

RESEARCH

Open Access



Understanding how retweets influence the behaviors of social networking service users via agent-based simulation

Yizhou Yan¹, Fujio Toriumi² and Toshiharu Sugawara^{1*} 

*Correspondence:
sugawara@waseda.jp

¹ Department
of Computer Science
and Communications
Engineering, Waseda
University, 3-4-1 Okubo,
Shinjuku, 169-8555 Tokyo,
Japan
Full list of author information
is available at the end of the
article

Abstract

The retweet is a characteristic mechanism of several social network services/social media, such as Facebook, Twitter, and Weibo. By retweeting tweet, users can share an article with their friends and followers. However, it is not clear how retweets affect the dominant behaviors of users. Therefore, this study investigates the impact of retweets on the behavior of social media users from the perspective of networked game theory, and how the existence of the retweet mechanism in social media promotes or reduces the willingness of users to post and comment on articles. To address these issues, we propose the retweet reward game model and quote tweet reward game model by adding the retweet and quote tweet mechanisms to a relatively simple social networking service model known as the reward game. Subsequently, we conduct simulation-based experiments to understand the influence of retweets on the user behavior on various networks. It is demonstrated that users will be more willing to post new articles with a retweet mechanism, and quote retweets are more beneficial to users, as users can expect to spread their information and their own comments on already posted articles.

Keywords: Retweet, Social media, Meta-norms game, Quote tweet, Complex network, Agent-based simulation, Facebook, Twitter

Introduction

Twitter, Facebook, Instagram, and many other *social network services* (SNS) on social media platforms have attracted global attention in recent years. Increasing numbers of people are using these online platforms to post a variety of information, including text, voice, sound, images, and videos, for purposes, such as personal and group communication, education [1], business [2], and political discussions [3]. This informative collection has become a valuable resource and asset generated by numerous social media users. For the further growth of these assets, articles and related comments must be constantly updated by users; thus, it is necessary to identify factors that incentivize and promote people to provide information.

Substantial research has been conducted on this topic by studying these issues from viewpoints including social network analysis [4], social psychology [5–7], and

agent-based simulation using evolutionary game theory [8–11]. For example, Zhao and Rosson [4] demonstrated the potential influence of microblogging sites, such as Twitter. Several studies have also attempted to identify the reasons that microblogs are used as informal communication tools and the characteristics of the user behavior. Toriumi et al. [8] modeled social media activities according to the *public goods game* [12], as posted articles are public resources. However, lurkers may exist who simply read articles and provide nothing, because by posting articles, people must incur certain costs and responsibilities, whereas they can obtain benefits by simply reading articles and comments. Toriumi et al. introduced the following aspects: (a) rewards, corresponding to posting comments on existing articles, (b) cooperation, corresponding to posting new articles, and (c) meta-rewards, corresponding to comments on existing comments. They found that meta-rewards help to maintain cooperation [8]. However, the manner in which *retweet mechanisms*, including *quote tweets*, influence the user behaviors in social media has not been sufficiently studied to date, although it is understandable that retweets improve the spread of information, and thus, facilitate cooperation; that is, they cause users to post articles more frequently.

The retweet, which is a mechanism that has been implemented in several social media platforms, allows users to view an article posted by a stranger (within the social network connections of the user) and to express their opinions in a reply to the article contributor. The quote tweet is a type of retweet, which also enables retweeters to add their opinions or comments. As a result, the article contributor may have quite a large number of potential readers/commenters. Furthermore, retweets can increase the influence of microblogs/tweets at a small cost. However, situations in which many articles are posted may be advantageous for lurkers. Thus, understanding the effects of retweets can aid in identifying the conditions that are necessary for sustained social media influence.

We experimentally investigated the impact of retweets and quote tweets on communication among users by varying the values of the variables that limit the diffusion of retweeted information. Although we previously reported the results of an extended reward game, known as the *RT reward game*, by introducing only the retweeting mechanism to reveal the effect of retweets on user behavior [13], we further extended the RT reward game by adding the quote tweet mechanism. This extension enables us to understand the effect of different types of retweet mechanisms on user behaviors by comparing the results derived from the mechanisms of retweets with and without quote tweets. Furthermore, we conducted experimental analyses with more extensive experiments based on these models.

For our experimental analysis, we conducted multi-agent simulations using genetic algorithms on a complete graph, networks that were generated based on the *connecting nearest neighbor model* [14], and real-world social networks observed on Facebook and Twitter [15]. The results of this experiment indicated that, as demonstrated in existing research, a reward game without the retweet mechanism could not maintain cooperation (posting of articles) owing to the lack of a meta-reward, but a moderately high probability of retweets enhanced the cooperation of users. Furthermore, when quote tweets were available, the same tendency was observed, but closer inspection revealed that agents had a slightly lower posting rate and a generally higher commenting rate in all

networks. Nevertheless, we think that quote tweets are quite beneficial to users, as they are expected to spread users' comments as well as the posted information.

Related works

Numerous studies have been conducted to understand the role of retweeting. However, the majority of works aimed to predict the retweeting behavior. Kupavskii et al. [16] attempted to understand the reasons why a tweet becomes popular and trained an algorithm that could predict the number of retweets during a certain interval length from the initial moment. Peng et al. [17] aimed to determine the factors that motivate users to retweet and whether the retweeting decisions were predictable, based on the tweeting history and social relationships of users. They subsequently modeled the retweet patterns using conditional random fields. Macskassy and Michelson [18] investigated what information was spread and why it was spread in tweets or microblogs. They presented and evaluated several retweet behavior models and found that most people did not retweet information on topics that they themselves tweeted about or from people who were "like them." Tang et al. [19] adopted a "microeconomics" approach to anticipate the retweeting behavior of each individual and investigated how a particular retweeting behavior affects both the originator (sender) and receiver of the retweeting behavior. However, the majority of studies have focused on the factors that would influence retweeting behaviors, and few studies have investigated how the existence of the retweeting mechanism influences the posting and commenting behaviors of users.

In addition to the work of Toriumi et al. [8], many researchers further proposed models that were also attempts to extend the public goods game to investigate the mechanisms and conditions for maintaining the influence on social media activities. Osaka et al. [11] attempted to investigate the influence of the *direct reciprocity* and network structure on the lasting prosperity of social networking services. Hirahara et al. [9, 10] extended the model by adding feedback mechanisms with almost no cost, such as the "Like!" option/button and "read marks" feature, and investigated their effects on the user activities using Facebook data as well as on other artificial complex networks. They found that such mechanisms considerably encouraged cooperation. Furthermore, Toriumi et al. [20] investigated the types of incentive systems consisting of rewards and negative rewards (punishments) to foster and sustain cooperation in an example groupware. Thereafter, Toriumi et al. [21, 22] modified the meta-reward model for more realistic situations that could achieve cooperation in *consumer-generated media* and analyzed the influence on the informative behavior. However, these studies did not discuss how the retweeting mechanism affects the user strategies. Therefore, to study the manner in which the retweet and quote tweet mechanisms affect the willingness of social media users to post and comment on articles, we propose a novel evolutionary model based on a conventional reward game to express these mechanisms.

Proposed model

Reward game with retweets and quote tweets

To model the user behaviors, we propose a *retweet (RT) reward game* and a *quote tweet (QT) reward game*, which are evolutionary games on networked agents. The games are extensions of the *reward game* proposed by Toriumi et al. [8]. For the RT reward game,

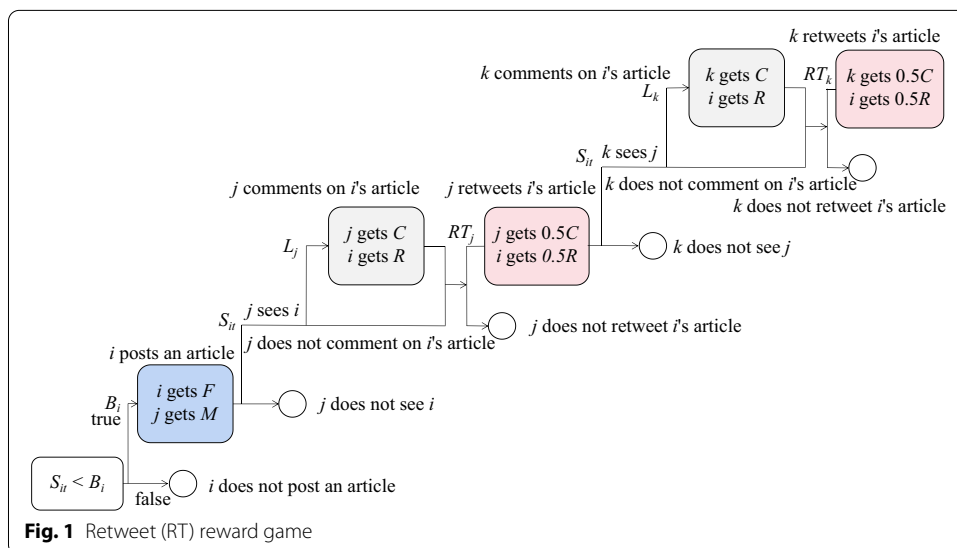
we extend the reward game by introducing several rounds of retweets for a posted article. The QT reward game is obtained by implementing quote tweets in the RT reward game.

Intuitively, retweeting is the action of reposting an article or a tweet of a user or forwarding it to her/his followers. Quote tweets refer to retweeting articles with comments that can be read by the followers, and unlike retweets, quote tweets produce new tweets/articles of the quote tweeters. Posting an article is often represented as *cooperating*, whereas commenting on an article is often represented as *rewarding*. Let A be a set of n agents, where an agent indicates a user in a social networking service. The graph $G = (A, E)$ denotes the *agent network*, where E is the set of undirected edges expressing the followee/follower (thus, usually friendly) relationships. The edge between agents i and j is denoted by $e_{ij} \in E$. For simplicity, we assume that the edges are undirected, meaning that users automatically follow their followers. The set of neighbors of agent i is denoted by $N_i (\subset G)$; that is, $\forall i \in A$

$$N_i = \{j \in A | e_{ij} \in E\}.$$

Four learning parameters exist for agent i that can decide his/her behavior: the *cooperation rate* (that is, posting rate) B_i , *comment rate* L_i , *retweet rate* RT_i , and *quote tweet rate* QT_i ; their values are the probabilities with which the corresponding behavior will be performed and thus take a number between 0 and 1. Note that we generally use the term cooperation rate instead of posting rate, because reward and meta-reward games are variants of the prisoner’s dilemma game.

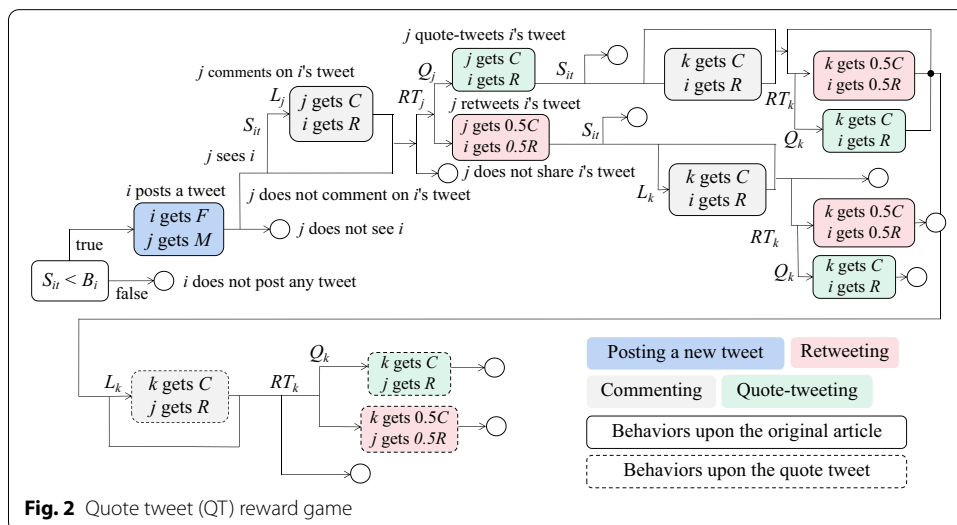
The procedure of the RT reward game is depicted in Fig. 1. The parameter S_{it} ($0 \leq S_{it} \leq 1$), which is the *viewing probability*, provides an indication of how attractive the article of agent i is at time t and is set randomly every time the game starts. A higher S_{it} value indicates greater probability that the article of i will be read. For agent i at time t , if $S_{it} < B_i$, agent i cooperates with B_i (by posting an article or a tweet). If agent i cooperates, all agents in N_i receive a positive reward M , and agent i receives a negative reward F (corresponding to a cost) for posting the article. Agent $j \in N_i$ reads



the article posted by i with S_{it} . If j reads the article, j may comment on the article with probability L_j . If j comments on the article, it receives a reward C (< 0) as the cost of posting a comment, and i receives a positive reward R . Provided that agent j views the article posted by i , j may retweet the article to its neighbors with probability RT_j . If agent j retweets this article, j receives $0.5C$ and i receives $0.5R$. Agent $\forall k \in N_j$ has the opportunity to read the article posted by i with probability S_{it} . If agent k reads the retweeted article of agent i and has not commented on it previously, k can comment on the article with probability L_k . If agent k comments on the article, agent k receives a negative reward C , and agent i receives a positive reward R . Moreover, if agent k is yet to retweet the article, agent k can also retweet it with probability RT_k . If agent k retweets the article, agent k receives $0.5C$, and agent i receives $0.5R$. This ends one period of the RT reward game for agent i .

The procedure of the QT reward game, which is similar to that of the RT reward game, is illustrated in Fig. 2. In this case, if agent j decides to retweet article T , it retweets it with a comment (that is, a quote tweet) with probability QT_j , which means that it will simply retweet it with $(1 - QT_j)$. If j quote tweets the article instead of simply retweeting the article, j will receive a negative reward C , and the article poster will receive a positive reward R . In this situation, j will post a new article T' . Agent $\forall k \in N_j$ will have access to not only T , but also T' , so that k may comment on, retweet, or quote tweet T or T' with probabilities L_k , RT_k , or QT_k , respectively. Note that we can also define RT and QT meta-reward games by introducing meta-rewards [8] in the same manner.

The reward and cost of simple retweets are set to half of the values of reward R and cost C , because retweets only forward articles without posting any comments. Clicking the retweet button should cost less than commenting, resulting in relatively lower rewards for the article poster. The cost and reward of a quote retweet are set to C and R , because, unlike retweeting, quote tweeting does not expect as many replies as tweeting, thereby reducing the costs and sharing the costs slightly more. Once all agents have completed their own periods of the RT/QT reward game, one game round is completed. Table 1 lists the aforementioned parameters.



We present an example of a RT reward game in which seven users, denoted by $\{a, b, c, d, e, f, g\}$, are connected, as illustrated in Fig. 3. First, if user a posts a tweet or an article T (see (1) in Fig. 3), her/his friends, namely, d, b , and e , can read T . Second, as shown in (2), in Fig. 3, a friend of a ; for example, d , reads the tweet and decides to retweet the tweet, and another friend b also reads T and is willing to retweet it; however, e reads T , but does nothing. Because b retweets T , his/her friends, f, c , and g (including a, d , and e) may be able to read T . As d has previously commented on T , d does not comment on it, but it has the opportunity to retweet it again. Agent e , who has not commented on the tweet thus far, may comment on the article of a . This indicates that agents who are not friends of the tweet poster will be able to comment on the tweet if a neighbor of the agent retweets it. Third (see (3) in Fig. 3), a friend of b ; for example, f , reads T and comments on it, and c retweets T . It is worth noting that users can comment on and retweet the same article at the same time.

For the QT reward game, as illustrated in Fig. 4, at the second step mentioned above, the friends of a may quote tweet the tweet T . For example, agent h quote tweets T , posting a new tweet T' . The friends of h , namely, n, m , and o , may view T' , and at the same time, they will also have access to the original tweet T . Among these, n comments on tweet T' , and m retweets T' , bringing a reward to the quote tweeter h . User o comments on the original tweet T and gives a reward to the original poster a .

Process of evolution in agent networks

A generation consists of four rounds of the game described above, following which each agent calculates the payoff, which corresponds to the total reward earned in one generation and is used as its fitness value for the evolution. Note that the fitness value is initialized to 0 at the start of each generation. The parameters B_i, L_i, RT_i , and QT_i that specify the behavior of agent i are encoded into three bits, representing positive integers from 0 to 7. Therefore, we assume that each of these values corresponds to one of $0/7, 1/7, \dots, 7/7$, because they are probabilities. Thus, the agents individually have 12-bit genes in total.

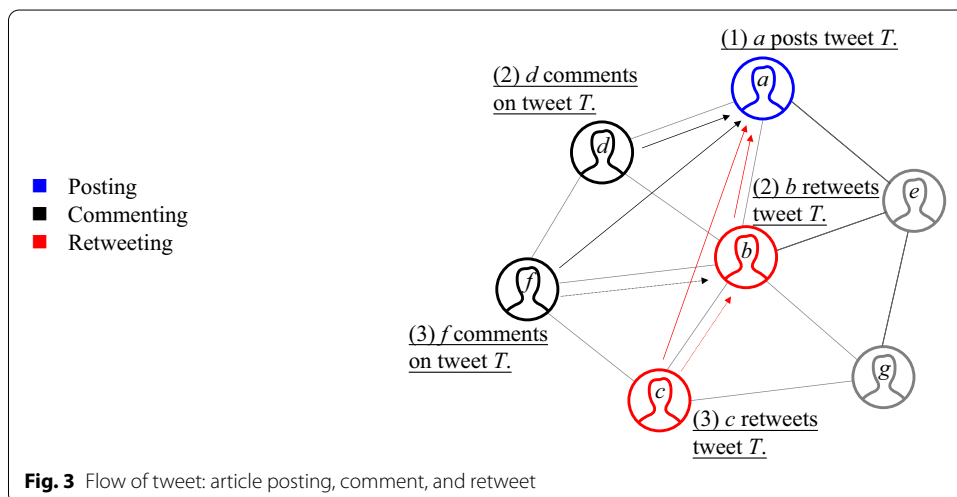


Fig. 3 Flow of tweet: article posting, comment, and retweet

The genetic algorithm used in our experiments comprises three phases: *parent selection*, *crossover*, and *mutation*. In the parent selection phase, agent $i \in A$ selects two agents from $N_i \cup \{i\}$ as parents for the next generation. The probability of agent j ($\in N_i \cup \{i\}$) being selected is as follows:

$$\Pi_j = \frac{(v_j - v_{min})^2}{\sum_{k \in N_i \cup \{i\}} (v_k - v_{min})^2}, \quad (1)$$

where v_{min} is the minimum fitness value among those of $N_i \cup \{i\}$, and v_j is the fitness value of j ; therefore, agents with higher fitness values are likely to be selected as parents by the agents adjacent to them.

Subsequently, the next generation of genes for agent i is produced by uniform crossover; that is, each bit of its new gene is selected with equal probability from one of the two parent agents. After producing the 12-bit gene, each bit is inverted with the probability, which is known as the *mutation rate*. The mutation rate was set to 0.01 in our experiment. The genes obtained in this manner are used as the next generation of agents; therefore, the behavior of i is determined by the obtained gene.

Experimental analysis

Experimental setting

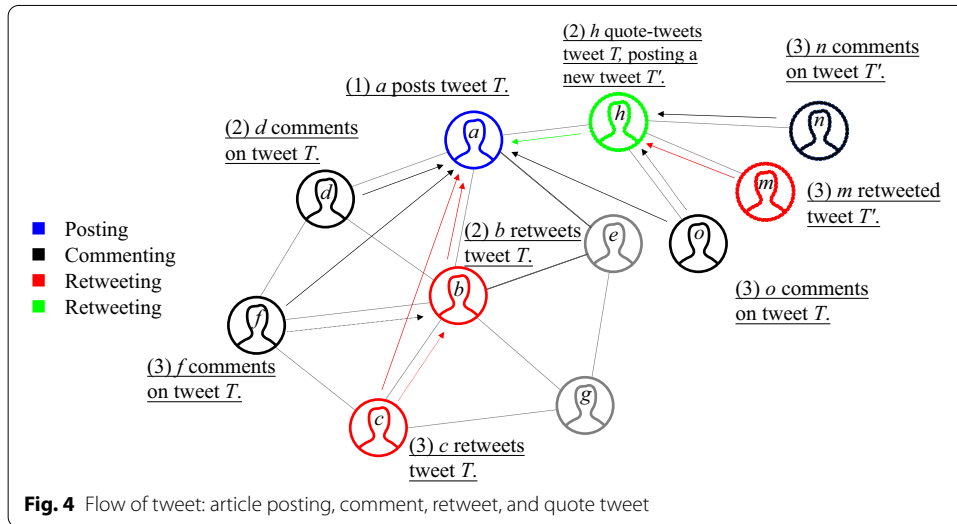
The purpose of our experiments was to explore the dominant (beneficial) strategies that are the most common among users, where the strategy is represented by the agent gene that is the concatenation of B_i , L_i , RT_i , and QT_i . Furthermore, this dominant strategy suggests the extent to which the presence of a retweet mechanism will improve or inhibit the willingness of users to post articles and comments. The difference in behavior between the strategies with and without the retweet and quote tweet mechanisms can be analyzed by comparing the values of the cooperation rate (or post rate) B , comment rate (or reward rate) L , retweet rate RT , and quote tweet rate QT . In the following experimental analysis, the average values of the parameters of all agents are denoted by B , L , RT , and QT . For example, $B = \sum_{i \in A} B_i / |A|$.

The experiments were conducted using a complete graph and nine connecting nearest neighbor networks [14] as these are generally used in these types of experiments. We also conducted the same experiment using a Twitter (ego) network and a Facebook (ego) network to see the effects of retweet and quote tweet in a real-world network and compared them with those obtained using the synthetic networks. We set the numbers of agents to 20 in the complete graph and 1000 in the connecting nearest neighbor networks. The features of the connected nearest neighbor networks used in our experiments are listed in Table 2. Note that, to generate the connecting nearest neighbor networks, the network parameter u , namely, *the probability of changing a potential edge to a real edge* was varied from 0.1 to 0.9 in 0.1 increments. The Facebook network used in this experiment consists of 4039 agents and its average cluster coefficient is 0.6055. The Twitter network consists of 237 agents and its average cluster coefficient is 0.3688. They were acquired from the Stanford Large Network Data Set Collection [15].

The values of the other parameters for the RT and QT reward games are presented in Table 1. Note that these values were determined based on previous studies [8, 12]. All of the experimental results were averaged over 10 independent experimental runs with

Table 1 Parameter values in experiments

Description	Parameter	Value in exp.
Viewing probability of agent i at t	$0 < S_{it} < 1$	Random
Cost of posting article	$F < 0$	- 3.0
Reward upon reading article	$M > 0$	1.0
Cost of comment	$C < 0$	- 2.0
Reward from posting comment	$R > 0$	9.0



different random seeds, whereas the results on the complete graph, and on the Twitter and the Facebook networks were averaged over 100 runs.

Experimental results for complete graph

In the first experiments, we selected the reward game, RT reward game, and QT reward game instead of the (RT/QT) meta-reward games to study the impact of retweets on the user behavior because of meta-reward games, in which every agent has to the opportunity for meta-rewards (by commenting on comments), are known to sustain high cooperation and comment rates, and thus, it is difficult to determine how the retweeting mechanism will affect the user behavior. Meanwhile, agents that play the reward game on connecting nearest neighbor networks and complete graphs are relatively less active, making it easier for us to observe the changes. First, we experimented with the reward game, RT reward game, and QT reward game on a complete graph. Figures 5, 6, and 7 plot the average values of the cooperation and comment rates over time.

The average cooperation rate of all generations was 0.1527 (fairly low) in the reward game (see Fig. 5), but it increased to 0.9060 after introducing retweets (the RT reward game; see Fig. 6) and to 0.8940 after introducing quote tweets (the QT reward game; see Fig. 7). Furthermore, the average value of the comment rate increased slightly, from 0.0287 to 0.0841, owing to the retweet mechanism (see Fig. 6), and subsequently, when adding the quote tweet, it decreased to 0.0538 (see Fig. 7). The results indicate that the

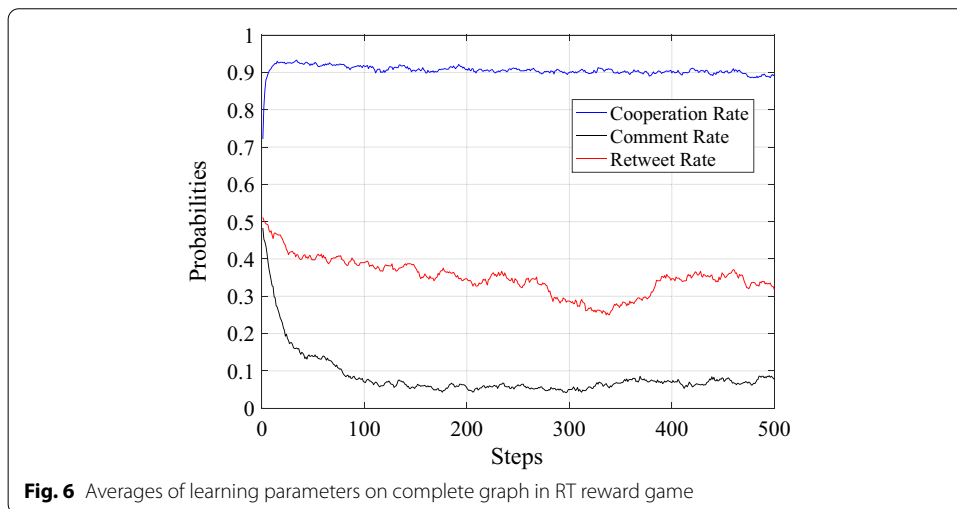
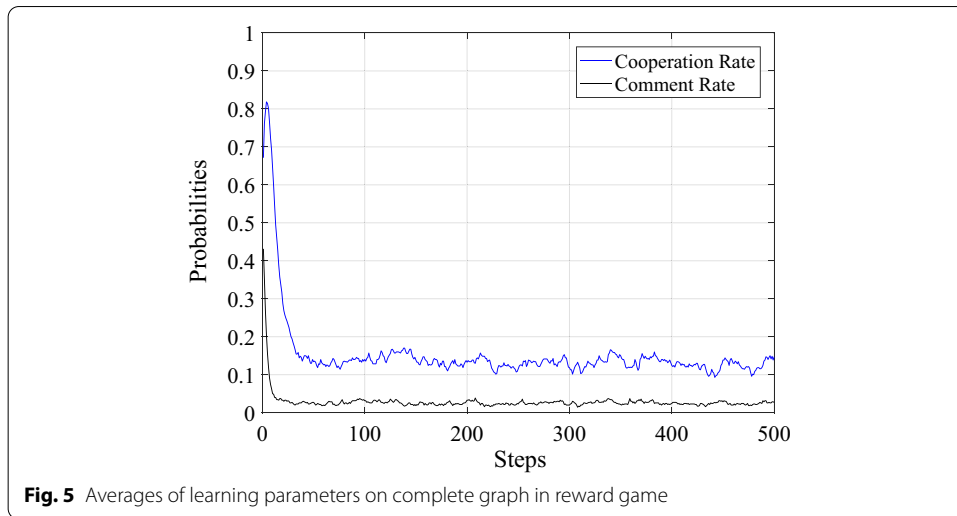


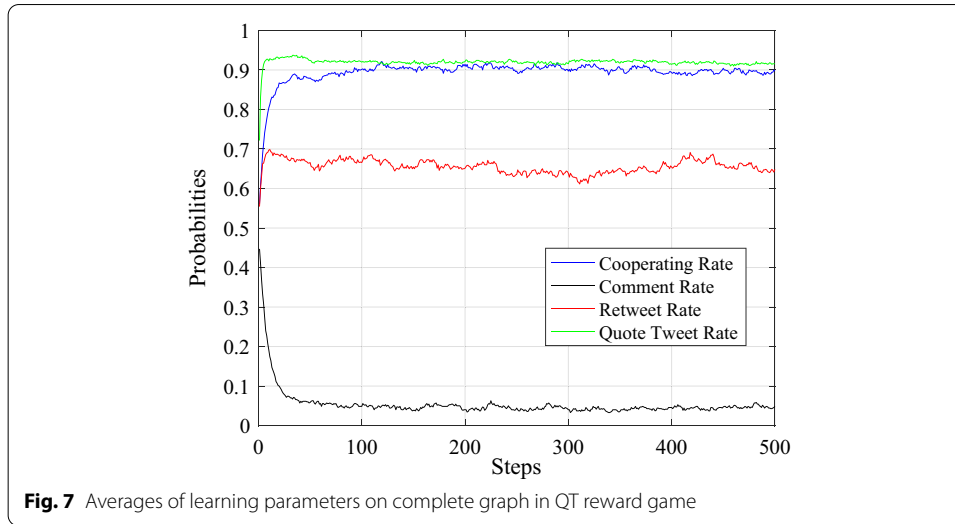
Table 2 Characteristics of connecting nearest neighbor networks (number of agents $n = 1000$)

Parameter	$u = 0.1$	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Average degree	2.20	2.44	2.77	3.19	3.84	4.78	6.40	9.68	17.6
Cluster coefficient	0.39	0.41	0.45	0.44	0.56	0.60	0.68	0.80	0.87

u : the probability of changing a potential edge to a real edge

retweets did not affect the commenting activities substantially but significantly activated cooperation; that is, the posting/tweeting behavior. Meanwhile, a comparison of Figs. (6, 7) and reveals that the quote tweet mechanisms appeared to reduce these two behaviors slightly in the complete graph.

According to the values of RT and QT in Figs. 6, 7, the values of RT were larger than those of the comment rate in both games. Retweeting can spread articles with a low cost and can induce many comments; thus, the actual number of comments increases even if the comment rate is slightly lower. Therefore, retweeting is considered to boost the



activity of social media. Furthermore, in the QT reward game, QT was quite high and RT was also slightly higher than that in the RT reward game. Quote tweets are expected to induce even more activity than retweets, because they not only spread information at a low cost but also provide additional opportunities for users to express their opinions.

To measure the degree to which the cooperation rate changed, we used the following definition of the *increasing ratios of B* , Inc_{rt} and Inc_{qt} : for example, Inc_{rt} is defined as

$$Inc_{rt} = \frac{B_{rt} - B_{normal}}{B_{normal}}, \quad (2)$$

where B_{rt} and B_{normal} are the average values of the cooperation rates in the RT reward game and (conventional) reward game, respectively. We can define Inc_{qt} from B_{qt} and B_{normal} in the same manner. Subsequently, we found that in the complete graph, $Inc_{rt} = 4.93$ and $Inc_{qt} = 4.85$.

Experimental results of connecting nearest neighbor networks

We conducted the same experiments using the reward game, RT reward game, and QT reward game on the connecting nearest neighbor networks by varying the value of u (the probability of changing a potential edge to a real edge) from 0.1 to 0.9. The results are plotted in Figs. 8, 9, and 10. Moreover, the cooperation rate, comment rate, retweet rate, quote tweet rate, and increasing ratio of B , i.e., increasing ratio of posting rate, are listed in Table 3, where the data are the average values between 300 and 500 generations. Figure 8 indicates that the cooperation and comment rates obtained in the reward game on the connecting nearest neighbor networks were substantially higher than those on the complete graph.

Figure 9 demonstrates that, after the retweet mechanism was implemented, the agents became more proactive in posting new articles, although the comment rates did not differ substantially (these were somewhat lower in the RT reward game); this tendency was similar to that in the complete graph. This finding is also reasonable, because retweets provide articles with more opportunities to be read by other users who are

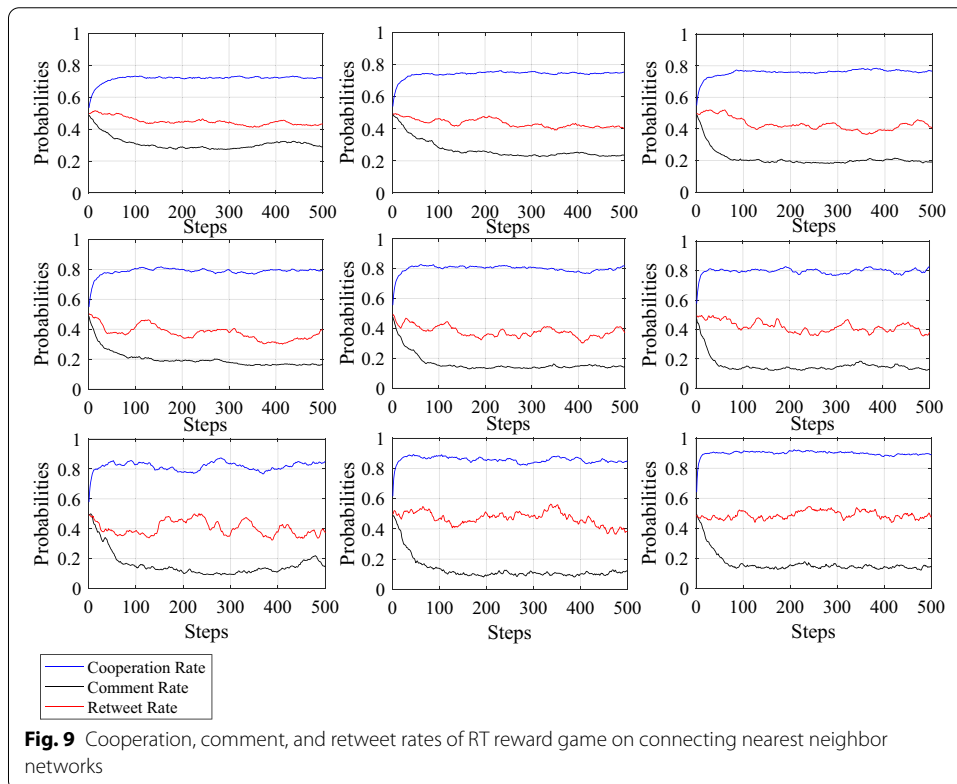
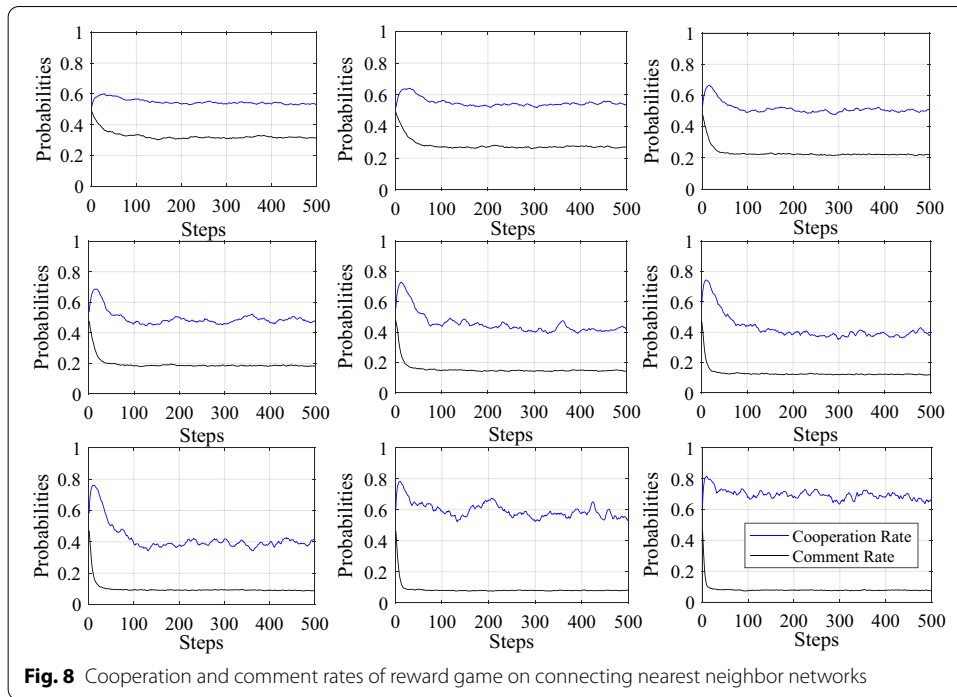


Table 3 List of cooperation rates B , comment rates L , retweet rates RT , quote tweet rate QT , and increasing ratios of B , Inc_{rt} and Inc_{qt} , on various connecting nearest neighbor networks

u	Game model	B	L	RT	QT	Inc_{rt} and Inc_{qt}
0.1	Reward game	0.5384	0.3187	–	–	–
	RT reward game	0.7237	0.3024	0.4302	–	0.3442 (Inc_{rt})
	QT reward game	0.6361	0.3929	0.6145	0.6587	0.1815 (Inc_{qt})
0.2	Reward game	0.5423	0.2711	–	–	–
	RT reward game	0.7465	0.2380	0.4140	–	0.3471
	QT reward game	0.6537	0.3630	0.6568	0.6894	0.2053
0.3	Reward game	0.5058	0.2210	–	–	–
	RT reward game	0.7701	0.1987	0.4059	–	0.5224
	QT reward game	0.6807	0.3325	0.7003	0.7261	0.3458
0.4	Reward game	0.4862	0.1843	–	–	–
	RT reward game	0.7892	0.1640	0.3402	–	0.6231
	QT reward game	0.7089	0.2915	0.7321	0.7508	0.4580
0.5	Reward game	0.4191	0.1471	–	–	–
	RT reward game	0.7919	0.1449	0.3688	–	0.8896
	QT reward game	0.7339	0.2374	0.7648	0.7774	0.7512
0.6	Reward game	0.3884	0.1222	–	–	–
	RT reward game	0.7982	0.1491	0.4075	–	1.0547
	QT reward game	0.7511	0.1997	0.7857	0.8039	0.9338
0.7	Reward game	0.3908	0.0913	–	–	–
	RT reward game	0.8170	0.1407	0.3875	–	1.0905
	QT reward game	0.7692	0.1733	0.7955	0.8303	0.9683
0.8	Reward game	0.5699	0.0796	–	–	–
	RT reward game	0.8533	0.1040	0.4572	–	0.4972
	QT reward game	0.7893	0.1335	0.7642	0.8541	0.3850
0.9	Reward game	0.6823	0.0759	–	–	–
	RT reward game	0.8950	0.1416	0.4873	–	0.3117
	QT reward game	0.7708	0.1194	0.4053	0.8500	0.1297

u : the probability of changing a potential edge to a real edge

slightly further away from the original article contributor. In the case of the QT reward game (Fig. 10), the tendency differed from that in the complete graph. The value of B was maintained at around 0.8, which was always lower than that in the complete graph (Fig. 7), whereas L was higher than that in the complete graph.

Thereafter, we investigated the manner in which agents learn the parameter values with the value of u . First, we discuss the results of the reward game. Figure 8 shows that the cooperation rate in the reward game was approximately 0.5; therefore, the agents in the connecting nearest neighbor networks were relatively willing to cooperate, as opposed to the agents in the complete graph. Subsequently, the cooperation rate decreased only marginally as u increased from 0.1 to 0.7, and increased rapidly to approximately 0.7 as u increased from 0.7 to 0.9. However, the comment rate L constantly decreased as u increased.

In contrast, as illustrated in Figs. 9 and 10, the cooperation rates in the RT and QT reward games were fairly higher than that in the reward game and always appeared to increase with the increase in u . As in the reward game results, the comment rate L decreased monotonically in the RT and QT reward games as u increased. The results of

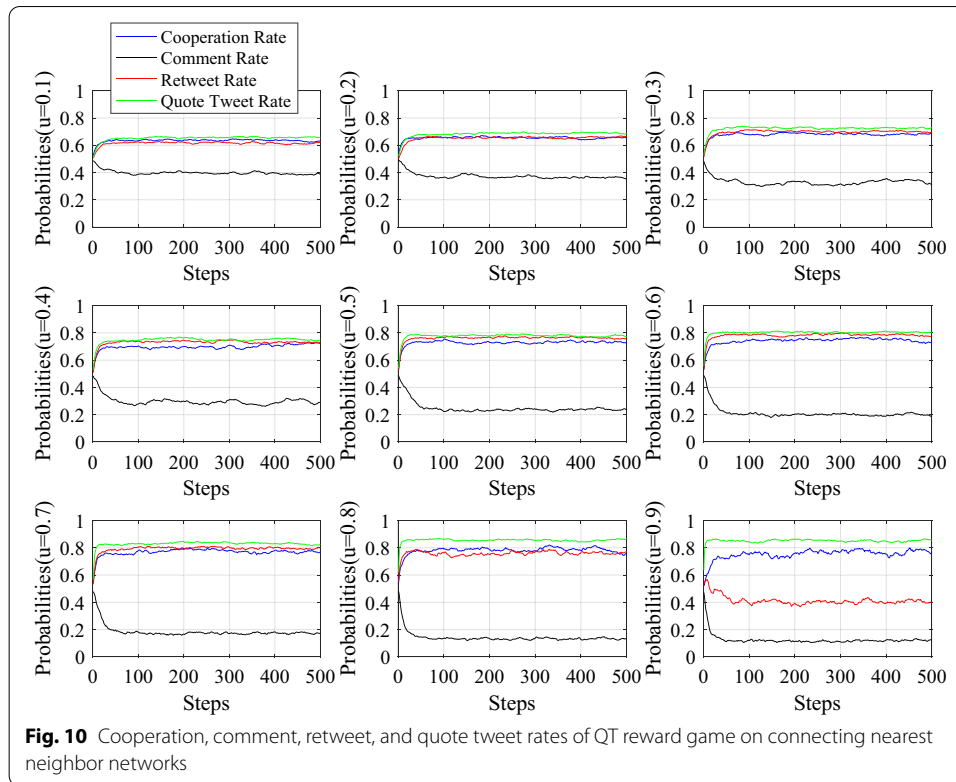


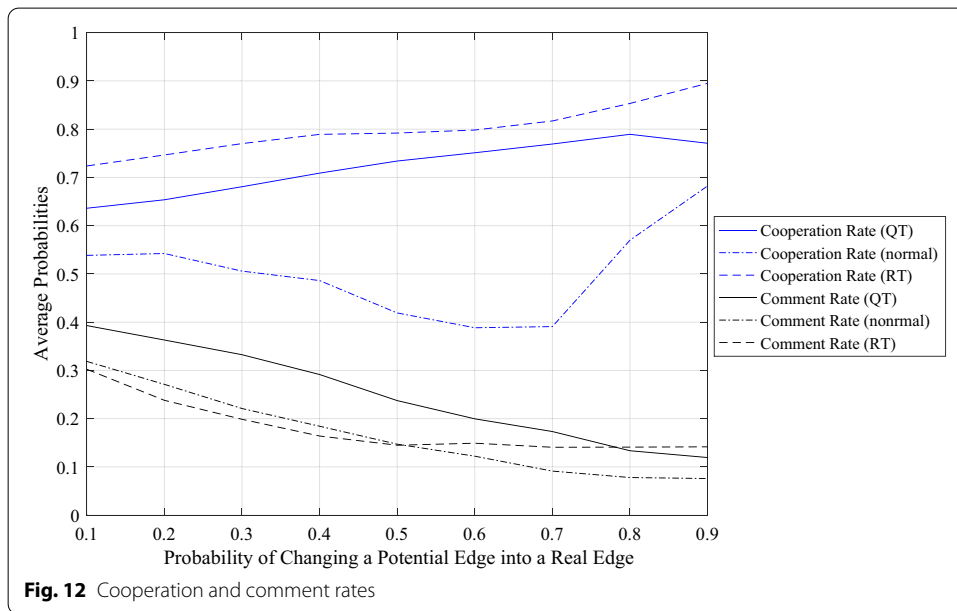
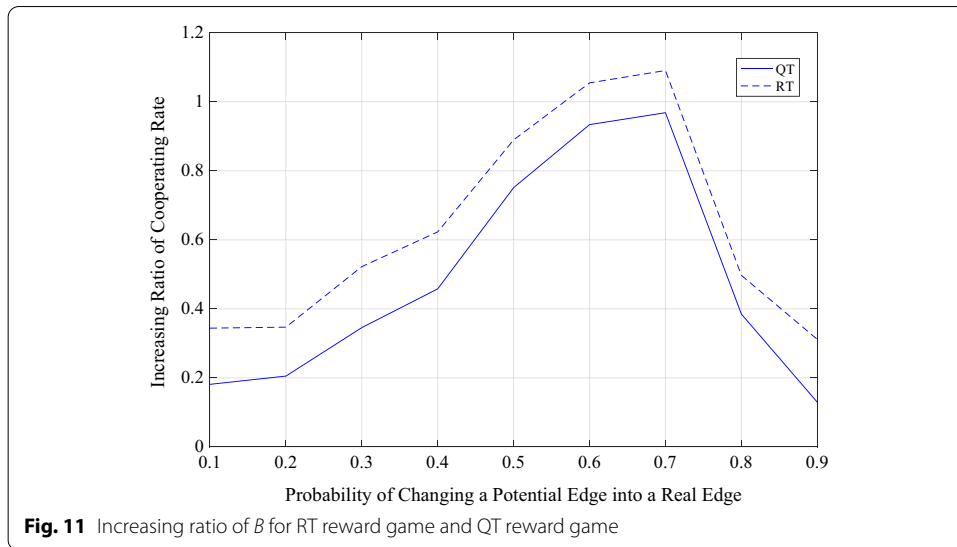
Fig. 10 Cooperation, comment, retweet, and quote tweet rates of QT reward game on connecting nearest neighbor networks

this comparison are summarized in Fig. 12. However, no significant change was observed in the retweet rate in the RT reward game (see Table 3 and Fig. 9). In the QT reward game, the cooperation rate, retweet rate, and quote tweet rate exhibited very close values except when $u = 0.9$, at which point the retweet rate suddenly decreased from approximately 0.7 to 0.4. Instead, the quote tweet rate gradually increased as u increased.

Finally, the relationships between the increasing ratios of B , Inc_{rt} and Inc_{qt} , and the value of u are plotted in Fig. 11. This figure clearly indicates that the values of Inc_{rt} and Inc_{qt} in the RT reward and QT reward games exhibited the same tendency; that is, they increased as the value of u increased in the range of 0.1 to 0.7, and decreased as the value of u increased in the range of 0.7 to 0.9. However, Table 3 indicates that the comment rate L gradually decreased with the increase in u . Moreover, the retweet rate in the QT reward game was higher than that in the RT reward game, except when $u = 0.9$. Furthermore, the retweet rate in the retweet game decreased in the range from $u = 0.1$ to 0.4 and then increased in the range of $u = 0.4-0.9$.

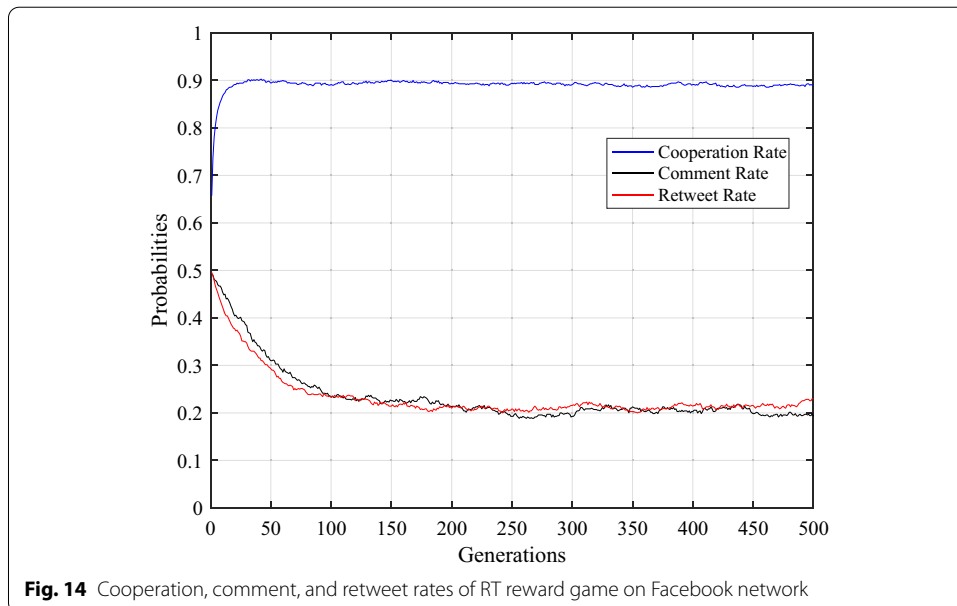
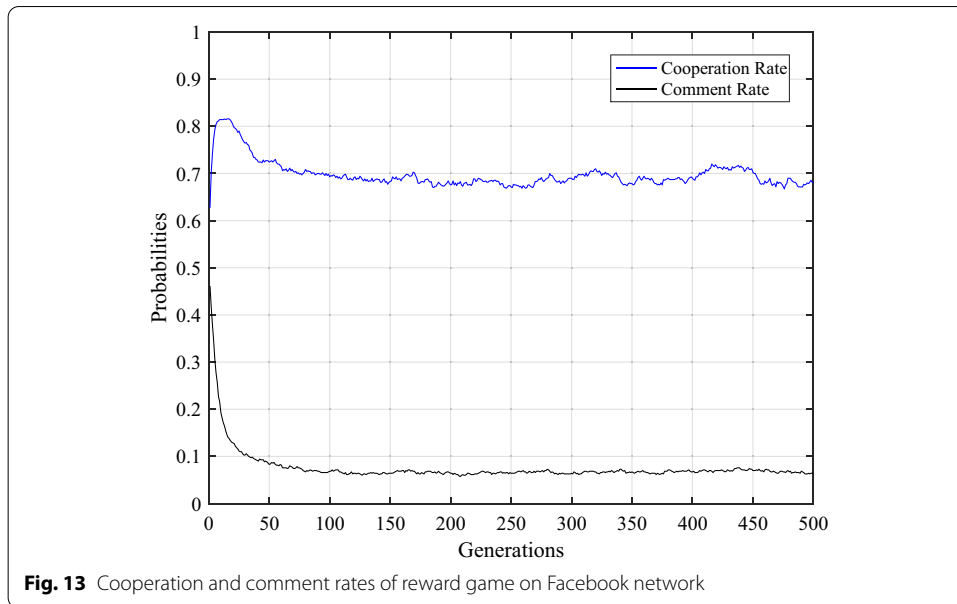
Experimental results for Facebook network

Next, we conducted the experiments using the reward, RT reward, and QT reward games on the Facebook network. The results are plotted in Figs. 13, 14, and 15. In addition, the cooperation rate, comment rate, retweet rate, quote tweet rate, and increasing ratios of B are listed in Table 4, where the data are the average values between 300 and 500 generations. Figure 13 indicates that the cooperation rates obtained in the reward game on the Facebook network were higher than those on



the connecting nearest neighbor networks and the complete graph. The tendency was quite similar to that of the connecting nearest neighbor network, especially when $u = 0.9$ (Fig. 8).

Figure 14 demonstrates that the agents became more willing to post new articles and comments after the retweet mechanism was implemented in the RT reward game (see Table 4). Similarly, the cooperation and comment rates were similar to those in the connecting nearest neighbor network, especially when $u = 0.9$, but the retweet rate was relatively low (Fig. 9). Table 4 and Fig. 15 show that after the quote tweet was implemented, the posting rate of agents decreased to that obtained in the reward game, and the retweet rate rose to about three times of that in the RT reward game. The quote tweet rate was 0.8845, which means almost all users



who pushed the retweet button chosen to share the article with a comment. Again, the tendency was quite similar to that of the connecting nearest neighbor network especially when $u = 0.9$ (Fig. 10), and so it seems that the retweet and quote tweet have been enhanced. The increasing ratios B in the RT and QT reward games were $Inc_{rt} = 0.286$ and $Inc_{qt} = 0.0251$ in the Facebook network, which is slightly smaller than those of the connecting nearest neighbor networks. However, this does not mean that SNS became less active; we will discuss this topic more in the next section.

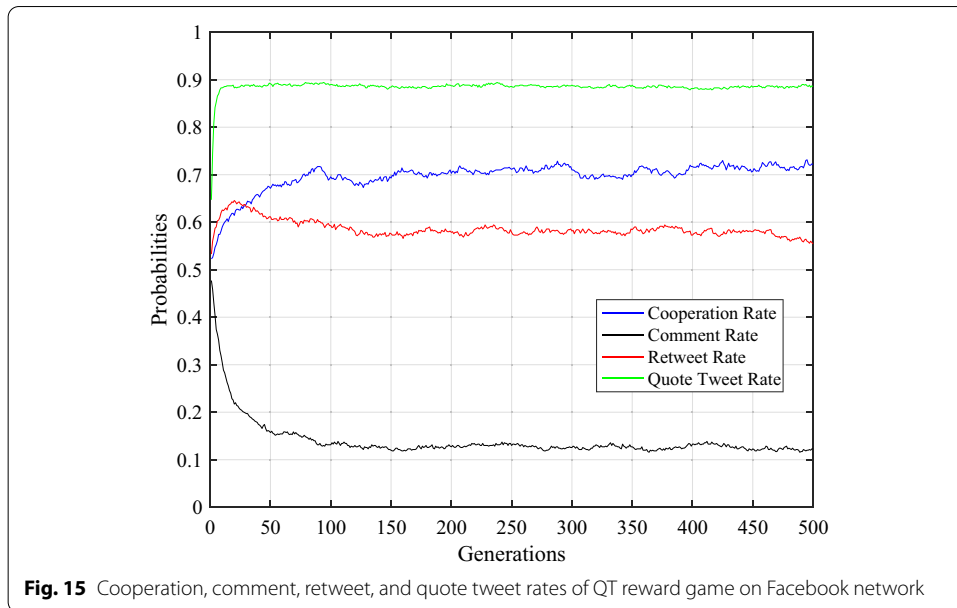
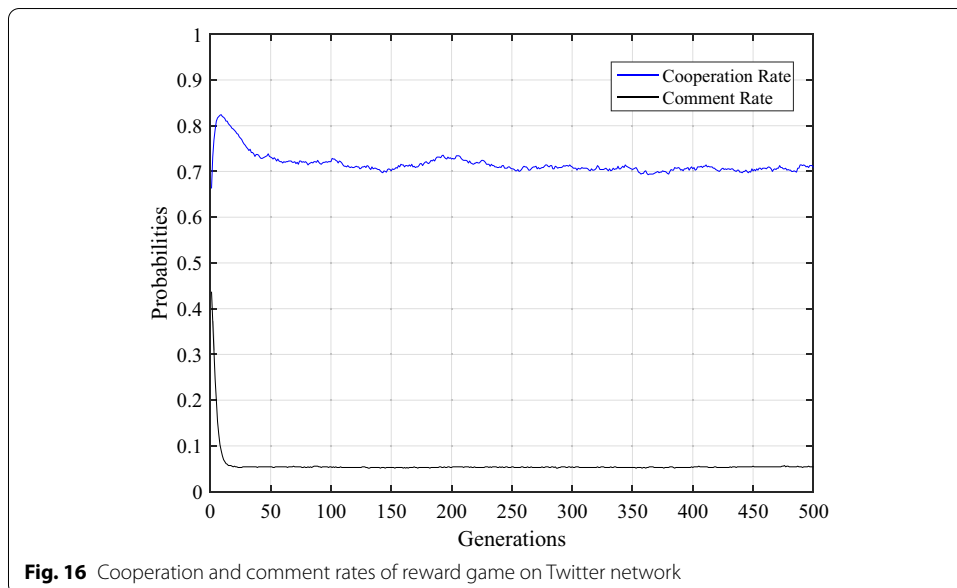


Table 4 List of cooperation rates B , comment rates L , retweet rates RT , quote tweet rate QT , and increasing ratio of B , Inc_r,t and Inc_{qt} , on a Facebook network

Game model	B	L	RT	QT	Inc_r,t and Inc_{qt}
Reward game	0.6922	0.0678	–	–	–
RT Reward game	0.8902	0.2044	0.2141	–	0.2860 (Inc_r,t)
QT Reward game	0.7096	0.1253	0.5784	0.8845	0.0251 (Inc_{qt})



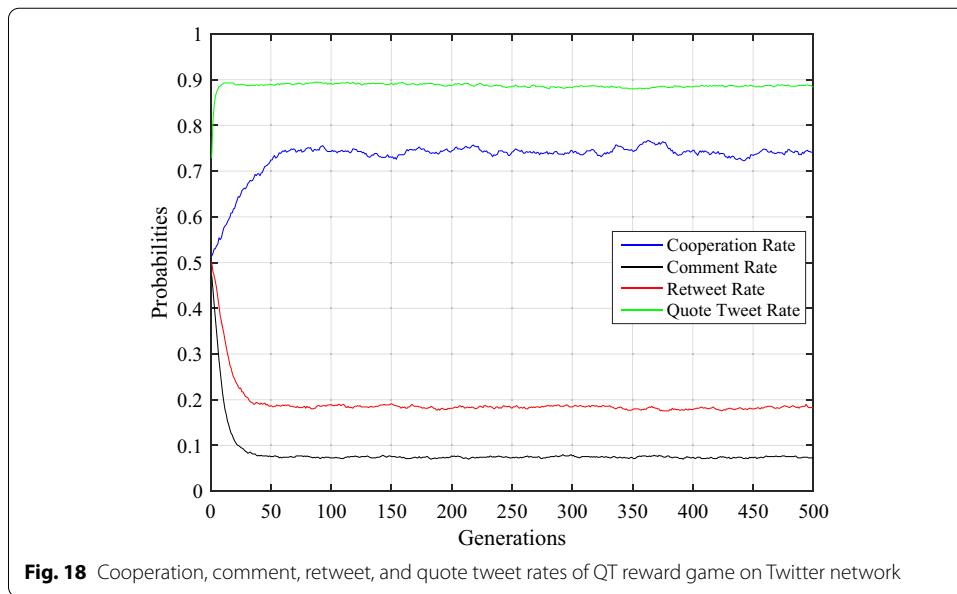
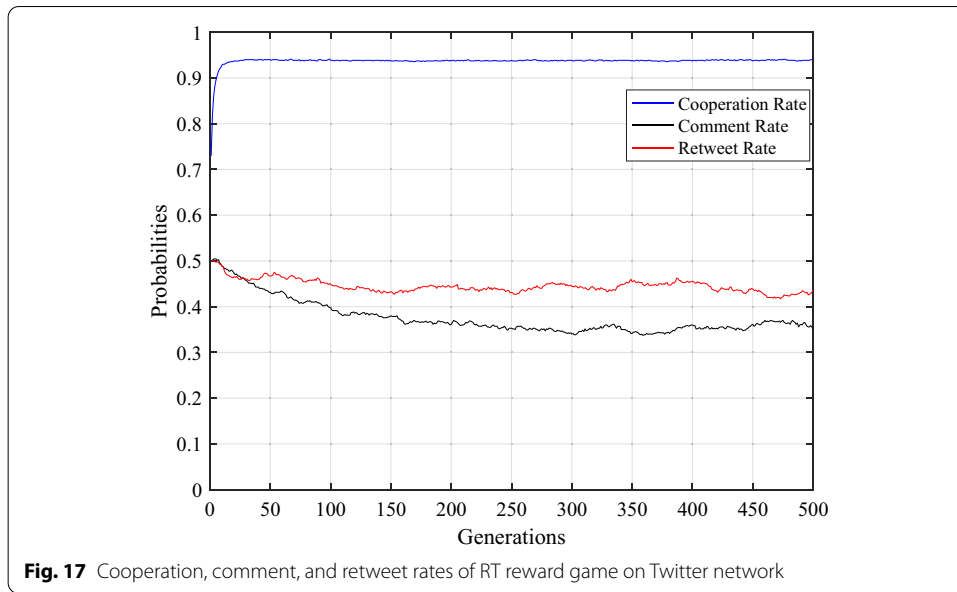


Table 5 List of cooperation rates B , comment rates L , retweet rates RT , quote tweet rate QT , and increasing ratio of $B, Inc_r t$ and Inc_{qt} , on a Twitter network

Game model	B	L	RT	QT	$Inc_r t$ and Inc_{qt}
Reward game	0.7048	0.0536	–	–	–
RT Reward game	0.9384	0.3535	0.4403	–	0.3314 ($Inc_r t$)
QT Reward game	0.7428	0.0743	0.1818	0.8850	0.0539 (Inc_{qt})

Experimental results for Twitter network

Finally, we conducted the experiments using the reward, RT reward, and QT reward games on the Twitter network. The results are plotted in Figs. 16, 17, and 18. We also listed the cooperation rate, comment rate, retweet rate, quote tweet rate, and increasing ratio of B in Table 5, where the data are the average values between 300 and 500 generations. By comparing Figs. 16, 17, we can see that the retweet made the cooperation rate (posting articles), comment rate and retweet rate keep higher. Moreover, by introducing quote tweet, i.e., in the QT reward game, Fig. 18 also indicates that comment rate kept high although the cooperate rate and retweet rate slightly decreased (see Table 5). These tendencies are quite similar to those in the Facebook network; we will discuss more on this topic in the following section.

The increasing ratio of B , Inc_{rt} and Inc_{qt} , in Table 5 shows that retweet and quote tweet raised the cooperation rate on the Twitter network; these results suggest that they were likely to activate article posts (i.e., tweets) on the network. However, quote tweet considerably decreased the comment rate and the retweet rate, but we think that the activities in this network were enhanced, since the quote tweet rate was significantly large.

Discussion

First, it has to be pointed out that the increasing ratios of B , Inc_{rt} and Inc_{qt} , were positive in all networks including Facebook and Twitter networks, thus we can say that the retweet and quote retweet enhanced the cooperation, i.e., posting activities of users. In complete graphs, which correspond to dense sub-communities in SNS networks, a retweet creates opportunities for an agent who missed an article in the original post to read the article. Moreover, for agents who read the article but did not retweet/comment, the retweeting of other agents may cause them to re-read the article and provides another opportunity to react. Every time an agent retweets an article, the neighboring agents know that the agent is interested in the article, which serves as an incentive for them to re-read the article. Thus, they have a new opportunity to perform certain activities relating to the article, such as commenting or retweeting, bringing rewards to the article poster. Therefore, a retweet from an agent connected by a complete graph could significantly increase the likelihood that an article would be read and commented on. Because the quote tweet could produce a new tweet to be rewarded with a relatively low cost, it made the retweets more profitable, increasing the probability of retweets from 0.21 to 0.66.

Furthermore, given the existence of mutual friends of the tweeter and contributor, retweets in the connecting nearest neighbor networks helped to activate friends of the article posters. Moreover, retweets may be able to increase the potential readership of an article by encouraging agents who do not know the poster directly to read and respond to it. All of these effects make it easier for article posters to receive comments, which significantly increases the possibility of article submissions. In the connecting nearest neighbor networks, the increasing ratio of B was the highest when u was approximately 0.7 for both games, because the cooperation rate in the reward game was the smallest. However, the reason for this phenomenon is unknown, and its clarification will be the focus of future work.

It was observed that the comment rates in the RT reward game were larger than those in the reward game in all networks, which implies that agents are more willing to comment on the articles of others. In general, commenting more means losing a greater fitness value due to its cost, but owing to the retweet mechanism, the cooperation rate will subsequently increase; therefore, agents will have additional opportunities to decide whether to comment on the articles of others, and thus, commenters who are less active may have a larger opportunity to benefit.

In the QT reward game, with the implementation of the quote tweet, the cooperation rate decreased slightly compared to the RT reward game. This is interesting, because quote tweets should not influence the reward amount that the article poster may receive. Similar to the results of the complete graph, the quote retweet mechanism increased the probability of retweets from approximately 0.45 to 0.7 in the connecting nearest neighbor networks. However, when $u = 0.9$, the probability of retweets decreased to approximately 0.4 as u increased. We believe that this is because the density of the networks reduced the number of close strangers that could bring rewards to the quote tweeters.

Moreover, Figs. 7, 10, 15, and 18 show that the QT value stayed high in all networks and was always higher than the RT value, because the quote tweet mechanism appeared to be more advantageous for users than the simple retweets, and it could spread their comments and opinions of the articles that were already posted. We can also see that the quote retweet mechanism increased the probability of retweets from approximately 0.45 to 0.7 in all networks. However, in the connecting nearest neighbor network with $u = 0.9$, the probability of retweets decreased to approximately 0.4. We believe that this is because the density of the networks reduced the number of close strangers that could bring rewards to the quote tweeters, and the quote retweets were more beneficial than the simple retweets. Meanwhile, in a complete graph, because everyone knew each other, the main effect of the quote retweets was to increase the chances of reading and commenting on articles, rather than spreading information.

If we compare the results on the Facebook and Twitter networks, their characteristics look similar, and they have properties similar to those of the connecting nearest neighbor network with $u = 0.9$. However, there are a few differences when looking at the details. For example, Tables 4 and 5 indicate that in the Facebook network, the retweet rate increased from 0.2141 in the RT reward game to 0.5784 in the QT reward game on the Facebook network but decreased from 0.4404 in the RT reward game to 0.1818 in the QT reward game on the Twitter network. Furthermore, the comment rate L decreased from 0.2044 to 0.1253 on the Facebook network and from 0.3535 to 0.0743 on the Twitter network. Meanwhile, the increasing ratios of B on the Twitter network, which were $Inc_{rt} = 0.3314$ and $Inc_{qt} = 0.0539$, were higher than those on the Facebook network, which were $Inc_{rt} = 0.2860$ and $Inc_{qt} = 0.0251$. Thus, it means that the retweet and quote tweet enhanced the cooperation, i.e., tweeting/posting articles, on the Twitter network.

Finally, our experiments indicate that the cooperation and comment rates fell in the QT reward game compared to those in the RT reward game in all networks including the Facebook and the Twitter networks. In general, the retweet rate in the QT reward game increased to that in the RT reward game; the quote tweet rate kept high in all networks, which indicates a large number of quote tweeting. Quote tweeting contains

posting a comment to the original poster and posting a new article on someone's own opinion. In this sense, it can be treated as both posting and comment activities to some degree. In the QT reward game, it cannot be said that information provision became less active, but rather society itself was more active.

Conclusions

This study investigated the influence of retweets on users in social media networks. We have proposed new models by extending the conventional reward game with the introduction of the retweet and quote tweet mechanisms. In these models, an article experiences two rounds of retweets. We found that the retweet mechanism causes users to read articles posted by others who are close but unknown on the network, thereby expanding the potential readership of the article posters. Thereafter, we investigated the cooperation (article posting) and comment rates of the agents, which would change with the existence of retweet mechanisms. We found that retweets could motivate agents to post new articles, and quote tweets slightly suppressed the posting activities while improving the commenting activities. In the connecting nearest neighbor networks, the cooperation rate appeared to exhibit the most significant increase when u was near 0.7.

In the future, we plan to study the proposed RT and QT reward games by varying the costs and rewards and by implementing meta-rewards and negative rewards in our model. Moreover, we will conduct several experiments using other real-world networks and will apply the *multiple world genetic algorithm* [23] to analyze the diverse strategies for individual agents.

Abbreviations

RT reward game: Retweet reward game; QT reward game: Quote tweet reward game.

Acknowledgements

Not applicable.

Further information

A preliminary version of this journal paper appeared as an article of proceedings: Benito R.M., Cherifi C., Cherifi H., Moro E., Rocha L.M., Sales-Pardo M. (eds) *Complex Networks & Their Applications IX. COMPLEX NETWORKS 2020*, Studies in Computational Intelligence, vol 943, Springer. The current paper proposed additional new game models that reflect not only retweets but also quote tweets and conducted experimental analyses based on more extensive experiments.

Authors' contributions

All authors (YY, FT, and TS) conceived the idea and participated in the discussion of designing model and planning experiments and thus almost equally contributed to the work. YY mainly designed and implemented the code for experiments. TS and YY composed the draft of the manuscript. All authors read and approved the final manuscript.

Funding

This work is partly supported by JSPS KAKENHI Grant Numbers 20H04245, 19H02376, and 18H03498.

Availability of data and materials

This paper uses the data provided by SNAP [15] whose URL is "<http://snap.stanford.edu/>", and other data used in this paper are synthetic.

Declarations

Competing interests

The authors declare that they have no competing interests.

Author details

¹Department of Computer Science and Communications Engineering, Waseda University, 3-4-1 Okubo, Shinjuku, 169-8555 Tokyo, Japan. ²Graduate School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo, 113-8656 Tokyo, Japan.

Received: 1 March 2021 Accepted: 29 August 2021

Published online: 13 September 2021

References

1. Chugh, R., Ruhi, U.: Social media in higher education: a literature review of Facebook. *Educ. Inf. Technol.* **23**(2), 605–616 (2018)
2. Culnan, M.J., McHugh, P.J., Zubillaga, J.I.: How large us companies can use twitter and other social media to gain business value. *MIS Q Exec* **9**(4), (2010)
3. Conway, B.A., Kenski, K., Wang, D.: The rise of twitter in the political campaign: searching for intermedia agenda-setting effects in the presidential primary. *J. Comput.-Mediat. Commun.* **20**(4), 363–380 (2015)
4. Zhao, D., Rosson, M.B.: How and why people twitter: the role that micro-blogging plays in informal communication at work. In: Proceedings of the ACM 2009 International Conference on Supporting Group Work, pp. 243–252 (2009)
5. Yu, A.Y., Tian, S.W., Vogel, D., Kwok, R.C.-W.: Can learning be virtually boosted? An investigation of online social networking impacts. *Comput. & Educ.* **55**(4), 1494–1503 (2010)
6. Ellison, N., Steinfield, C., Lampe, C.: Spatially bounded online social networks and social capital. *Int. Commun. Assoc.* **36**(1–37), (2006)
7. Burke, M., Marlow, C., Lento, T.: Social network activity and social well-being. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1909–1912 (2010)
8. Toriumi, F., Yamamoto, H., Okada, I.: Why do people use social media? agent-based simulation and population dynamics analysis of the evolution of cooperation in social media. In: 2012 IEEE/WIC/ACM International Conferences on Web Intelligence and Intelligent Agent Technology, vol. 2, pp. 43–50 (2012). IEEE
9. Hirahara, Y., Toriumi, F., Sugawara, T.: Evolution of cooperation in SNS-norms game on complex networks and real social networks. In: International Conference on Social Informatics, pp. 112–120 (2014). Springer
10. Hirahara, Y., Toriumi, F., Sugawara, T.: Cooperation-dominant situations in SNS-norms game on complex and Facebook networks. *N. Gener. Comput.* **34**(3), 273–290 (2016)
11. Osaka, K., Toriumi, F., Sugawara, T.: Effect of direct reciprocity and network structure on continuing prosperity of social networking services. *Comput. Soc. Netw.* **4**(1), 2 (2017)
12. Axelrod, R.: An evolutionary approach to norms. *Am. Political Sci. Rev.* 1095–1111, (1986)
13. Yan, Y., Toriumi, F., Sugawara, T.: Influence of retweeting on the behaviors of social networking service users. In: International Conference on Complex Networks and Their Applications, pp. 671–682 (2020). Springer
14. Vázquez, A.: Growing network with local rules: preferential attachment, clustering hierarchy, and degree correlations. *Phys. Rev. E* **67**(5), 056104 (2003)
15. Leskovec, J., Sosič, R.: Snap: a general-purpose network analysis and graph-mining library. *ACM Trans. Intell. Syst. Technol.* (2016). <https://doi.org/10.1145/2898361>
16. Kupavskii, A., Ostroumova, L., Umnov, A., Usachev, S., Serdyukov, P., Gusev, G., Kustarev, A.: Prediction of retweet cascade size over time. In: Proceedings of the 21st ACM International Conference on Information and Knowledge Management, pp. 2335–2338 (2012)
17. Peng, H.-K., Zhu, J., Piao, D., Yan, R., Zhang, Y.: Retweet modeling using conditional random fields. In: 2011 IEEE 11th International Conference on Data Mining Workshops, pp. 336–343 (2011). IEEE
18. Macskassy, S., Michelson, M.: Why do people retweet? Anti-homophily wins the day! In: Proceedings of the International AAAI Conference on Web and Social Media, 5 (2011)
19. Tang, X., Miao, Q., Quan, Y., Tang, J., Deng, K.: Predicting individual retweet behavior by user similarity: a multi-task learning approach. *Knowl.-Based Syst.* **89**, 681–688 (2015)
20. Toriumi, F., Yamamoto, H., Okada, I.: Exploring an effective incentive system on a groupware. *J. Artif. Soc. Soc. Simul.* **19**(4), 6 (2016). <https://doi.org/10.18564/jasss.3166>
21. Toriumi, F., Yamamoto, H., Okada, I.: A belief in rewards accelerates cooperation on consumer-generated media. *J. Comput. Soc. Sci.* **3**, 19–31 (2019)
22. Toriumi, F., Yamamoto, H., Okada, I.: Rewards visualization system promotes information provision. In: Annual Conference of the Japanese Society for Artificial Intelligence, pp. 55–65. Springer (2019)
23. Miura, Y., Toriumi, F., Sugawara, T.: Multiple-world genetic algorithm to identify locally reasonable behaviors in complex social networks. In: 2019 IEEE International Conference on Systems, Man and Cybernetics, pp. 3665–3672 (2019)

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.