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Public opinion analysis in pandemic management: an evolutionary game theory perspective

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Abstract

The ways the government releases information to the general public through social media is an important method of communication. Currently, such communication plays a crucial role in pandemic control and management due to the popularity of social media, and in fact, it has become an integral part of daily life. This study examines the issues related to public opinion management during a pandemic. To achieve this, it applies evolutionary game theory to analyse the factors in the information that affect public opinion in a pandemic, in particular, using payoff matrices for modelling the likely outcomes from different situation management strategies. Social media has gradually become a key platform for opinion sharing and exchange during a pandemic, so it is necessary to understand the multi-players of government, social media, and the general public in this process as well as paying attention to the strategic choices of those multi-players and their impact on public opinion. This study has developed a tripartite behaviour evolutionary game model of three players, namely, the government, social media, and the general public, and has constructed the replicator dynamic equation. The equilibrium point has been examined, and its stability has been analysed. Simulation-based evaluations have been conducted.

Keywords: public opinion; evolutionary game theory; strategic choices

1、Introduction

Public opinion analysis plays an important role in the control of a pandemic for social stability and national security (Major, 1998; Ma et al., 2014; Xie et al., 2017). Public opinion is referred to as the attitude of the public towards certain events or topics in social media, and it has immense significance for social governance and the formulation of public policies (Dong et al., 2020). Compared to other events, a pandemic could be of long duration, and there could be more severe consequences given the greater uncertainty surrounding its nature (Verikios, 2020), e.g., the coronavirus (COVID-19) pandemic has presented with seemingly high transmissibility and has led to extraordinary socioeconomic disruption. Social media is an important source of real-time information for emergency events, including natural calamities, man-made disasters, epidemics/pandemics, and so on (Saptarshi et al., 2018). The pandemic can swiftly become a topic for intense debate in social media and can rapidly contribute to the formation of public opinion.

Public opinion could significantly affect many aspects of how epidemics are handled. Regarding the positive impact, it could lead the public to believe the scientific evidence and so respond to the calls of experts by actively reducing unnecessary contact amongst people, reducing the number of inessential trips, and complying with the need to wear masks, for example, in the case of COVID-19. However, the negative impact is that it could affect epidemic prevention and control (Chen et al., 2020).

The general public obtain information released by the government and on social media, among other sources; they also post their comments and form opinions on social media. Social media has become very popular amongst general public, and its use by governments has been shaped towards a very wide range of diverse purposes, from increasing information provision and transparency (Stamati et al., 2015) to monitoring and management. Since social media has been a part of people's daily lives; it has become one of the main platforms for governments to publish information, and it plays a vital role in alleviating information asymmetry (Yang et al.,2020). Thus, governments produce their messages and make them publicly available on social media. Then, each social media platform provides its users with access to the generated content as well as distributing it to them through recommendation algorithms (Bakshy et al., 2015). As a result, social media provides both government information and the general public's view and feedback. In general, the government needs to take account of public opinion in order to minimize misunderstanding and avoid social crisis when they release information and take actions to deal with pandemics.

However, most of the existing studies on public opinion during a pandemic management focus on reported opinions and so often are qualitative in nature (Duan, Y., Edwards, J. S., Dwivedi, Y. K. (2019). Artificial intelligence for decision making in the era of Big Data–evolution, challenges and research agenda. International Journal of Information Management, 48, Pages 63-71.), with basic statistical analysis (e.g., Moussa et al., 2018; Dawes et al., 2019; Yamada, Ko., 2020), as surveys and questionnaires are widely used for collecting data (e.g., Upham & Shackley, 2007; Qazi et al., 2017). Meanwhile, several mathematical models are developed for studying public opinion; for example, opinion dynamics models to address forecasting issues offer some valuable inspirations (Ines et al., 2013), while a physical Mass-Spring-Damper system was used to describe and predict the development of public opinion (Dong et al., 2020).

Evolutionary game theory is the study of large populations of individuals who interact at random rather than focusing on small numbers of players (Wallace & Young, 2015). It is a method to model and analyse the strategic relationships, situations, and interactions between players to understand the most likely or best outcomes (Akio & Ferenc, 2015; Hassan et., al., 2012). Furthermore, evolutionary game theory has been gradually applied to studies of human behaviours and used to examine issues between multiple players (Hafezalkotob, 2018). Thus, evolutionary game theory provides a promising theoretical framework to analyse relationships amongst the government, the general public, and social media, and to study the strategies for pandemic management and control. Different control and management measures are examined and adopted by governments according to the development of a pandemic (Wang et al., 2020). The general public are concerned about the spread of the pandemic and obtain information from social media. However, due to a fear of uncertainty, negative social emotions may occur, and the negative impacts of media misreports may persist (Tang et al., 2017). In order to examine these conflicts, evolutionary game theory is applied to explore the problems of neglecting the bounded rationality and the dynamic process of the game (Liu et al., 2015). Therefore, this study attempts to apply evolutionary game theory to study the role of public opinion during a pandemic. It addresses the following questions: (1) What are the equilibrium points in the tripartite evolutionary game model of social media, the general public, and the government? (2) What are the evolutionary stability strategies for public opinion management in the model? and (3) How do the changes in the utility of public trust and social trust of game theory affect the evolution of tripartite participants' behaviours?

With these issues in mind, the main research objective of this study is to construct the tripartite behaviour evolutionary game model of the government, social media, and the general public and further analyse the impacts of tripartite behaviour changes. First, the evolutionary game theory is used to determine the payoff matrices of the model and calculate the replicator dynamics equations of each participant (Wang, 2018). Subsequently, we obtain the evolutionary stability strategies and their conditions by using the Jacobian matrix (Zhe et al., 2020). Finally, we use simulations to study the case of the COVID-19 pandemic and draw several conclusions.

This study finds that the model development will not converge to a certain stable strategy in public opinion. For different conditions, the stability strategy of the system may converge to seven modes: (1,1,1), (1,0,1), (1,1,0), (0,1,1), (0,0,1), (0,1,0), and (1,0,0), while (0,0,0) is an unstable strategy. The government releases the pandemic information on social media, and their actions affect general public opinion under different conditions. Thus, the general public are influenced by both the government and social media.

The rest of paper is organized as follows. Section 2 reviews the related literature. Section 3 constructs evolutionary game theory to model the interaction strategies. The study analyses the equilibrium state of the model and draws a conclusion to study the relationship amongst the three players. Section 4 presents the simulation results and analysis. Finally, Section 5 provides the conclusion.

2、Related work

2.1 Public opinion analysis

Public opinion is defined as the aggregated preferences of the populace, or some subset thereof, on a matter of social interest (Kepplinger, 2008). Public opinion has been studied as one of the main topics in various fields, such as public relations, social governance, public attitudes, and so on. The ways that people access information have changed in recent years; various types of online social media tools allow people to use mobile communication devices to access information at anytime and anywhere and to express their views, feelings, and attitudes more conveniently and more frequently (Song, 2020). Public opinion on social media (social network) is a popular source of information in the event of an emergency, for example.

Due to the concealed and complicated transmission of public opinion on social media, the traditional “point to surface” transmission routes have been replaced with “point to point” peer casting, and the opinions of the public thus transmitted via social media are in the spotlight (Wang et al., 2019). There are many ways to analyse public opinion: Bird et al. (2014) studied public opinion in relation to climate change and the Fukushima disaster by use of a nation-wide survey, while Li et al. (2020) used the social network analysis method to study the law and effect of network public opinion communication from the perspective of network space structure. The empirical evidence is assessed on public opinion linkaging between social media and governance dynamics, which is based on ordinary least squares and quantile regressions (Asongu & Odhiambo, 2019).

Studies in recent years have shown that social network public opinion reflects people's social attitudes, so it is of great significance to study the trend prediction and evaluation of network public opinion, which can provide a decision basis for managers (Chen et al., 2017). Graham and Avery (2015) proposed that in times of crisis, social media is a significant communication channel between the government and the public. The above studies have called for more attention to be paid to the actions of the general public in social media. The evolution of public opinion on emergencies is a dynamic process, which involves three main bodies: the government, social media, and the general public (Chen et al., 2017). The public need to have clear and sufficient information to understand the situation and the actions needed.

2.2 Evolutionary game theory

Game theory was originally grounded in the field of economics by von Neumann and Morgenstern (von Neumann & Morgenstern, 1944) and further developed by Nash and Shapley (1953). Today there are numerous applications in public policy support, strategical decision-making, and so on. Game theory studies strategic interactions in which the agents make rational decisions (Wallace & Young, 2015).

The concept of evolutionary theory emerged from and subsequently was influenced by the study of game theory. Evolutionary game theory merges population ecology with game theory (Sigmund & Nowak, 1999). Compared with traditional game theory, which emphasizes complete rationality, in evolutionary game theory, participants are considered to have bounded rationality, and through continuous trial and error, imitation, and learning, to eventually seek evolutionary stability strategies (Weibull, 1997). Thus, evolutionary game theory is widely used to analyse the causes and influencing factors of social norms and systems (Babu & Mohan, 2018).

The basic principle of evolutionary game theory is to track the change of every strategy’s frequency in the population as the evolution proceeds (Taylor & Jonker 1978); two core concepts are evolutionary stable strategy (ESS) and the replicator equation (RE) (Smith, 1982). From the perspective of evolutionary games, public opinion involves the group behaviour of parties that seek to change the rules of the game under an internal crisis and external impact, and information exchange amongst the players affects the evolution toward convergence on a stable equilibrium (Rajiv, 1998).

Evolutionary game theory has been applied to examine the behavioural strategies of the manufacturers in response to various combinations of carbon taxes and subsidies and this has resulted in the development of the model of the interaction between governments and manufacturers (Chen & Hu, 2018). It has also been employed to model the evolutionary behaviours of governments and developers, thus providing a quantitative method to illustrate the effectiveness of incentives and the strategy changes of the players (Fan & Hui, 2020). In addition, evolutionary game theory has also been used in solving the game problem between multiple stakeholders. The e-waste recycling industry used evolutionary game theory to construct the tripartite evolutionary game model including the government, the recycler, and the consumer, and developed three optimal evolutionary stability strategies (Hassan et., al., 2012, Wang et al., 2020). Based on an evolutionary game model, the influence of shore power implementation on the ESS of multiple stakeholders is discussed among the strategic choices of a shore power system including the government, port enterprises, and liner companies (Xu et al., 2021).

3、The tripartite behaviour evolutionary game model

3.1 Model assumptions

The formation of public opinion in a pandemic is a dynamic process (Dong et al., 2020), which, as stated earlier, involves three main players: the government, social media, and the general public. To examine the development process of public opinion and the role and effects of each party involved, the following assumptions have been made in this study.

Assumption 1: Game players are bounded rationalists and their strategies are independent (Damme, 2015). In this game model, the government releases information, and the general public obtain information and post their comments on social media. Figure 1 shows the relationships amongst those three groups of participants.

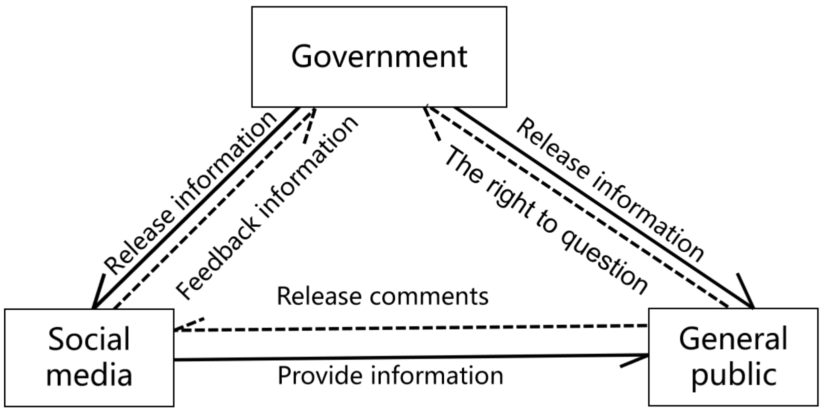


Figure 1 Relationships

Assumption 2: It is assumed that the behaviours of all players are a finite set of strategies with two elements. The government releases sufficient or insufficient information. Social media accelerates the diffusion and evolution of opinions, which is social media’s influence (Li & Zhu, 2020). The general public may post positive or negative comments in the social media.

The strategies of the game players are denoted as (G1, G2), (SM1, SM2), and (GP1, GP2), respectively. For the government, G1 denotes the strategy of releasing sufficient/adequate information, and G2 denotes the strategy of releasing insufficient/inadequate information to social media. For social media, SM1 denotes the strategy of presenting and recommending epidemic information, and SM2 denotes the strategy of recommending irrelevant information or presenting information in an ineffective way. For the general public, GP1 denotes the strategy of posting positive and supporting comments on social media, and GP2 denotes the strategy of posting negative comments on social media.

Assumption 3: During a pandemic, the government releases information on social media. Indeed, social media is being increasingly used as a platform to recommend information. A pandemic poses a threat to public health and security giving governments the responsibility to respond with measures that ensure the health and safety of their communities (Vardavas et al., 2020). Given that public health is heavily dependent on government policies and that governments are conversely reliant on the population for implementing measures to contain the pandemic, the public's trust towards government policies is critical in flattening the pandemic curve. Public trust in governments is an important determinant of citizens’ compliance with public health policies, especially in times of crisis. If governments release insufficient information, or if social media recommend irrelevant information, it may cause the general public to lose interest in important information, and subsequently will damage people’s health, etc. Therefore, the government and social media may lose the public’s trust. It may lead to the general public being unable to obtain sufficient information to guide their behaviours in a pandemic.

Assumption 4: Social media makes decisions based on the probability weighting function (Tversky & Kahneman, 1992):

$$C(\eta)=\frac{\eta^k}{[\eta^k+(1-\eta)^k]^{\frac{1}{k}}} \tag{3-1}$$

Decision maker's subjective judgment of the probability of events or the tendency to choose strategies. It is a monotone increasing function of probability evaluation. In the equation, k represents the decision influence coefficient. A smaller value of k refers to a larger amount of probability weighting; the larger the value of k, the more curved the decision weight function will be.

3.2 The Model

3.2.1 Variables and parameters

According to the behaviours of the government, social media, and the general public in the model, the definitions of variables and parameters are shown in Table 1:

Table 1 Variables and parameters

Symbols	Significance
R_1	The utility of public trust when government chooses G1
R_2	The revenue when social media chooses SM1
R_3	The utility of social trust when general public choose GP1
C_1	The cost of social media when government chooses SM2
L_1	The cost when government chooses G2
L_2	The cost when social media chooses SM2
L_3	The cost when general public choose GP2
T_1	The loss of public trust when government chooses G2
T_2	The loss of public trust when government chooses G2 and social media chooses SM1
T_3	The loss of social trust when general public choose GP2
x	The probability of government choosing G1

y	The probability of social media choosing SM1
p	The probability of general public choosing GP1

Based on the above assumptions and variables, the structure tree of the evolutionary game model for public opinion analysis is illustrated in Figure 2. The eight dots represent the end of the game (Wu et al., 2020), and the lines drawn from the players represent the game strategies that the players can choose

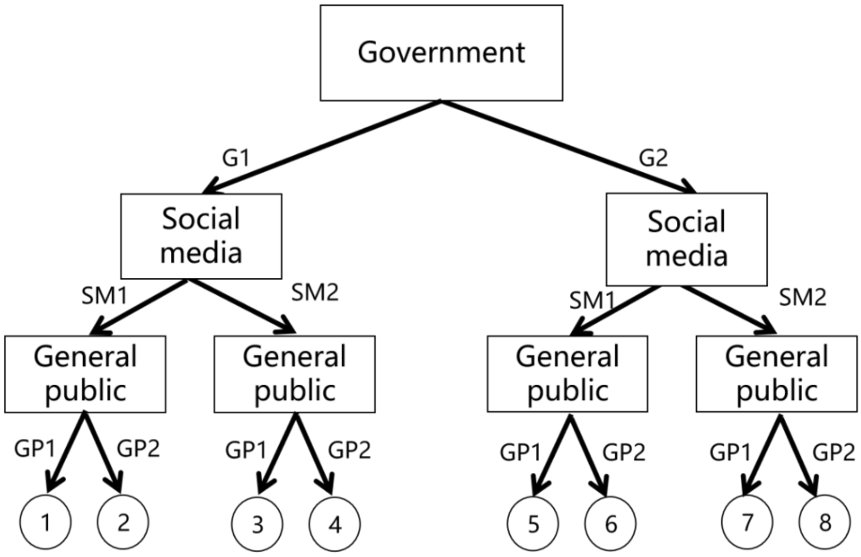


Figure 2 Game theory tree of relationships

3.2.2 Payoff matrix

According to both assumptions and model variables, the payoff matrix is presented in Table 2:

Table 2 Payoff matrix

Game strategies	Government; social media; general public	Payoff matrix
1	Release sufficient information; recommend epidemic information; post positive comments	$R_1 - L_1, R_2 - L_2, R_3 - L_3$
2	Release sufficient information; recommend epidemic information; post negative comments	$R_1 - L_1, R_2 - L_2, -T_3$

3	Release sufficient information; recommend irrelevant information; post positive comments	$R_1-L_1,0,R_3-L_3$
4	Release sufficient information; recommend irrelevant information; post negative comments	$R_1-L_1,0,-T_3$
5	Release insufficient information; recommend epidemic information; post positive comments	$-T_1-C_1,C_1+R_2-L_2-T_2,$ $R_3-L_3-T_1-T_2$
6	Release insufficient information; recommend epidemic information; post negative comments	$-T_1-C_1,C_1+R_2-L_2-T_2,-T_1-T_3-T_2$
7	Release insufficient information; recommend irrelevant information; post positive comments	$-T_1,0,R_3-L_3-T_1$
8	Release insufficient information; recommend irrelevant information; post negative comments	$-T_1,0,-T_1-T_3$

3.3 Solving evolutionary stability strategies and analysing the strategies

3.3.1 Payoff function

It is assumed in this study that the probability of government (Wang et al., 2020) choosing G1 is $x, x\in[0,1]$, the probability of choosing G2 is $1\text{-}x$; the probability of social media choosing SM1 is $y, y\in[0,1]$ and the probability of choosing SM2 is $1\text{-}y$; the probability of the general public choosing GP1 is $p, p\in[0,1]$, and the probability of choosing GP2 is $1\text{-}p$; where x, y and p are the functions of time t.

Let E_{11} and E_{12} represent respectively value functions of "releasing sufficient information" and "releasing insufficient information" for the government. According to Table 3-2, the payoffs of the government with the two different behaviour strategies are as follows:

$$\begin{aligned}E_{11} &= py(R_1-L_1)+p(1-y)(R_1-L_1)\\ &+(1-p)y(R_1-L_1)+(1-p)(1-y)(R_1-L_1)\\ &=(R_1-L_1)\end{aligned} \tag{3-2}$$

$$
\begin{aligned}
&E_{12} = py(-T_1 - C_1) + p(1-y)(-T_1) \\
&(1-p)y(-T_1 - C_1) + (1-p)(1-y)(-T_1) \\
&= -T_1 - yC_1
\end{aligned}
\tag{3-3}
$$

The mixed strategy value function of the government is:

$$
\begin{aligned}
\overline{E_1} &= xE_{11} + (1\text{-}x)E_{12} \\
&= x(R_1 - L_1) + (1\text{-}x)(-T_1 - yC_1)
\end{aligned}
\tag{3-4}
$$

Let E_{21} and E_{22} represent respectively the value functions of "recommending epidemic information" for social media. According to Table 3-2, the payoffs of social media with the two different behaviour strategies are as follows:

$$
\begin{aligned}
&E_{21} = px(R_2 - L_2) + p(1-x)(C_1 + R_2 - L_2 - T_2) + \\
&(1-p)x(R_2 - L_2) + (1-p)(1-x)(C_1 + R_2 - L_2 - T_2) \\
&= (R_2 - L_2) + (1-x)(C_1 - T_2)
\end{aligned}
\tag{3-5}
$$

$$
E_{22} = 0 \tag{3-6}
$$

The mixed strategy value function of social media is:

$$
\begin{aligned}
\overline{E_2} &= yE_{21} + (1-y)E_{22} \\
&= y(R_2 - L_2) + y(1-x)(C_1 - T_2)
\end{aligned}
\tag{3-7}
$$

Let E_{31} and E_{32} represent respectively the value functions of "posting positive information" and "posting negative information" for the general public. According to Table 3-2, the payoffs of the general public with the two different behaviour strategies are as follows:

$$
\begin{aligned}
&E_{31} = yx(R_3 - L_3) + y(1-x)(R_3 - L_3 - T_2 - T_1) \\
&+(1-y)(1-x)(R_3 - L_3 - T_1) + x(1-y)(R_3 - L_3) \\
&= (R_3 - L_3) + (1-x)(-T_1 + (1-y)L_3 - yT_2)
\end{aligned}
\tag{3-8}
$$

$$
\begin{aligned}
&E_{32} = yx(-T_3) + y(1-x)(-T_1 - T_3 - T_2) \\
&+(1-y)(1-x)(-T_1 - T_3) + x(1-y)(-T_3) \\
&= (1-x)(-yT_2 - T_1) - T_3
\end{aligned}
\tag{3-9}
$$

The mixed strategy value function of the general public is:

$$\begin{aligned}\overline{E_3} &= pE_{31} + (1-p)E_{32} \\ &= p\{(R_3 - L_3) + (1-x)(-T_1 + (1-y)L_3 - yT_2)\} + \\ &(1\text{-}p)\{(1-x)(-yT_2 - T_1) - T_3\}\end{aligned} \tag{3-10}$$

3.3.2 Replicator dynamic equation

The ESS of the replicator dynamics equation (Yang et al., 2018) for the government, social media, and the general public are solved respectively:

(1) The replicator dynamic equation of the government is:

$$\begin{aligned}f_1(x) &= \frac{dx}{dt} = x(E_{11} - \overline{E_1}) \\ &= x(1-x)(R_1 - L_1 + T_1 + yC_1)\end{aligned} \tag{3-11}$$

(2) The replicator dynamic equation of social media is:

$$\begin{aligned}f_2(y) &= \frac{dy}{dt} = y(E_{21} - \overline{E_2}) \\ &= y(1-y)[R_2 - L_2 + (1-x)(C_1 - T_2)]\end{aligned} \tag{3-12}$$

(3) The replicator dynamic equation of the general public is:

$$\begin{aligned}f_3(p) &= \frac{dp}{dt} = p(E_{31} - \overline{E_3}) \\ &= p(1-p)\{R_3 - L_3 + T_3 + (1-x)(1-y)L_3\}\end{aligned} \tag{3-13}$$

3.4 Solving evolutionary stability strategy based on the replicator dynamic equation

In this section, the stability analysis of eight equilibrium points in the three-dimensional dynamic system are presented. According to the Malthusian dynamic equation (Yang et al., 2018), the government, social media and the general public constitute a three-dimensional dynamic system of the evolutionary game, that is

$$
\begin{cases}
f_1(x) = x(1-x)(R_1 - L_1 + T_1 + yC_1) \\
f_2(y) = y(1-y)\{R_2 - L_2 + (1-x)(-T_2 + C_1)\} \\
f_3(p) = p(1-p)\{R_3 - L_3 + T_3 + (1-x)(1-y)L_3\}
\end{cases} \tag{3-14}
$$

The Jacobian matrix (Karim &Harn-Jou, 1997) of the above dynamic equation is:

$$
J = \begin{bmatrix}
(1-2x)(R_1 - L_1 + T_1 + yC_1) & x(1-x)(-C_1) & 0 \\
y(1-y)\{-(R_2 - L_2 - T_2 + C_1)\} & (1-2y)\{R_2 - L_2 + (1-x)(-T_2 + C_1)] & 0 \\
p(1-p)\{-(1-y)L_3\} & p(1-p)\{-(1-x)L_3\} & \begin{array}{c}(1-2p)\{R_3 - L_3 + T_3 \\ +(1-x)(1-y)L_3\}\end{array}
\end{bmatrix} \tag{3-15}
$$

Evolutionary equilibrium is a local progressive equilibrium point in a dynamic system, and the strategy combination corresponding to the equilibrium point of the replicator dynamic system is an equilibrium of evolutionary games.

Proposition 1: Since the asymptotically stable solution of the multi-group evolutionary game replicator dynamic system must be a strictly Nash equilibrium (Kohlberg, 2019), we need only to consider eight evolutionary equilibrium points: (0, 0, 0), (1, 0, 0), (0, 1, 0), (0, 0, 1), (1, 0, 1), (0, 1, 1), (1, 1, 0), and (1, 1, 1) .

Proof 1:

Let the replicator dynamic system (3-14) be Eq. (3-11) =0、Eq. (3-12) =0 and Eq. (3-13), we can get the equilibrium points (0, 0, 0), (1, 0, 0), (0, 1, 0), (0, 0, 1), (1, 0, 1), (0, 1, 1), (1, 1, 0), and (1, 1, 1).

The equilibrium points obtained by the replicator dynamic system (3-14) are not necessarily the ESS point. The equilibrium points obtained by the replicator dynamic system (3-14) are not necessarily the ESS. According to the Lyapunov indirect method (Weibull, 1997), if the point is the ESS point, the corresponding characteristic root of the Jacobian matrix must be less than 0.

Proposition 2: The (0, 0, 0) is an unstable point.

Proof 2:

The evolution equilibrium point is (0, 0, 0) and the corresponding Jacobian matrix is:

$$J=\begin{bmatrix} R_1-L_1+T_1 & 0 & 0 \\ 0 & R_2-L_2-T_2+C_1 & 0 \\ 0 & 0 & R_3+T_3 \end{bmatrix} \tag{3-16}$$

Since (R_3+T_3) must be greater than 0, this point is an unstable point, and it is an unstable strategy.

Proposition 3: According to the local stability analysis method of the Jacobian matrix (Narayan, 1977), we analysed the local stability of seven equilibrium points obtained from Proposition 1 under different constraints. The results are shown in this part.

Proof 3:

1. The evolution equilibrium point is (0, 0, 1), and the corresponding Jacobian matrix is:

$$J=\begin{bmatrix} R_1-L_1+T_1 & 0 & 0 \\ 0 & R_2-L_2-T_2+C_1 & 0 \\ 0 & 0 & -(R_3+T_3) \end{bmatrix} \tag{3-17}$$

According to the Lyapunov indirect method, if (0, 0, 1) is the evolutionary stable strategy (ESS), the corresponding characteristic root of the Jacobian matrix must be less than 0, so the following equations can be obtained:

$$\begin{cases} (R_1-L_1+T_1)<0 \\ (R_2-L_2-T_2+C_1)<0 \end{cases} \tag{3-18}$$

The cost of releasing adequate information is less than the utility when the government chooses G2. It can be expressed as $(R_1-L_1+T_1)<0$. The utility of recommending epidemic information is greater than the cost when social media chooses SM2. It can be expressed as $(R_2-L_2-T_2+C_1)<0$. Due to the asymmetry of the information, the general public will release positive comments.

2. The evolution equilibrium point is (1, 0, 0), and the corresponding Jacobian matrix is:

$$J=\begin{bmatrix} -(R_1-L_1+T_1) & 0 & 0 \\ 0 & (R_2-L_2) & 0 \\ 0 & 0 & (R_3-L_3+T_3) \end{bmatrix} \tag{3-19}$$

According to Lyapunov's indirect method, if it is the evolutionary stable strategy (ESS), the corresponding characteristic root of the Jacobian matrix must be less than 0. Hence, the following system of equations can be obtained:

$$\begin{cases} (R_1-L_1+T_1)>0 \\ (L_2-R_2)>0 \\ (L_3-R_3-T_3)>0 \end{cases} \tag{3-20}$$

The evolution equilibrium point is (1, 0, 1), and the corresponding Jacobian matrix is:

$$J=\begin{bmatrix} -(R_1-L_1+T_1) & 0 & 0 \\ 0 & (R_2-L_2) & 0 \\ 0 & 0 & -(R_3-L_3+T_3) \end{bmatrix} \tag{3-21}$$

According to Lyapunov's indirect method, if it is the evolutionary stable strategy (ESS), the corresponding characteristic root of the Jacobian matrix must be less than 0. The following system of equations can be obtained:

$$\begin{cases} (R_1-L_1+T_1)>0 \\ (L_2-R_2)>0 \\ (R_3-L_3+T_3)>0 \end{cases} \tag{3-22}$$

The cost of releasing sufficient information is less than the benefits when government chooses G1. It can be expressed as $(R_1-L_1+T_1)>0$. The benefit of recommending epidemic information is less than the cost when social media chooses SM2. It can be expressed as $(L_2-R_2)>0$. The cost of releasing positive comments is less than the benefits when the general public choose GP1. It can be expressed as $(R_3-L_3+T_3)>0$; otherwise, the general public choose GP2. It can be expressed as $-(R_3-L_3+T_3)>0$. This shows that although the government releases sufficient epidemic information, it may be that the public panic due to the expansion of the epidemic information.

3. The equilibrium point of the evolutionary game is (0, 1, 0), and the corresponding Jacobian matrix is:

$$J=\begin{bmatrix} (R_1-L_1+T_1+C_1) & 0 & 0 \\ 0 & -(R_2-L_2-T_2+C_1) & 0 \\ 0 & 0 & (R_3-L_3+T_3) \end{bmatrix} \tag{3-23}$$

If (0, 1, 0) is the evolutionary stable strategy (ESS), the corresponding characteristic root of the Jacobian matrix must be less than 0. The following equations can be obtained:

$$\begin{cases} (R_1-L_1+T_1+C_1)<0 \\ (R_2-L_2-T_2+C_1)>0 \\ (R_3-L_3+T_3)<0 \end{cases} \tag{3-24}$$

The equilibrium point of the evolutionary game is (0, 1, 1), and the corresponding Jacobian matrix is:

$$J=\begin{bmatrix} (R_1-L_1-T_1-C_1) & 0 & 0 \\ 0 & -(R_2-L_2-T_2+C_1) & 0 \\ 0 & 0 & -(R_3-L_3+T_3) \end{bmatrix} \tag{3-25}$$

If (0, 1, 1) is the evolutionary stable strategy (ESS), the corresponding characteristic root of the Jacobian matrix must be less than 0. The following equations can be obtained:

$$\begin{cases} (R_1-L_1+T_1+C_1)<0 \\ (R_2-L_2-T_2+C_1)>0 \\ (R_3-L_3+T_3)>0 \end{cases} \tag{3-26}$$

The cost of releasing sufficient information is less than the utility when the government chooses G2. It can be expressed as $(R_1-L_1+T_1+C_1)<0$. The utility of recommending epidemic information is greater than the cost when social media chooses SM1. It can be expressed as $(R_2-L_2-T_2+C_1)>0$. The cost of recommending epidemic information is less than the utility when the general public choose GP1. It can be expressed as $(R_3 - L_3 + T_3) > 0$; otherwise, the general public choose GP2. It can be expressed as $-(R_3 - L_3 + T_3) > 0$. The general public have limited judgment in the face of insufficient information. Therefore, the government will lose credit and will fail to control the panic of the general public when they cannot handle the epidemic. At the same time, social media cooperates with advertisers, thus causing a loss of public trust. Therefore, the government and social media base their judgment on current interests. Their strategies may cause adverse effects in a later period; in particular, if the public trust is lost, it may lead to the destruction of social order.

4. The (1, 1, 1) is the evolutionary stable point, and the Jacobian matrix of the above equation is:

$$J=\begin{bmatrix} -(R_1 - L_1 + T_1 + C_1) & 0 & 0 \\ 0 & -(R_2 - L_2) & 0 \\ 0 & 0 & -(R_3 - L_3 + T_3) \end{bmatrix} \tag{3-27}$$

According to the Lyapunov indirect method (Weibull, J.W., (1997). Evolutionary Game Theory. MIT press.), if (1, 1, 1) is the evolutionary stable strategy (ESS), the corresponding characteristic root of the Jacobian matrix must be less than 0. The following system of equations can be obtained:

$$\begin{cases} (R_1 - L_1 + T_1 + C_1) > 0 \\ (R_2 - L_2) > 0 \\ (R_3 - L_3 + T_3) > 0 \end{cases} \tag{3-28}$$

The evolutionary equilibrium point is (1, 1, 0), and the corresponding Jacobian matrix is:

$$J=\begin{bmatrix} -(R_1 - L_1 + T_1 + C_1) & 0 & 0 \\ 0 & -(R_2 - L_2) & 0 \\ 0 & 0 & (R_3 - L_3 + T_3) \end{bmatrix} \tag{3-29}$$

If (1, 1, 0) is the evolutionary stable strategy (ESS), the corresponding characteristic root of the Jacobian matrix must be less than 0. The following system of equations can be obtained:

$$\begin{cases}(R_1 - L_1 + T_1 + C_1) > 0 \\ (R_2 - L_2) > 0 \\ -(R_3 - L_3 + T_3) > 0\end{cases} \tag{3-30}$$

The cost of releasing sufficient information is less than the utility when government chooses G1. It can be expressed as $(R_1 - L_1 + T_1 + C_1) > 0$. The utility of recommending epidemic information is greater than the cost when social media chooses SM1. It can be expressed as $(R_2 - L_2) > 0$. The cost of posting positive comments is less than the benefits when the general public choose GP1. It can be expressed as $(R_3 - L_3 + T_3) > 0$; otherwise, the general public choose GP2. It can be expressed as $-(R_3 - L_3 + T_3) > 0$.

4、Simulation result and analysis

Simulation experiment studies have been performed to evaluate the model developed in this study. This study takes COVID-19 as a case due to its nature of being a pandemic and a grave threat to human life and health (Chen et al., 2020).

Suppose the probability that the government chooses to release sufficient information strategy at time *t* is: $x_t = h(t)$; the probability that social media chooses to recommend epidemic information at time *t* is: $y_t = j(t)$, the probability that the general public choose to post positive comments at time *t* is $p_t = k(t)$. At the time *t+1* of the next period, the probability that the government chooses to release sufficient information is: $x_{t+1} = h(t+1)$, the probability that social media chooses to offer the information platform is: $y_{t+1} = j(t+1)$, and the probability that the general public choose to post positive comments is $p_{t+1} = k(t+1)$:

According to Lagrange's median theorem (Grattan-Guinness, 1990), the following formula are:

$$g(b) - g(a) = g^{'}(\xi)(b-a), \xi \in [a,b] \tag{4-1}$$

$$h(t+1)=\frac{dx}{dt}(t+1-t)+h(t)=f_1(x)+x_t$$
$$=x(1-x)(R_1-L_1+T_1+yC_1)+x_t \tag{4-2}$$

$$j(t+1)=\frac{dy}{dt}(t+1-t)+j(t)=f_2(y)+y_t$$
$$=y(1-y)[R_2-L_2+(1-x)(-T_2+C_1)]+y_t \tag{4-3}$$

$$k(t+1)=\frac{dp}{dt}(t+1-t)+k(t)=f_3(y)+p_t$$
$$=p(1-p)\{R_3-L_3+T_3+(1-x)(1-y)L_3\}+p_t \tag{4-4}$$

Experimental approach: The equilibrium solutions of the tripartite game were analysed and verified by means of numerical simulation, and the influences of the relevant variables were further analysed.

Experimental input: This study conducted a numerical simulation, and initial value of the parameters was set referring to the practical situation as follows.

In the simulation process, the simulation step h = 1 is taken to simulate the evolution process of the strategies of both sides under different conditions. At the beginning of the pandemic, the government will cautiously release pandemic information. For the click-through rate, social media will have a greater probability of recommending pandemic information to the general public. The general public has limited judgment in the face of insufficient information and may post negative comments. Therefore, it is assumed that the initial state of strategy selection is x = 0.5, y = 0.6, p=0.3.

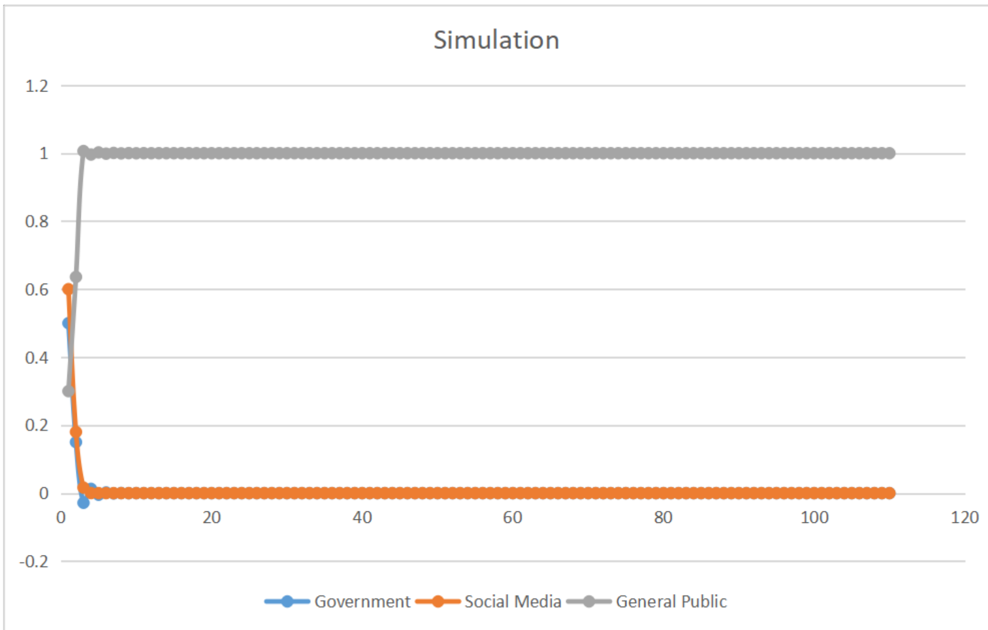
1. Taking (0, 0, 1) as the evolutionary stable point, the parameters satisfy the equation and are listed in Table 3. The results are shown in Figure 3：

Table 3 The value of parameters in (0,0,1)

Parameters	Value	Parameters	Value
R_1	1	T_1	1

R_2	3	T_2	2
R_3	2	T_3	2
C_1	1	x	0.5
L_1	4	y	0.6
L_2	3	p	0.3
L_3	3		

Figure 3 Simulation in (0,0,1)



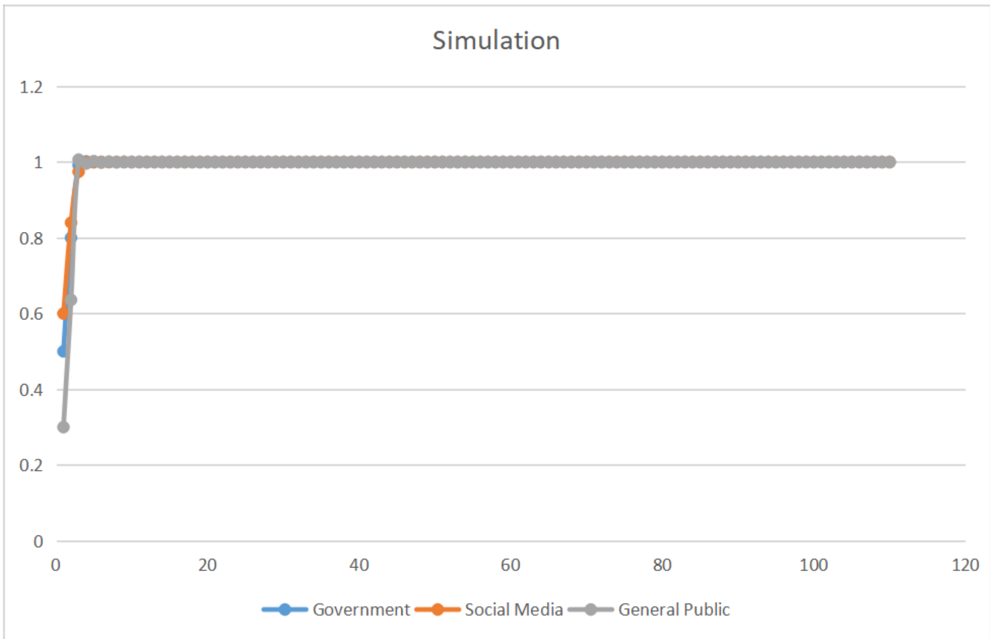
With the increase in the iteration steps of the simulation, the stability points of the game behaviour evolution of the government, social media, and the general public are (0, 0, 1). The stabilization strategy is that the government decides to release insufficient information, social media does not release pandemic information, and the general public choose to post positive comments in an environment of asymmetric information. The public trust and social trust will gradually be lost.

2. Taking (1, 1, 1) as the evolutionary stable point, the parameters satisfy the equation and are listed in Table 1. The results from the numerical simulation are shown in Figure 4.

Table 4 The value of parameters in (1,1,1)

Parameters	Value	Parameters	Value
R_1	3	T_1	1
R_2	3	T_2	2
R_3	2	T_3	2
C_1	2	x	0.5
L_1	4	y	0.6
L_2	2	p	0.3
L_3	3		

Figure 4 Simulation in (1,1,1)



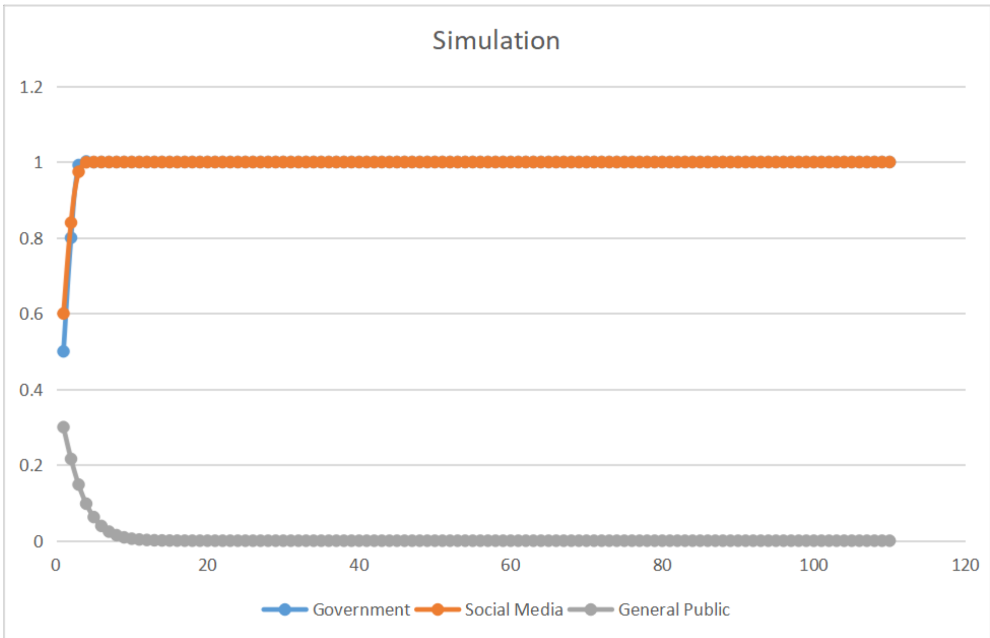
With the increase in the iteration steps of the simulation, the numerical simulation shows that the evolutionary stable point is (1, 1, 1). The strategy is that the government decides to release sufficient information, social media chooses to release pandemic information, and the general public choose to post positive comments. Public opinion actively cooperates with the government in epidemic prevention, and the government can better handle the epidemic and get public trust and social trust.

Taking (1, 1, 0) as the evolutionary stable point, the parameters satisfy the equation and are listed in Table 5. The results of the numerical simulation are shown in Figure 5.

Table 5 The value of parameters in (1,1,0)

Parameters	Value	Parameters	Value
R_1	3	T_1	1
R_2	3	T_2	2
R_3	1	T_3	1
C_1	2	x	0.5
L_1	4	y	0.6
L_2	2	p	0.3
L_3	4		

Figure 5 Simulation in (1,1,0)



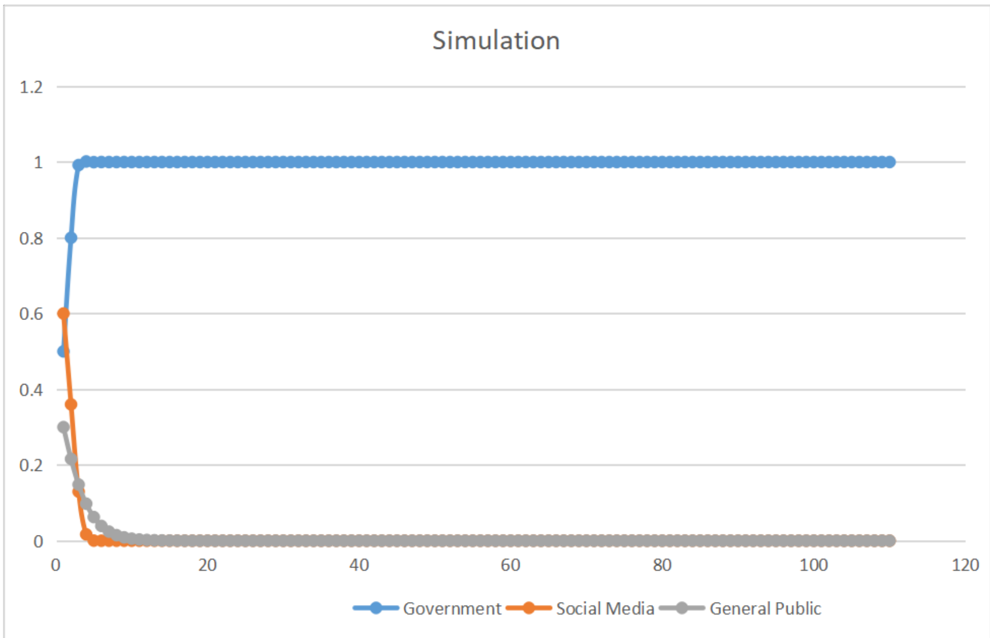
With the increase in the iteration steps of the simulation, the stability points of the game behaviour evolution of the government, social media, and the general public are (1, 1, 0). The stabilization strategy is that government decides to release sufficient information, the strategy of social media is to release pandemic information, and the general public choose to post negative comments. This shows that sometimes, the government releases sufficient information on the pandemic, which can also cause the public to panic.

3. Taking (1, 0, 0) as the evolutionary stable point, the parameters satisfy the equation and are listed in Table 6. The results of the numerical simulation are shown in Figure 6.

Table 6 The value of parameters in (1,0,0)

Parameters	Value	Parameters	Value
R_1	3	T_1	1
R_2	2	T_2	2
R_3	1	T_3	1
C_1	2	x	0.5
L_1	4	y	0.6
L_2	3	p	0.3
L_3	4		

Figure 6 Simulation in (1,0,0)



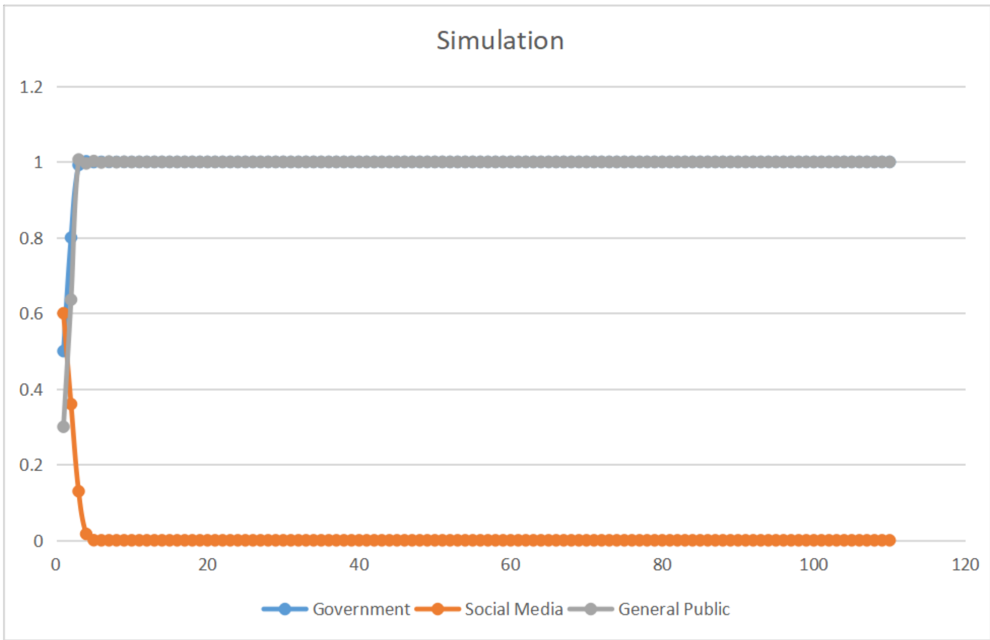
With the increase in the iteration steps of the simulation, the stability points of game behaviour of the government, social media, and the general public are (1, 0, 0). The strategy is that the government decides to release sufficient information, social media releases irrelevant information, and the general public post negative comments. This shows that sometimes, the government releases sufficient information on the pandemic, which can also cause the public to panic.

Taking (1, 0, 1) as the evolutionary stable point, the parameters satisfy the equation and are listed in Table 7. The results of the numerical simulation are shown in Figure 7.

Table 7 The value of parameters in (1,0,1)

Parameters	Value	Parameters	Value
R_1	3	T_1	1
R_2	2	T_2	2
R_3	1	T_3	1
C_1	2	x	0.5
L_1	4	y	0.6
L_2	3	p	0.3
L_3	4		

Figure 7 Simulation in (1,0,1)



With the increase in the iteration steps of the simulation, the stability points of the game model of the government, social media, and the general public are (1, 0, 1). The strategy is that the government decides to release sufficient information, social media releases irrelevant information, and the general public post positive comments. Even if social media releases irrelevant information, the general public can learn about the information released by the government from other channels and so take precautions.

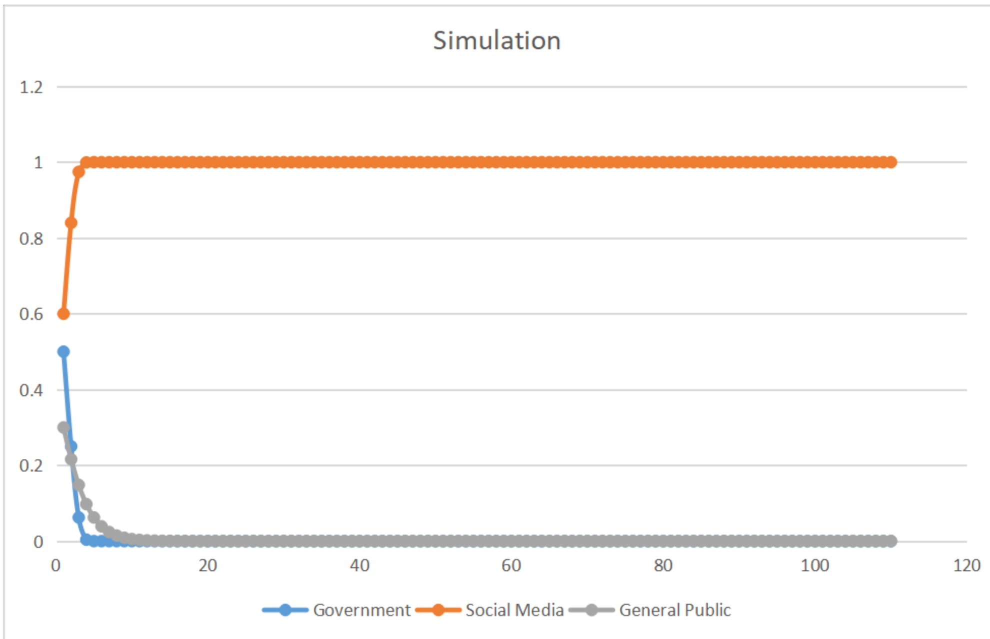
4. Taking (0, 1, 0) as the evolutionary stable point, the parameters satisfy the equation and listed in Table 8. The results of the numerical simulation are shown in Figure 8.

Table 8 The value of parameters in (0,1,0)

Parameters	Value	Parameters	Value
R_1	1	T_1	1
R_2	3	T_2	2
R_3	1	T_3	1
C_1	1	x	0.5
L_1	4	y	0.6
L_2	2	p	0.3

L_3	4		

Figure 8 Simulation in (0,1,0)



With the increase in the iteration steps of simulation, the stability points of game model of the government, social media, and the general public are (0, 1, 0). The strategy is that government decides to release insufficient information, social media chooses the strategy of releasing epidemic information, and the general public post negative comments. The government loses public trust and social trust.

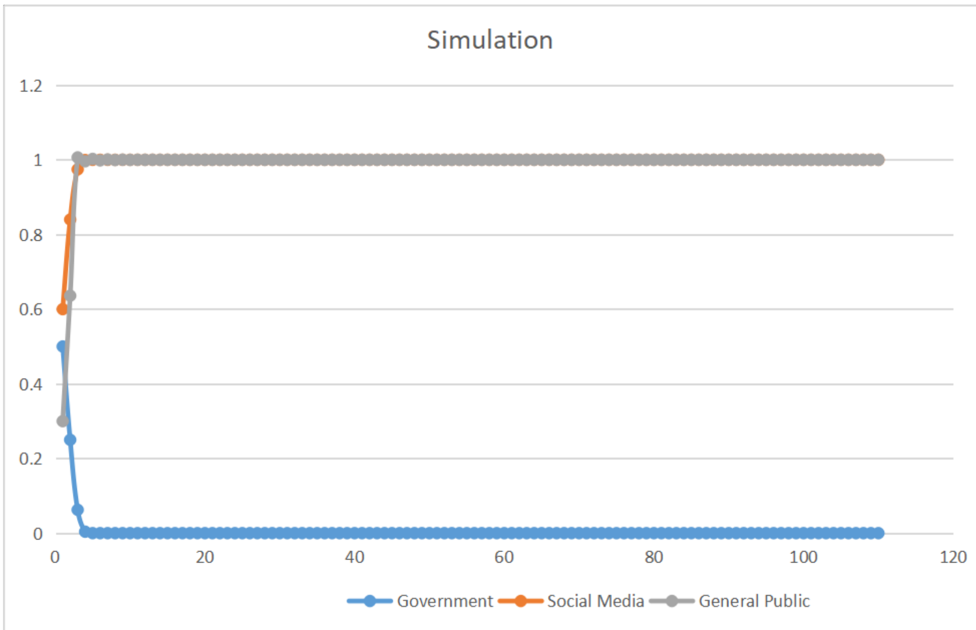
Taking (0, 1, 1) as the evolutionary stable point, the parameters should satisfy the equation and are listed in Table 9. The result of the numerical simulation is shown in Figure 9.

Table 9 The value of parameters in (0,1,1)

Parameters	Value	Parameters	Value
R_1	1	T_1	1
R_2	3	T_2	2
R_3	2	T_3	2

C_1	1	x	0.5
L_1	4	y	0.6
L_2	2	p	0.3
L_3	3		

Figure 9 Simulation in (0,1,1)



With the increase in the iteration steps of the simulation, the stability points of the game model of the government, social media, and the general public are (0, 1, 1). The strategy is that government chooses to release insufficient information, social media adopts the strategy of promoting information diffusion, and the general public post positive comments. The general public get information about the pandemic from social media.

The model focuses on the game evolution process and discusses eight situations. A numerical simulation analysis was carried out. The research shows that the game model of the government, social media, and the general public will not converge to a certain stable strategy in the public's opinion. This is because the government, social media, and the general public have a variety of strategic choices regarding public opinion. Once a random factor changes, it will lead to a change in the strategy of a game player. Because of the mutual influence of the players' behaviours, their strategy decision is continuously adjusted. For different conditions, the stability strategy of the system may converge to seven modes: (1, 1, 1), (1, 0, 1), (1, 1, 0), (0, 1, 1), (0, 0, 1), (0, 1, 0), (1, 0, 0) and the mode (0, 0, 0) is an unstable strategy.

5、Conclusion

This paper uses the tripartite behaviour evolutionary game model to study public opinion in a pandemic. It constructs the strategic payment matrix of the evolutionary game among the government, social media, and the general public, and establishes a replicator dynamic equation. The equilibrium points are obtained, and the stability of the equilibrium point is analysed. The stability of the equilibrium point will be changed when the conditions change. This shows that the game theory method is a robust approach to study public opinion management.

Theoretical implication

We considered the utility of adopting different strategies based on evolving trends in terms of game players' behaviours. The results also highlight the impact of the strategic choice adopted by governments on the evolution of the behaviour of the general public. Traditional theories stress that the government should choose an appropriate strategy according to the degree of its own responsibility for the crisis event, but the general public do not necessarily respond to the actions of the government based on their behaviours.

This model expands the application fields of game theory, especially evolutionary game theory. It is used in public opinion, and the model can finally reach a more stable strategy through simulation: (1,1,1), (1,0,1), (1,1,0), (0,1,1), (0,0,1), (0,1,0), and (1,0,0). For the (1,1,1) strategy, if the government releases sufficient information of the Covid-19 pandemic and social media recommends pandemic information, the general public will be attracted by pandemic information and take timely measures. The general public is most likely to post positive comments on social media. If the government handles the pandemic properly, it will also gain public trust and social trust.

Practical implications

During a pandemic, it is vital that the government release information in a timely manner. In addition, it is necessary to respond appropriately when negative information appears on social media. Based on the result of this study, governments will have a new way to assess different ways to release information during the pandemic and the approach to respond to the public. Therefore, this study would help practitioners to handle information about infectious diseases through social media and achieve the optimal effect.

When social media is operated in the right way, it promotes information diffusion. When the government adopts a negative strategy, social media recommends pandemic information to the general public. The existence of social media would support the government to take effective countermeasures to the pandemic, and the general public will be able to access more infectious diseases information through social media services.

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