a certain number of times. δ_1 denotes the bonus and τ_1 indicates the cumulative times for which knowledge sharing occurred. Thus, the payoff obtained by each player is calculated as follows:

$$\pi_i' = \sum_{j \in \Omega_i} \left(r \frac{\sum_{m \in j} C_m}{k_j + 1} - C_i \right) + \delta_1 \tag{4}$$

2.3. Model 3: punishment mechanism

In Model 3, cost is added by giving the player a penalty when the player hoards knowledge for a certain number of times, as the player may instead choose a cooperative strategy to avoid losing profit. δ_2 denotes the fine and τ_2 indicates the cumulative times for which knowledge hoarding occurred. Consequently, the payoff obtained by each player is summed as follows:

$$\pi_i'' = \sum_{j \in \Omega_i} \left(r \frac{\sum_{m \in j} C_m}{k_j + 1} - C_i \right) - \delta_2 \tag{5}$$

2.4. Model 4: mixed mechanism

In Model 4, both reward and punishment mechanisms are adopted simultaneously by following the same rules of Model 2 and Model 3. In this case, the payoff obtained by each player is calculated as follows:

$$\pi_i''' = \sum_{j \in \Omega_i} \left(r \frac{\sum_{m \in j} C_m}{k_j + 1} - C_i \right) + \delta_1 - \delta_2 \tag{6}$$

3. Simulation results and discussions

Java programming language was used to simulate the evolution processes of knowledge sharing. All simulations were conducted on a network with $N = 1000$ and $a_{vn} = 36$. To ensure the reliability of the evolutionary results, a large number of simulations are conducted. Each data point is obtained by averaging 20 independent runs with 10,000 time steps for each. A representative index to characterize the knowledge sharing behavior is the fraction of knowledge contributors (θ), defined as the ratio of the knowledge contributors to the total number of players. Initially, $\theta = 0.5$.

3.1. Incentive mechanisms

In this section, punishment, reward, and mixed incentive mechanisms are compared to identify whether reward or punishment better facilitates knowledge sharing. Additionally, simultaneously adopting reward and punishment mechanisms, in the mixed mechanism, is considered. The simulation results regarding incentive mechanisms are specifically exhibited as follows.

Fig. 1 aims to characterize the dynamical evolutionary processes of the fraction of knowledge contributors (θ) for four types of incentive mechanisms: no incentive ($y1$), reward ($y2$), punishment ($y3$) and mixed mechanism ($y4$). Fig. 1(a) shows the results of $y1$, $y2$, $y3$, and Fig. 1(b) shows the results of $y1$, $y2$, $y3$, $y4$. In Fig. 1(a), $y2$ and $y3$ are both higher than $y1$, but the effect of $y3$ is more significant than that of $y2$. Accordingly, either reward or punishment can promote knowledge sharing behavior, but knowledge contribution increases more noticeably with punishment rather than with reward. Meanwhile, in Fig. 1(b), the green curve ($y4$) is between the black curve ($y1$) and the red curve ($y2$). Thus, θ is hardly improved in the mixed mechanism. In other words, the mixed mechanism is not a good choice to promote knowledge sharing. Implementing one incentive mechanism can better promote knowledge sharing than implementing both. Furthermore, punishment is more effective than reward in sustaining knowledge sharing. This phenomenon may be explained by the prospect theory [63], i.e., losses cause a greater emotional impact on an individual than does an equivalent amount of gain.

Since the punishment mechanism facilitates better knowledge sharing than does the reward mechanism, the punishment mechanism was investigated more deeply. Regarding the effect of a fine on knowledge sharing, we considered: does a higher fine facilitate a higher knowledge contribution? Additionally, the influence of the frequency of punishment on knowledge sharing was also investigated. During the simulation processes, different punishment patterns were implemented by adjusting two aspects: changing the amount of fines (δ_2) and altering the cumulative times (τ_2) a player chooses the hoarding strategy. This means a player would get the fine δ_2 when the player withholds knowledge for τ_2 rounds. Fig. 2 indicates the different results of the fraction of knowledge contributors (θ) for different fines (Fig. 2(a)) and different cumulative times (Fig. 2(b)).

Accordingly, several conclusions are drawn from Fig. 2: (1) Punishment can significantly promote knowledge sharing behavior. In Fig. 2(a), θ improves noticeably after the fine is changed from 0 to 10, 50, 200, and 300. (2) A higher fine does not necessarily yield a better result. That is, the amount of the fine is nonlinearly related to the quality of the knowledge shared. As Fig. 2(a) shows, θ reaches a maximum value when the fine is 50; then, it does not increase further but remains roughly at the same value when the fine is higher than 50. Thus, within a certain range, θ improves as the fine increases. It is easy to make up for the player's loss by becoming a free-rider when the fine is small. Thus, the payoff-driven player would like to obtain more benefit from choosing the hoarding strategy even when doing so requires paying a small penalty. However, the situation changes as the fine reaches a certain level. When the fine exceeds the benefit from being a free-rider, the player alters the strategy taken to avoid the big fine, and consequently, the knowledge contribution improves. Nevertheless, θ has a maximum value when the fine increases. Thus, a moderate fine is suggested as the satisfactory choice to promote knowledge sharing with the punishment mechanism. (3) θ attains a higher equilibrium state when the frequency of penalty is higher. Fig. 2(b) illustrates the different results of θ for four values of τ_2: $\tau_2 = 1$, 2, 3, and 5, respectively. The lower value of τ_2 represents the higher frequency of fining. It is shown that θ achieves the highest equilibrium status when $\tau_2 = 1$ (black curve). Based on the above conclusions, the satisfactory solution to facilitate knowledge sharing with the punishment mechanism is to set a high frequency of punishment with a moderate fine. Nonetheless, punishment is a kind of negative incentive mechanism that may cause dissatisfaction among employees. Thus, organizations should set an appropriate frequency of punishment (τ_2) according to their realistic circumstances.

Next, the reward mechanism is considered as it ignites cooperativeness [64]. Particularly, we investigated whether a bigger bonus may contribute to a better knowledge contribution. The simulation results regarding reward mechanisms are exhibited as follows.

Fig. 3 depicts the different results of the fraction of knowledge contributors (θ) for different bonuses. Generally, the change of θ is not particularly significant when the bonus is adjusted. However, a moderate bonus can promote contribution better than either a high or low bonus. We compare the values of θ under three bonuses (Fig. 3(a) and (b)): the bonus equals 10 (black curve), 50 (red curve), and 100 (blue curve). Herein, θ reaches the highest equilibrium state when the bonus is 50. The low bonus is not attractive enough for a free-rider to transform into a knowledge contributor. Understandably, the profit-driven player would choose to hoard knowledge since the benefit from being a free-rider is higher than the small reward. Similarly, a free-rider converts to a knowl-

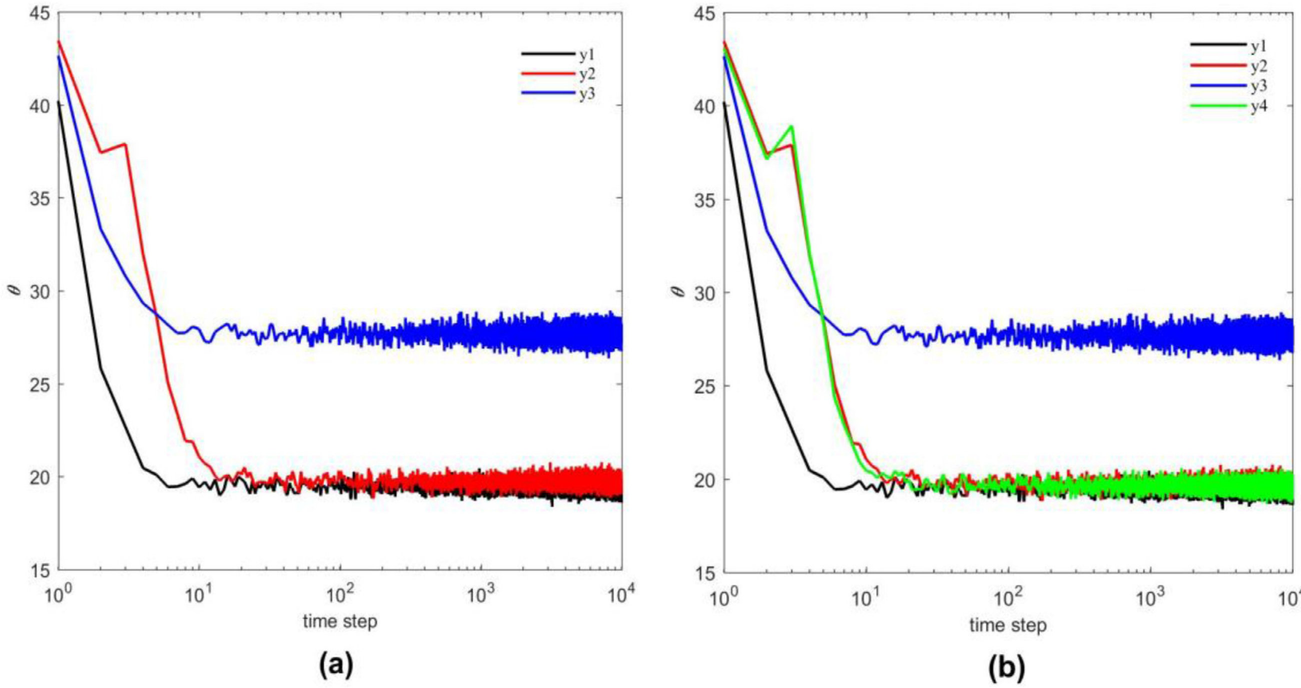

Fig. 1. Time evolution of the fraction of knowledge contributors θ for different incentive mechanisms. The *y*1, *y*2, *y*3, *y*4 graphs represent Model 1, Model 2, Model 3, and Model 4, respectively. Models 1–4 represent four types of incentive mechanisms, respectively: no incentive, reward, punishment, and mixed mechanism. (a) Shows the results of *y*1, *y*2, *y*3; (b) shows the results of *y*1, *y*2, *y*3, *y*4. Other parameter settings are as follows: $T_r = 25$, $r = 1.8$, $\rho_1 = 0.1$, $\rho_2 = 0.4$, $\rho_3 = 0.5$, $\emptyset_a = \emptyset_b = 0.5$, $P_a = P_b = 0.002$, $P_p = P_t = 0.5$, $\delta_1 = 50$, $\tau_1 = 1$, $\delta_2 = 50$, $\tau_2 = 1$.

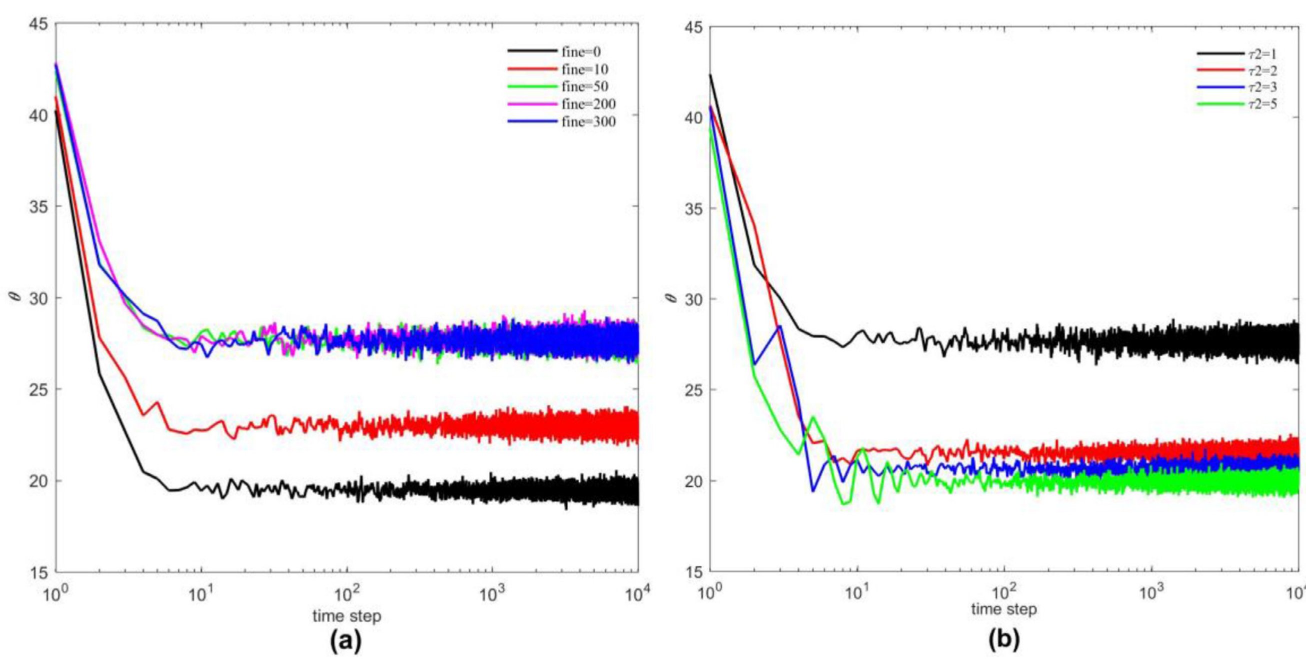

Fig. 2. Time evolution of the fraction of knowledge contributors θ for different fines (a) and different cumulative times (τ_2) of a player choosing the hoarding strategy (b) with the punishment mechanism. Other parameter settings for (a) are as follows: $T_r = 25$, $r = 1.8$, $\rho_1 = 0.1$, $\rho_2 = 0.4$, $\rho_3 = 0.5$, $\emptyset_a = \emptyset_b = 0.5$, $P_a = P_b = 0.002$, $P_p = P_t = 0.5$, $\tau_2 = 1$, and for (b): $T_r = 25$, $r = 1.8$, $\rho_1 = 0.1$, $\rho_2 = 0.4$, $\rho_3 = 0.5$, $\emptyset_a = \emptyset_b = 0.5$, $P_a = P_b = 0.002$, $P_p = P_t = 0.5$, $\delta_2 = 50$.

edge contributor when the bonus is high enough. However, when the bonus exceeds a certain range, the process does not work as hypothesized. In Fig. 3(b), the blue curve is lower than the red curve, signifying that a high bonus is less effective in promoting knowledge sharing than is a moderate bonus. Accordingly, the satisfactory solution to promote knowledge sharing with the reward mechanism is to set a moderate bonus.

3.2. Pressures and coworkers' attitudes

In this section, the impacts of time pressure, peer pressure, and coworkers' attitudes on the evolution of knowledge sharing behavior are considered.

Fig. 4 explains the influences of peer pressure and time pressure on knowledge sharing. In the absence of other external condi-

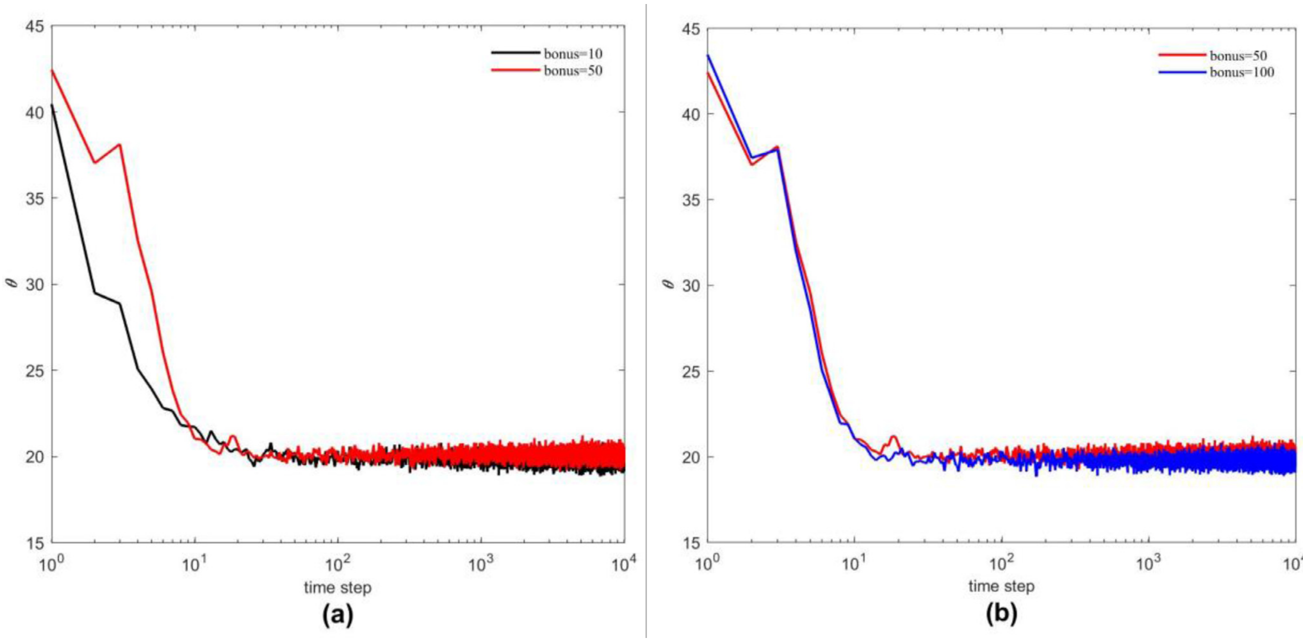

Fig. 3. Time evolution of the fraction of knowledge contributors θ for different bonuses in the reward mechanism. (a) Shows the different results when bonuses equal 10 (black curve) and 50 (red curve). (b) Shows the different results when bonuses equal 50 (red curve) and 100 (blue curve). Other parameter settings include: $T_r = 25$, $r = 1.8$, $\rho_1 = 0.1$, $\rho_2 = 0.4$, $\rho_3 = 0.5$, $\emptyset_a = \emptyset_b = 0.5$, $P_a = P_b = 0.002$, $P_p = P_t = 0.5$, $\tau_1 = 1$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

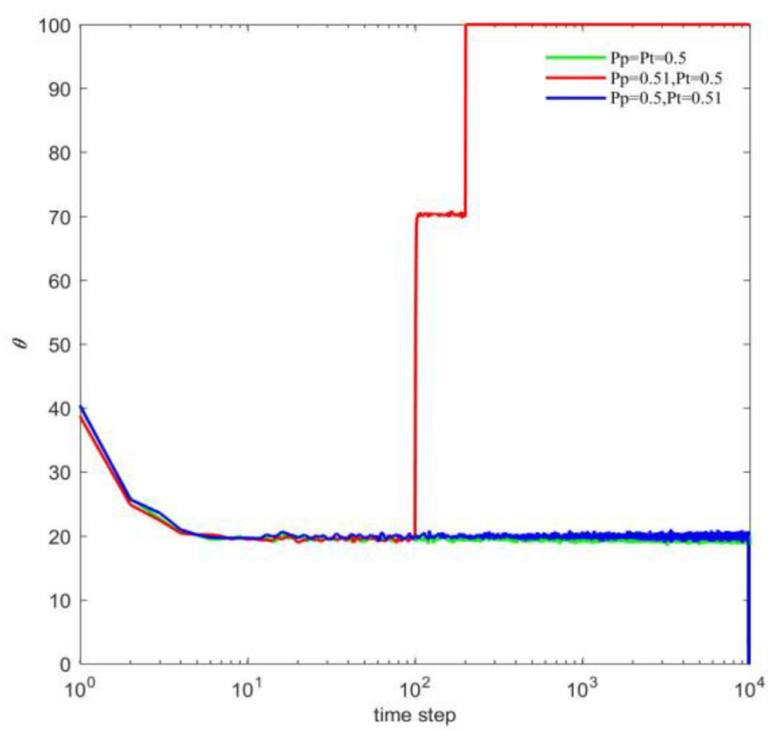

Fig. 4. Time evolution of the fraction of knowledge contributors θ under time pressure (P_t) and peer pressure (P_p). Other parameter settings include: $T_r = 25$, $r = 1.8$, $\rho_1 = 0.1$, $\rho_2 = 0.4$, $\rho_3 = 0.5$, $\emptyset_a = \emptyset_b = 0.5$, $P_a = P_b = 0.002$.

tions, when P_p (peer pressure) is equal to P_t (time pressure) (green curve), θ is maintained at a stable state of around 20%. This indicates that the effects of P_p and P_t can likely be offset. When P_p exceeds P_t (red curve), θ reaches 70% in 100 time steps; after another 100 time steps, θ achieves the equilibrium state of 100%. Thus, P_p has a significant effect on θ, as it can promote the rapid increase of θ. Conversely, when P_p is less than P_t (blue curve), θ is sustained at about 20% for most of the rounds until the time step is close to 10,000. Then, θ drops sharply to 0, signifying that P_t has an inhibitory impact on θ; however, this affect is not very strong. Overall, knowledge sharing is easier to promote and maintain when P_p exceeds P_t, thus partially illustrating the importance of the role of P_p.

Then, the effect of coworkers' attitudes on knowledge sharing behavior was investigated. Specifically, the roles of N_a (the number of the players with the personality traits of openness, agreeable-

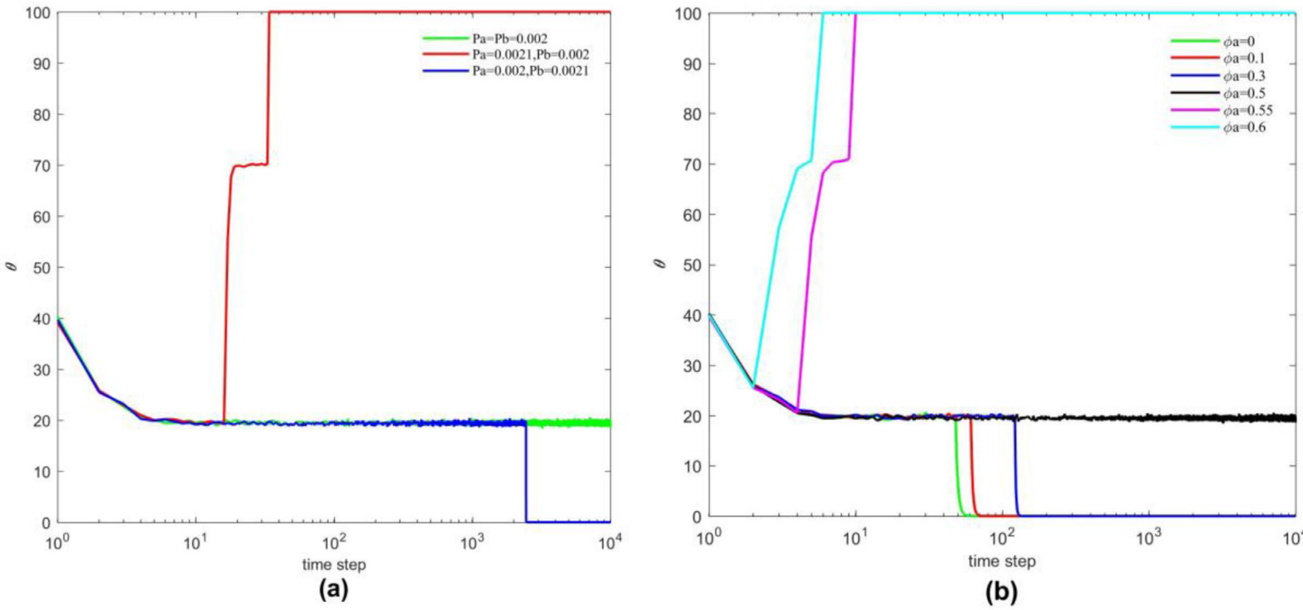

Fig. 5. (a): Time evolution of the fraction of knowledge contributors θ for P_a and P_b. N_a is the number of the players with personality traits of openness, agreeableness, and conscientiousness; N_b is the number of the players who have greater self-interest. $\emptyset_a$ and $\emptyset_b$ are the percentage ratios for N_a and N_b among all the players, respectively. Meanwhile, P_a and P_b are the influence coefficients of N_a and N_b, respectively, which either facilitate or inhibit knowledge sharing. Other parameter settings include: $T_r = 25$, $r = 1.8$, $\rho_1 = 0.1$, $\rho_2 = 0.4$, $\rho_3 = 0.5$, $\emptyset_a = \emptyset_b = 0.5$, $P_p = P_t = 0.5$. (b) Time evolution of the fraction of knowledge contributors θ for varying $\emptyset_a$. Other parameter settings include: $T_r = 25$, $r = 1.8$, $\rho_1 = 0.1$, $\rho_2 = 0.4$, $\rho_3 = 0.5$, $P_a = P_b = 0.002$, $P_p = P_t = 0.5$, $\emptyset_a + \emptyset_b = 1$.

ness, and conscientiousness), N_b (the number of the players who have greater self-interest), P_a (the influence coefficient of N_a), and P_b (the influence coefficient of N_b) are considered in the PGG. For the convenience of explanation, $\emptyset_a$ and $\emptyset_b$ are defined as the percentage ratios for N_a and N_b among all the players, respectively. Fig. 5(a) indicates the influences of P_a and P_b on knowledge sharing; the result shows that P_a (the promotion effect) has a stronger influence on θ than P_b (the inhibition effect). Thus, P_a contributes to the quick improvement of θ, which achieves an equilibrium state of 100%. Fig. 5(b) demonstrates the impacts of $\emptyset_a$ and $\emptyset_b$ on knowledge sharing. When $\emptyset_a = \emptyset_b = 0.5$, θ remains at a stable status of approximately 20% (black curve). For the next step, the value of $\emptyset_a$ is altered to 0, 0.1, and 0.3 respectively (green, red, and blue curves, respectively); contributions die gradually, and finally, all the players turn into free-riders as the time steps reach 63, 78, and 136, respectively. Alternatively, when $\emptyset_a$ is set to equal 0.55 and 0.6, respectively, the knowledge sharing strategy is adopted by all players after only a few rounds, and θ quickly achieves the equilibrium state of 100%. Therefore, the facilitating effects from the work environment have important influences on knowledge sharing; they can influence θ to grow rapidly and reach an equilibrium status of 100%. The effects of P_a and $\emptyset_a$ on θ are stronger than that of P_b and $\emptyset_b$, signifying the relative ease with which knowledge contribution can be improved and maintained when P_a is bigger than P_b, or when $\emptyset_a$ is bigger than $\emptyset_b$.

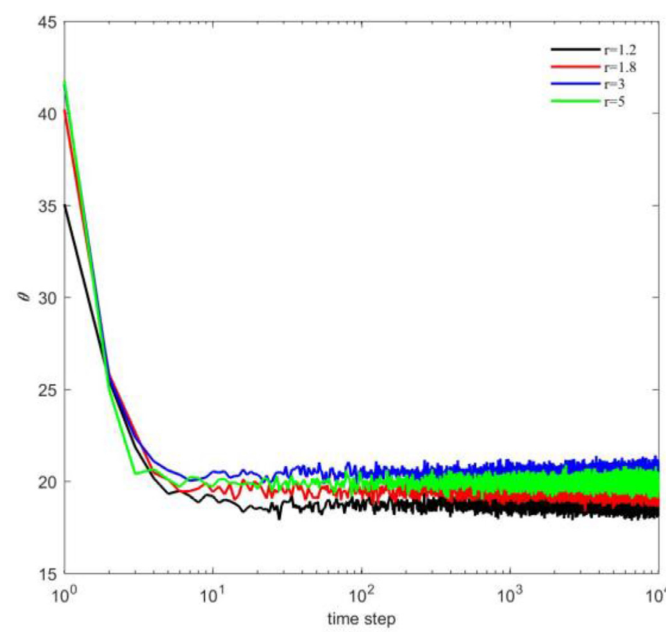

Fig. 6. Time evolution of the fraction of knowledge contributors θ for different values of r (synergy factor). Other parameter settings include: $T_r = 25$, $\rho_1 = 0.1$, $\rho_2 = 0.4$, $\rho_3 = 0.5$, $\emptyset_a = \emptyset_b = 0.5$, $P_a = P_b = 0.002$, $P_p = P_t = 0.5$.

3.3. Other parameters

To analyze the models comprehensively, other important parameters, including r (the synergy factor) and ρ_1 (the percentage of *CA*, knowledge contributor with altruistic intention), need to be tested. The simulation results are elaborated upon in the following content.

Fig. 6 illustrates the effects of different values of r (synergy factor) on knowledge sharing. Four cases are compared here, when r is set to be 1.2, 1.8, 3, and 5, respectively. As shown, θ reaches its highest point when $r = 3$ (blue curve), signifying that optimal value of r (= 3) exists, allowing the evolution to achieve its high-point.

As a minimal number of cooperators are needed to elicit cooperation [52], a deeper investigation into the influence of *CA* players on promoting knowledge sharing is still needed. As in Fig. 7, θ could be greatly increased as ρ_1 is increased, suggesting that ρ_1 has a significant effect on θ and can promote the rapid increase of θ.

Please cite this article as: Z. Zhang, F. Song and Z. Song, Promoting knowledge sharing in the workplace: Punishment v. reward, Chaos, Solitons and Fractals, https://doi.org/10.1016/j.chaos.2019.109518

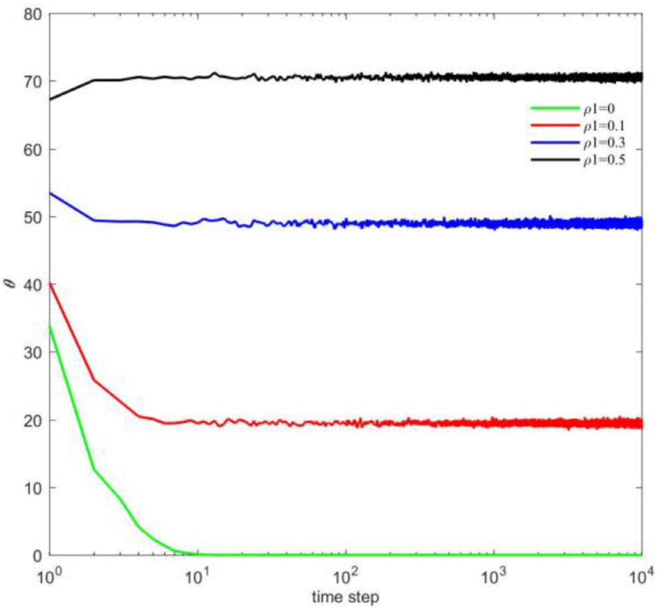

Fig. 7. Time evolution of the fraction of knowledge contributors θ for different values of ρ_1. Other parameter settings include: $T_r = 25$, $r = 1.8$, $\rho_1 + \rho_2 = 0.5$, $\rho_3 = 0.5$, $\emptyset_a = \emptyset_b = 0.5$, $P_a = P_b = 0.002$, $P_p = P_t = 0.5$.

4. Conclusion

Previous studies have elucidated that both punishment and reward can improve knowledge sharing to some extent; however, which one better encourages knowledge sharing has been debatable. Additionally, the ability of either a higher fine or a higher bonus to lead to a better knowledge sharing performance has remained largely uninvestigated. Therefore, we analyzed the knowledge contribution behavior by introducing four models of a PGG followed by the following incentive mechanisms: no incentive mechanism, a reward mechanism, a punishment mechanism, and a mixed incentive mechanism. Each model was used to simultaneously consider the effects of difficult pressures and coworkers' attitudes in the work environment. With a Java simulation, the following conclusions were ascertained:

First, either punishment or reward can promote knowledge sharing behavior; however, punishment can lead to a much better performance than reward. Contrary to what was expected, the mixed mechanism is not as effective as either punishment or reward in facilitating knowledge sharing. Second, the amount of a fine is nonlinearly related to the knowledge sharing performance. Within a certain range, θ improves as the fine increases; however, θ reaches a maximum value when the fine reaches a certain level. Accordingly, a moderate fine is suggested as the most satisfactory choice to promote knowledge sharing with the punishment mechanism. Additionally, knowledge sharing can attain a higher equilibrium state when the frequency of penalty is higher. Nonetheless, punishment is a kind of negative incentive mechanism that may cause dissatisfaction among employees. Thus, organizations should set an appropriate frequency of punishment according to their realistic circumstances. Third, the change of θ is not particularly significant when the bonus amount is adjusted; however, a moderate bonus can promote knowledge contribution better than either a high or low bonus. Thus, the most satisfactory solution to promote knowledge sharing with the reward mechanism is to set a moderate bonus. Fourth, the influences of peer pressure, time pressure, and coworkers' attitudes on knowledge sharing were investigated, wherein they all demonstrated crucial roles in knowledge sharing behavior. Furthermore, it is easier to improve and maintain knowledge contribution under three conditions: (1) when peer pressure is stronger than time pressure, (2) when the attitude of sharing from coworkers is stronger than that of hoarding, and (3) when the number of players who have personality traits of openness, agreeableness, or conscientiousness is greater than that of those with greater self-interest. Lastly, the synergy factor r and the number of *CA* players both have important influences in promoting knowledge sharing. Moreover, there exists an optimal value r $(= 3)$ that allows the evolution to achieve its highest point.

From the above conclusions, the following management suggestions are proposed to promote knowledge sharing in an organization. First, it is necessary to create an open and caring organizational climate, as such an environment is essential to encouraging knowledge sharing. Organizational climate refers to an organization's value system in terms of risk taking, reward systems, and providing a warm and supportive environment [65]. A good climate can facilitate knowledge sharing [66] for several reasons: (1) It encourages interaction among individuals and, consequently, the exchange of learning and knowledge. (2) It helps to reduce the cost of communication between employees while enhancing the synergy factor of knowledge sharing. (3) The influence of the group norm or subjective norm, such as peer pressure, can prompt employees to adopt the strategy of knowledge sharing. Secondly, to more effectively overcome the knowledge sharing dilemma in an organization, punishment should be adopted rather than reward. However, a higher fine or higher bonus does not induce better knowledge sharing. Rather, a moderate fine or bonus is the more satisfactory choice for the organization to promote knowledge sharing. Thirdly, leaders should pay more attention to an individual's personality trait. Different personality traits tend to exhibit different behaviors and attitudes; namely, whether an employee has a facilitating or inhibiting attitude towards knowledge sharing is related to the individual's personality. Additionally, different personalities are perhaps better suit a different level of pressure. If leaders could provide the appropriate level and type of pressure based on an individual's personality trait, employees may be better encouraged to share knowledge and thus create a better learning environment. Lastly, it is beneficial to help employees deal with time pressure while reducing the negative impact of time pressure. This not only promotes knowledge sharing, but also ensures the physical and mental health of employees. Therefore, it is conducive to the overall wellbeing of employees, and thus the development of the competitive advantages of an organization. Ultimately, this work informs the use of incentive mechanisms in the workplace and seeks a further understanding of workplace pressures that impact knowledge sharing.

Declaration of Competing Interest

None.

Acknowledgements & funding

This work was funded by the Chinese National Funding of Social Sciences under Grant No. 16BGL138.

We are grateful to Michael Allen Watson, and Kaladevi Sakthivel for their suggestions and proofreading.

References

[1] Wang S, Noe RA. Knowledge sharing: a review and directions for future research. Hum Resour Manage Rev 2010;20(2):115–31.
[2] Eisenhardt KM, Santos FM. Knowledge-based view: a new theory of strategy. Handbook Strat Manage 2002;1(1):139–64.
[3] Wang WT, Hou YP. Motivations of employees' knowledge sharing behaviors: a self-determination perspective. Inf Organ 2015;25(1):1–26.
[4] Bock GW, Kankanhalli A, Sharma S. Are norms enough? the role of collaborative norms in promoting organizational knowledge seeking. Eur J Inf Syst 2006;15:357–67.

Please cite this article as: Z. Zhang, F. Song and Z. Song, Promoting knowledge sharing in the workplace: Punishment v. reward, Chaos, Solitons and Fractals, https://doi.org/10.1016/j.chaos.2019.109518

[5] Davenport R. Why does knowledge management still matter. T+D (Training & Development) 2005;59(2):18–25.
[6] Gray PH. The impact of knowledge repositories on power and control in the workplace. Inf Technol People 2001;14(4):368–84.
[7] Hickson DJ, Hinings CR, Lee CA, Schneck RE, Pennings JM. A strategic contingencies' theory of intra-organizational power. Adm Sci Q 1971;2(16):213–29.
[8] Renzl B. Trust in management and knowledge sharing: The mediating effects of fear and knowledge documentation. Omega 2008;36(2):206–20.
[9] Chan Kim W, Mauborgne R. Procedural justice, strategic decision-making, and the knowledge economy. Strat Manage J 1998;19(4):323–38.
[10] Bock GW, Kim YG. Breaking the myths of rewards: an exploratory study of attitudes about knowledge sharing. Inf Resour Manage J (IRMJ) 2002;15(2):14–21.
[11] Yang HL, Wu TCT. Knowledge sharing in an organization. Technol Forecast Soc Change 2008;75(8):1128–56.
[12] Mooradian T, Renzl B, Matzler K. Who trusts? personality, trust and knowledge sharing. Manage Learn 2006;37(4):523–40.
[13] Simon HA. A behavioral model of rational choice. Q J Econ 1955;69(1):99–118.
[14] Wang Y, Chen T. Heuristics guide cooperative behaviors in public goods game. Physica A 2015;439:59–65.
[15] Cabrera A, Cabrera EF. Knowledge-sharing dilemmas. Organ Stud 2002;23(5):687–710.
[16] Krogh G, Roos J, Slocum K. An essay on corporate epistemology. Strat Manage J 1994;15(S2):53–71.
[17] Von Krogh G. Care in knowledge creation. Calif Manage Rev 1998;40(3):133–53.
[18] Wang S, Noe RA, Wang ZM. Motivating knowledge sharing in knowledge management systems: a quasi–field experiment. J Manag 2014;40(4):978–1009.
[19] Dawes RM. Social dilemmas. Annu Rev Psychol 1980;31(1):169–93.
[20] Liu Y, Chen T, Wang Y. Sustainable cooperation in village opera based on the public goods game, chaos. Solitons Fractals 2017;103:213–19.
[21] Chu C, Hu X, Shen C, Li T, Boccaletti S, Shi L, et al. Self-organized interdependence among populations promotes cooperation by means of coevolution. Chaos 2019;29(1):1–6 013139.
[22] Chu C, Mu C, Liu J, Liu C, Boccaletti S, Shi L, et al. Aspiration-based coevolution of node weights promotes cooperation in the spatial prisoner's dilemma game. New J Phys 2019;21:1–7 063024.
[23] Chu C, Yao Z, Mu C, Die H, Tong L, Lei S. Reputation-based popularity promotes cooperation in the spatial prisoner's dilemma game. Appl Math Comput 2019;362:1–7 124493.
[24] Liu J, Meng H, Wang W, Xie Z, Yu Q. Evolution of cooperation on independent networks: The influence of asymmetric information sharing updating mechanism. Appl Math Comput 2019;340:234–41.
[25] Perc M, Gómez-Gardeñes J, Szolnoki A, Floría LM, Moreno Y. Evolutionary dynamics of group interactions on structured populations: a review. J R Soc Interface 2013;10(80):20120997.
[26] Davenport TH, Prusak L. Working knowledge: how organizations manage what they know. Harvard Business Press; 1998.
[27] Lambermont-Ford J, Lam A. Knowledge sharing in organisational contexts: a motivation-based perspective. J Knowl Manage 2010;14(1):51–66.
[28] Bock GW, Zmud RW, Kim YG. Behavioral intention formation in knowledge sharing: examining the roles of extrinsic motivators, social-psychological forces, and organizational climate. MIS Q 2005:87–111.
[29] Gibbert M, Krause H. Practice exchange in a best practice marketplace in knowledge management case book: siemens best practices. Erlangen, Germany: Publics Corporate Publishing; 2002. p. 89–105.
[30] Kelley HH, Thibaut JW. Interpersonal relations: a theory of interdependence. New York: Wiley; 1978.
[31] Santos M. The evolution of anti-social rewarding and its countermeasures in public goods games. Proc R Soc Lond B 2015;282(1798):20141994.
[32] Sigmund K, Hauert C, Nowak MA. Reward and punishment. Proc Natl Acad Sci 2001;98(19):10757–62.
[33] Hauert C, Traulsen A, Brandt H, Nowak MA, Sigmund K. Via freedom to coercion: the emergence of costly punishment. Science 2007;316(5833):1905–7.
[34] Li XL, Marko J, Wang Z, et al. Punishment diminishes the benefits of network reciprocity in social dilemma experiments. PNAS 2018;1(115):30–5.
[35] Szolnoki A, Perc M. Reward and cooperation in the spatial public goods game. EPL (Europhys Lett) 2010;92(3):38003.
[36] Sasaki T, Uchida S. Rewards and the evolution of cooperation in public good games. Biol Lett 2014;10(1):20130903.
[37] Hauert C. Replicator dynamics of reward & reputation in public goods games. J Theor Biol 2010;267(1):22–8.
[38] Ordonez L, Benson LIII. Decisions under time pressure: How time constraint affects risky decision-making. Organ Behav Hum Decis Process 1997;71(2):121–40.
[39] Oliver S, Reddy Kandadi K. How to develop knowledge culture in organizations? a multiple case study of large distributed organizations. J Knowl Manage 2006;10(4):6–24.
[40] Yukl GA, Malone MP, Hayslip B, Pamin TA. The effects of time pressure and issue settlement order on integrative bargaining. Sociometry 1976:277–81.
[41] Futoran GC, Kelly JR, McGrath JE, TEMPO JE. A time-based system for analysis of group interaction process. Basic Appl Soc Psychol 1989;10(3):211–32.
[42] He W, Wei KK. What drives continued knowledge sharing? an investigation of knowledge-contribution and -seeking beliefs. Decis Support Syst 2009;46(4):826–38.
[43] Bergeman CS, Chlpuer HM, Plomin R. Genetic and environmental effects on openness to experience, agreeableness, and conscientiousness: an adoption/twin study. J Pers 1993;61(2):159–79.
[44] Clasen DR, Brown BB. The multidimensionality of peer pressure in adolescence. J Youth Adolesc 1985;14(6):451–68.
[45] Ungar MT. The myth of peer pressure. Adolescence 2000;35(137):167–80.
[46] Kandel E, Lazear EP. Peer pressure and partnerships. J Polit Econ 1992;100(4):801–17.
[47] Bonein A, Denant-Boèmont L. Self-control, commitment and peer pressure: a laboratory experiment. Exp Econ 2015;18(4):543–68.
[48] Lin KJ, Hsieh YH, Lian WS. Knowledge sharing and personality traits moderated by transformational leadership. Hum Syst Manage 2018;37(1):67–80.
[49] Swift ML, Virick M. Perceived support, knowledge tacitness, and provider knowledge sharing. Group Organ Manage 2013;38(6):717–42.
[50] Goh SK, Sandhu MS. Affiliation, reciprocal relationships and peer pressure in knowledge sharing in public universities in malaysia. Asian Soc Sci 2013;9(7):290–8.
[51] Matzler K, Renzl B, Müller J. Personality traits and knowledge sharing. J Econ Psychol 2008;29(3):301–13.
[52] Chen Q, Chen T, Wang Y. How the expanded crowd-funding mechanism of some southern rural areas in china affects cooperative behaviors in threshold public goods game, chaos. Solitons Fractals 2016;91:649–55.
[53] Yang R, Chen T, Chen Q. The impact of lotteries on cooperation in the public goods game. Physica A 2018;512:925–34.
[54] Judge TA, Heller D, Mount MK. Five-factor model of personality and job satisfaction: a meta-analysis. J Appl Psychol 2002;87(3):530–41.
[55] Barrick MR, Mount MK. The big five personality dimensions and job performance: a meta-analysis. Pers Psychol 1991;44(1):1–26.
[56] Cabrera A, Collins WC, Salgado JF. Determinants of individual engagement in knowledge sharing. Int J Hum Resour Manage 2006;17(2):245–64.
[57] Marouf L, Alrikabi I. Knowledge sharing and personality traits. J Soc Sci 2015:10–34.
[58] Constant D, Kiesler S, Sproull L. What's mine is ours, or is it? a study of attitudes about information sharing. Inf Syst Res 1994;5(4):400–21.
[59] Mcdermott R, O'Dell C. Overcoming cultural barriers to sharing knowledge. J Knowl Manage 2001;5(1):76–85.
[60] Szabó G, Hauert C. Phase transitions and volunteering in spatial public goods games. Phys Rev Lett 2002;89(11):118101.
[61] Liao H, Chuang A. A multilevel investigation of factors influencing employee service performance and customer outcomes. Acad Manag J 2004;47(1):41–58.
[62] Wang Y, Chen T, Chen Q, Si G. Emotional decisions in structured populations for the evolution of public cooperation. Physica A 2017;468:475–81.
[63] Kahneman D, Tversky A. Prospect theory: an analysis of decision under risk. Econometrica 1979;47(2):263–92.
[64] Wang Z, Marko J, Lei S. Exploiting a cognitive bias promotes cooperation in social dilemma experiments. Nat Commun 2018;9(2954):1–7 2018.
[65] Litwin GH, Stringer RA. Motivation and organizational climate. Am J Sociol 1968;82(4):1220–35.
[66] Janz BD, Prasarnphanich P. Understanding the antecedents of effective knowledge management: the importance of a knowledge-centered culture. Decis Sci 2010;34(2):351–84.