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Dynamic Evolution of Safety Regulation of the Ridesharing Industry under Social Media Participation

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Abstract: The emergence of ridesharing has spread against the background of the sharing economy. There have been a lot of controversies since the emergence of ridesharing, particularly regarding regulatory issues. The safety regulation of the ridesharing industry involves many parties, including governments, platform companies, and society at large. Currently, because of the influence of information asymmetry, it increases the uncertainty of governments' regulation effect and the difficulty of making regulation measures. Meanwhile, social media, one of the most important forces of social regulation, has not paid enough attention to playing an appropriate role in the safety regulation of the ridesharing industry. Therefore, this study constructs an evolutionary game model between governments and platform companies that concerns the safety regulations of ridesharing passengers under social media participation. The influence path of social media is explored by model solution and numerical simulation. Our results indicate that social media participation has a positive impact on this safety regulation. Specifically, social media participation could reduce governments' regulatory costs and encourage it to strictly regulate. The exposure of social media could bring losses to platform companies involved and promote platform companies' investments in improving passengers' safety. This study provides a decision basis for governments to introduce social media in the safety regulation of the ridesharing industry.

Keywords: ridesharing; safety regulation; social media; evolutionary game

1. Introduction

Ridesharing is a new way of travel within the bounds of the sharing economy. It is a beneficial supplement to urban public transportation in China. Through ridesharing, multiple passengers can take a single vehicle to the same destination [1]. Ridesharing is intended to provide individuals with increased convenience and reduced costs of car usage. Lyft, UberX, Didi, and other ridesharing platform companies (henceforth, platform companies) use their apps to quickly connect passengers and drivers. Passengers pay for rides online and platform companies charge a proportional service fee from the price [2]. Ridesharing provides a larger number of benefits, such as reducing travel cost and increasing social benefits [3,4]. However, the policymakers in many countries have adopted only loose regulations for platform companies, which may result in some problems [5].

With the rapid development of the ridesharing market, platform companies generally gain more market shares by lowering service prices [6]. Then, most platform companies do not pay enough attention to safety [7]. Drivers and passengers are randomly matched through ridesharing apps [8].

The driving history or criminal background of ridesharing drivers is not always carefully checked by platform companies [9,10]. In this context, there are many potential safety risks for ridesharing passengers [11,12]. For example, from 2014 to 2018, approximately 100 Uber drivers in the United States were charged with sexual assault or abuse. In the same period, there were at least 50 cases in China where ridesharing drivers had sexually assaulted or harassed passengers. It caused community concern about the safety of ridesharing passengers. These reveal that there are serious problems in the safety regulations surrounding ridesharing [13].

There is a debate in academic fields about how the safety of ridesharing should be regulated. Some scholars have pointed out that the strict regulation by government regulatory authorities (hereinafter collectively referred to as governments) is to protect the interests of traditional industries and inhibit the development of the sharing economy [14,15]. However, more scholars believe that the intention of strict regulation would encourage innovation while ensuring public safety [13]. These scholars are also considered that the regulation should focus on passengers' safety rather than force platform companies to comply with obsolete regulations [16]. Relying on the self-discipline of platform companies cannot guarantee that they put in sufficient security funds. This point has been amply demonstrated by the cases of ridesharing passengers who were killed by drivers in China. Therefore, it is necessary to formulate strict regulation in order to protect ridesharing passengers. Nevertheless, few platform companies voluntarily submit the complete data of ridesharing to governments, which leads to the regulatory information asymmetry of governments in regulations [17]. Due to the asymmetry of information, governments must pay higher costs to regulate the ridesharing industry to achieve the expected results [18]. Faced with these issues, scholars suggest that governments should utilize social regulation forces to regulate the ridesharing industry [19,20].

Social media is the general term for some internet media, such as Facebook, Twitter, and Weibo [21]. As a regulation force, social media could provide governments with efficient information channels, which reduce the regulatory costs and decrease the information asymmetry [22,23]. However, governments generally lack scientific cognition about the role of social media in regulatory process [24]. Moreover, social media focuses public attention on events which may bring a negative impact to governments' credibility, which makes governments cautious about it [25]. The exposures of social media on safety issues would also bring economic and reputational losses to companies involved, which could prompt them to adopt a positive strategy in terms of safety [26–28]. Nevertheless, social media participation in regulation has its shortcomings. It is necessary to develop specific interventions to achieve a better regulatory effect [29,30].

Certain cases demonstrated that social media participation had a positive impact on ridesharing passengers' safety regulation. In May 2018, a flight attendant was murdered by a ridesharing driver in Zhengzhou, China. Social media, including some influential accounts like Sina Microblog, exposed this case timely and extensively. Due to public opinion on social media, governments quickly implemented strict supervision of the platform company (Didi) and ordered it to carry out safety rectification. Meanwhile, the exposure of social media caused users to question the safety of ridesharing and carefully choose their travel mode [31,32]. It resulted in the revenue of Didi decreasing sharply. In response to the government's strict regulation and in order to recover the user's trust, Didi quickly announced that it would invest enough money to rectify the safety issues. Subsequently, the safety of ridesharing passengers was improved.

There were many studies about the safety regulation of ridesharing industry [16]. However, most of them were researched from a qualitative or technical perspective [9,14]. Few studies considered the confrontation and dependence in subjects, as well as the impact of social media participation in safety regulation process. It has been recognized in other studies of safety regulation. On the basis of evolutionary game theory (EGT), most of these studies analyzed relationships and strategies between regulatory subjects. The EGT model was established to represent the multi-party dynamic game process of safety regulation. The study results indicated that active involvement from social media had a positive impact on regulatory effectiveness [33,34]. Therefore, some scholars have suggested

that social media could function as a supplemental regulatory force in the safety regulation of food or environment [35]. These studies provide new insights for solving the ridesharing industry's problem of safety regulation.

In the traditional Bayesian game, all players are required to be completely rational and perfectly analytical [36]. For players to be completely rational, the information must be symmetric. However, information asymmetry is common in reality, which limits the application of traditional games. EGT originated from biological evolutionary theory [37]. EGT's fundamental concept is that, during repeated games, the bounded rational players can analyze the game result of each round and adjust the strategy through their learning ability in order to maximize payoff [38]. The dynamic system may gradually evolve to the evolutionary stability strategy (ESS) with certain conditions. It could be clearly understood why and how the game system reaches a steady state by analyzing the dynamic evolution process [39]. Therefore, EGT could solve the above limitation of traditional game theory, such as the information asymmetry issue, which is more in line with actual game scenarios [40]. EGT has been adopted by some studies to research the safety regulation of coal mines [41,42], food [43,44], aviation [45], internet [46,47], construction industry [48,49], environment [50–52] and supply chain [53]. In addition, some scholars have introduced EGT into the field of ridesharing research, such as the discussion on a dynamic game between platform companies and passengers [54,55].

The above studies provide useful references and theoretical support for this study. Relevant research has already proposed that the regulatory process of ride-hailing is essentially an evolutionary game between governments and platform companies [5]. By analogy, the ridesharing passenger safety regulation process could be abstracted and simplified into the behavioral interaction and dynamic game evolution process between governments and platform companies. Therefore, it can be studied on the basis of EGT. From previous analysis, the involvement of social media could solve the government's regulatory problem to some extent, such as the high cost and information asymmetry, which may have a positive impact on the safety regulation of ridesharing passengers. This study introduces two variables of social media to the regulatory game on the basis of the EGT model, which describes the participation of social media. The influence of social media on this safety regulation dynamic game is quantitatively analyzed. The research results could provide new insights into assisting governments in achieving effective long-term regulation and further ensuring the safety of ridesharing passengers.

The rest of the study is organized as follows: First, the evolutionary game model is constructed and solved by the replication dynamic. Next, evolutionary states of this game system are analyzed during different social media participation situations. Then, the influence of social media participation in ridesharing passengers' safety regulation game is analyzed. The analysis is verified by simulation experiment and the system's good states are further discussed. The conclusions, suggestions, and future research directions are presented in the last section.

2. Evolutionary Game Model under Social Media Participation

2.1. Model Description

Social media has proven to be an indirect way to solve safety regulatory problems via reporting safety risks or cases [35,56]. When it actively participates in regulation, it could be regarded as an efficient channel of information for governments [57]. Particularly, this study uses the participation degree (PD) to express the probability of social media participating in the regulatory process. Its exposure to security risks will harm the reputations of companies and cause a loss for them [58]. This study also uses impact power (IP) to indicate the extent and coverage of security issues reported in social media. In general, if the IP is greater, the companies will suffer larger losses [35].

This study does not consider social media as an independent game player. Instead, it is introduced into the game as a parameter. Given the participation of social media, the game relationships between governments and platform companies is shown in Figure 1.

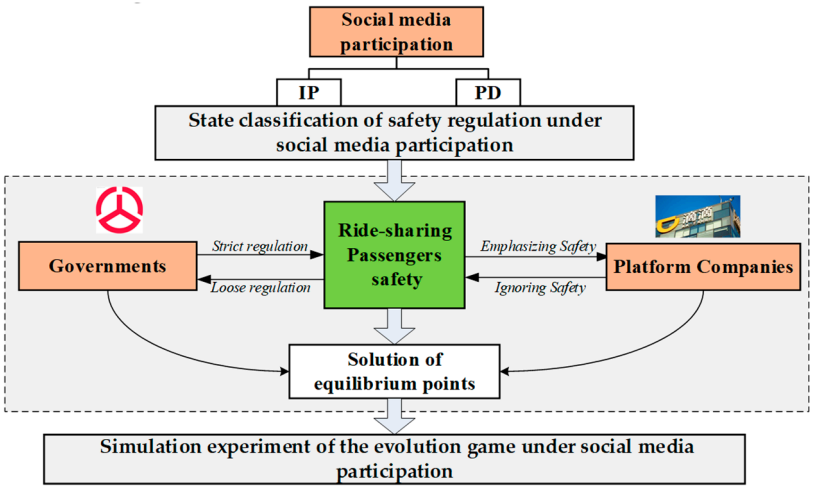


Figure 1. The game relationship considering the participation of social media.

2.2. Model Construction

2.2.1. Game Strategy

The current safety regulation of ridesharing passengers primarily involves two subjects: governments and platform companies. Governments are the regulators and platform companies are the subjects of regulations.

To ensure public safety and avoid the loss of social welfare, governments could adopt strict regulation (SR) strategies to check whether platform companies invest sufficiently in terms of passenger safety. Under the government's SR strategy, the safety hazards of passengers in ridesharing will be discovered. Through administrative power, governments can impose penalties such as fines and rectification on problematic platform companies. The cost of governments is usually high, while the efficiency is relatively low. Governments could also adopt loose regulation (LR) strategy. Under the LR strategy, governments only regulate platform companies after the occurrence of ridesharing passenger safety incidents. At the beginning of this game, the ratio of governments adopting SR strategy is x, and the proportion of adopting LR strategy is $(1-x)$, $x \in (0,1)$.

Confronted with government's regulation, platform companies could adopt a strategy that emphasizes security investment (ESI) or a strategy which ignores security investment (ISI). Under ESI strategy, platform companies invest sufficiently security funds to take positive actions, (e.g., reviewing driver's criminal records and installing security devices) to enhance passenger safety. However, in order to improve profit or competitiveness, platform companies are likely to adopt the ISI strategy, which saves on security funds. Similarly, the initial ratio of platform companies adopting the ESI strategy at the beginning of the game is y, and the proportion of adopting ISI strategy is $(1-y)$, $y \in (0,1)$.

Governments and platform companies have long been in a game, due to the conflict of pursuit goals in China. They always constantly adjust strategic choices to maximize their own interests according to the other subject's strategy. In this study, the evolutionary game is used to research the dynamic evolution of ridesharing passengers' travel safety.

2.2.2. Payoff Matrix of Governments and Platform Companies

The payoff matrix of governments and platform companies concerning the safety regulation of ridesharing passengers is constructed, as shown in Table 1.

Table 1. The payoff matrix of governments and platform companies.

	SR	**LR**
ESI	$(R-\Delta C,\ H-C+M)$	$(R-\Delta C,\ M)$
ISI	$(R-F,\ H-C-N)$	$(R-\gamma F,\ -\gamma L-N)$

The corresponding notations of the payoff matrix mentioned above are shown in Table 2.

Table 2. Notations and corresponding descriptions.

Notations	**Descriptions**
α	The IP of social media, where $\alpha \in [0,1]$. It represents the influence and extent of social media on safety hazard or incident reports of ridesharing passengers. $\alpha = 0$ represents the weakest level of IP, and $\alpha = 1$ represents the strongest level of IP.
β	The PD of Social media, where $\beta \in [0,1]$. It indicates the probability of social media participation in safety regulation of ridesharing passengers. $\beta = 0$ represents the lowest level of PD, and $\beta = 1$ represents the highest level of PD.
γ	In the case of government deregulation, as a social regulatory force, social media could find and expose ridesharing passenger safety issues in safety regulation with γ probability, where $\gamma \in [0,1]$.
R	The revenues of platform companies from ridesharing business. R is greater than the security input cost, $R > \Delta C$.
ΔC	The security cost of platform companies (including driving experience reviews, background checks, itinerary monitoring, and emergency management costs).
F	The losses suffered by platform companies after being regulated by governments or being exposed by social media (including the economic and reputational loss), where $F = \alpha R$.
H	The revenues of governments from SR strategy (including the rewards from higher levels of governments and the improvement of social credibility). In this case, it is assuming that H is equal to L.
L	The potential losses faced by governments adopting LR strategy after ridesharing passengers' security issues were exposed by social media.
C	The costs of governments to choose SR strategy, where $C(\beta,k) = C_0 + \frac{(1-\beta)}{k}$. The marginal regulatory cost is marked as $\frac{(1-\beta)}{k}$.
C_0	The fixed regulatory costs of governments' strict regulation. C_0 is less than or equal to C.
k	The regulatory capacity of governments, where $k \in [0,1]$. $k = 0$ represent the lowest level of government regulation, and $k = 1$ represent the highest level of government regulation.
M	The social welfare benefits. When platform companies choose ESI strategy, the social welfare benefits are obtained by governments.
N	The social welfare losses. When platform companies choose ISI strategy, the social welfare losses are paid by governments.

This is the further explanation of formula $(\beta,k) = C_0 + \frac{(1-\beta)}{k}$: Through the investigation of some local governments in China, such as Xi'an and Yan'an, it determined that regulatory cost mainly includes two parts: fixed cost and marginal cost. As the main purpose of our study is not to explore the specific impact of social media on regulatory costs, we simplified the cost function. As long as the governments regulate strictly, there will be a fixed regulatory cost (C_0), which could be regarded as a constant. The marginal costs are related to β and k. It is known from the analysis in the previous section that social media participation (β) could reduce the regulatory costs. Our investigation result shows that local governments with a higher level of regulation (k) have lower marginal costs. Therefore, according to the actual situation and research requirements, this paper sets the cost function of government's regulation as $C(\beta,k) = C_0 + \frac{(1-\beta)}{k}$.

In general, there are four combinations of strategies in the game between governments and platform companies: (SR, ESI), (SR, ISI), (LR, ESI), and (LR, ISI).

2.2.3. The Solution of Equilibrium Points

According to EGT, replication dynamic means that if the payoff of one behavior is higher than the average payoff of the population, this behavior will develop [59]. That is, the growth rate of the

proportion of individuals who choose this behavior in the population is greater than zero. It can be expressed by the following differential equation.

$$\frac{d_{x_h}}{d_t} = x_e[u(e,s) - u(s,s)], e = 1, 2, \cdots, E, \tag{1}$$

where s is the set of the population and e is an act in s. In this paper, "act" represents the strategic behavior of governments and platform companies in the safety regulation game mentioned in the previous section. Furthermore, x_e is the proportion of population which chooses behavior e. $u(e,s)$ is the payoff of the population which chooses behavior e. $u(s,s)$ is the average payoff of the population. E is the total number of different acts.

The rate of change in the proportion of a trait, dx/dt, is proportionate to the variance of governments in the population (x). It is also proportionate to the difference of payoffs $\left(\cup_G^1 - \overline{U}_G\right)$. Where $\cup_G^1$ represents the governments' payoff of SR strategy. $\overline{U}_G$ represents the average payoffs of governments. Similarly, the rate of change in the proportion of a trait, dy/dt, is proportionate to the variance of platform companies in the population (y). It is also proportionate to the difference of payoffs $\left(\cup_C^1 - \overline{U}_C\right)$. Where $\cup_c^1$ represents the platform companies' payoff of ESI strategy. $\overline{U}_C$ represents the average payoffs of platform companies.

Referring to the Malthusian Dynamic [60], the dynamic replication equations of governments and platform companies are expressed as follows:

$$\frac{dx}{dt} = x\left(\cup_G^1 - \overline{U}_G\right) = x(1-x)(H - C_0 - (1-\beta)/k + \gamma L - y\gamma L) \tag{2}$$

$$\frac{dy}{dt} = y\left(\cup_C^1 - \overline{U}_C\right) = y(1-y)(-\Delta C + \gamma\alpha R + x\alpha R(1-\gamma)) \tag{3}$$

Let $\frac{dx}{dt} = 0$ and $\frac{dy}{dt} = 0$, the above dynamic replication equation can then be solved. There are five equilibrium points of the game. They are $E_1(0,0)$, $E_2(1,0)$, $E_3(0,1)$, $E_4(1,1)$, $E_5(x^*, y^*)$, where $x^* = \frac{\Delta C - \gamma F}{F(1-\gamma)}$ and $y^* = \frac{H - C + \gamma L}{\gamma L}$.

3. State Classification of Regulation under Social Media Participation

3.1. Evolution State

The equilibrium points obtained by the dynamic replication equation may not be the ESS. Some points may be saddle points or unstable points. Scholars generally use the Jacobian matrix to make further analysis and there are many mature applications [61]. In this paper, the same method is used and the following Jacobian matrix (J) is obtained.

$$J = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} \frac{\partial G(x)}{\partial x} & \frac{\partial G(x)}{\partial y} \\ \frac{\partial G(y)}{\partial x} & \frac{\partial G(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} (1-2x)(H-C+\gamma L-y\gamma L) & -x(1-x)\gamma L \\ y(1-y)(1-\gamma)F & (1-2y)(xF(1-\gamma)-\Delta C+\gamma F) \end{bmatrix} \tag{4}$$

If J satisfies the conditions of $\det(J) > 0$ and $\mathrm{tr}(J) < 0$, the equilibrium point is the ESS of the system. The $\det(J)$ is the determinant of the Jacobian matrix and $\mathrm{tr}(J)$ is the trace of Jacobian matrix. The $\det(J)$ and $\mathrm{tr}(J)$ expressions of five equilibrium points (0,0), (0,1), (1,0), (1,1), (x^*, y^*) can be obtained in Table 3.

Table 3. The det(J) and tr(J) expressions of equilibrium points.

Equilibrium Points	det(J)	tr(J)
(0,0)	$(H-C+\gamma L)(\gamma F-\Delta C)$	$(H-C+\gamma L)+(\gamma F-\Delta C)$
(1,0)	$(H-C+\gamma L)(\Delta C-F)$	$-(H-C+\gamma L)+(F-\Delta C)$
(0,1)	$(H-C)(\Delta C-\gamma F)$	$(H-C)-(\gamma F-\Delta C)$
(1,1)	$(H-C)(F-\Delta C)$	$-(H-C)-(F-\Delta C)$
(x^*, y^*)	−AB [1]	0

[1] $A=\left(1-\frac{\Delta C-\gamma F}{F(1-\gamma)}\right)\left(1-\frac{H-C+\gamma L}{\gamma L}\right)$ and $B=\frac{\Delta C-\gamma F}{1-\gamma}(H-C+\gamma L)$.

According to the expression of det(J) and tr(J) in Table 3, and in combination with the two judgment conditions $\det(J)>0$, $\mathrm{tr}(J)<0$ mentioned above, whether the five equilibrium points are the ESS of the system can be analyzed.

(1) The conditions for equilibrium point (0,0) to be the ESS:

$det(J)=(H-C+\gamma L)(\gamma F-\Delta C)>0$ and $tr(J)=(H-C+\gamma L)+(\gamma F-\Delta C)<0$.

If the two determinative conditions above are satisfied at the same time, $(H+\gamma L)<C$ and $\gamma F<\Delta C$ are required.

The regulatory costs of governments are more than the sum of revenues from the SR strategy and expected loss from the LR strategy. Meanwhile, the security costs of platform companies are higher than the expected losses from the ISI strategy when it is only regulated by social media.

(2) The conditions for equilibrium point (1,0) to be the ESS:

$det(J)=(H-C+\gamma L)(\Delta C-F)>0$ and $tr(J)=-(H-C+\gamma L)+(F-\Delta C)<0$.

Similar to analysis in (1), $(H+\gamma L)>C$ and $F<\Delta C$ are required.

The regulatory costs of governments are less than the sum of revenues from SR strategy and expected loss from LR strategy. And the security costs of platform companies are higher than the expected loss from ISI strategy when it is regulated strictly by governments.

(3) The conditions for equilibrium point (0,1) to be the ESS:

$det(J)=(H-C)(\Delta C-\gamma F)>0$ and $tr(J)=(H-C)-(\gamma F-\Delta C)<0$.

At this time, $H<C$ and $\Delta C<\gamma F$ are required.

The revenues of governments from the SR strategy are less than regulatory costs. The security costs of platform companies are also less than the expected losses from the ISI strategy when it is only regulated by social media.

(4) The conditions for equilibrium point (1,1) to be the ESS:

$det(J)=(H-C)(F-\Delta C)>0$ and $tr(J)=-(H-C)-(F-\Delta C)<0$.

$C<H$ and $\Delta C<F$ are required.

The revenues of governments from the SR strategy are more than the regulatory costs. The security costs of platform companies are less than the expected losses from the ISI strategy when it is regulated strictly by governments.

(5) The conditions for equilibrium point (x^*, y^*) to be the ESS:

As above, the conditions of equilibrium point (x^*, y^*) to be the ESS are $\det(J)>0$ and $\mathrm{tr}(J)<0$. However, the calculation results in Table 3 show that $\mathrm{tr}(J)=0$ at this equilibrium. Apparently, the condition of $\mathrm{tr}(J)<0$ is not satisfied. Therefore, this equilibrium point is not the ESS of the system.

From the above conditions derived in (1)–(5), it can be concluded that there are only four kinds of ESS in the system: $E_1(0,0)$, $E_2(1,0)$, $E_3(0,1)$, and $E_4(1,1)$. The $E_5(x^*,y^*)$ is not the ESS of the game system. This demonstrates that there are five states of the system. In other words, if the conditions in (1)–(4) are not met, the system is in a peculiar state, in which the interior equilibrium only appears as a center spiral node.

According to the required conditions in (1)–(4), it can be deduced that the system is in a peculiar state, where $H-C<0$, $H+\gamma L-C>0$, $\gamma F-\Delta C<0$ and $F-\Delta C>0$. Under this peculiar state, the regulatory costs of governments are greater than the revenues from the SR strategy, which is less than the sum of expected losses from the LR strategy and revenues from the SR strategy. Meanwhile, the

security costs of platform companies are greater than the expected losses from the ISI strategy when it is only regulated by social media, which are less than the expected loss when it is regulated strictly by governments. The game system could not reach any ESS in this peculiar state.

3.2. States Classification according to IP and PD

The safety regulation of ridesharing passengers after the intervention of social media presents five states. The four states, according to different attractors including (0,0), (1,0), (0,1), (1,1), could be named as State 1, State 2, State 3, and State 4, respectively. In State 1, governments are deregulated and platform companies ignore security investment. In State 2, governments strictly regulate, but platform companies still ignore security investment. Both of the two states are poor regulatory results, and there are great hidden dangers for ridesharing passengers. In State 3, governments are deregulated, but platform companies emphasize security investment. In State 4, governments strictly regulate and platform companies also emphasize security investment. In these two states, the effect of regulation is better, and the travel safety of ridesharing passengers is guaranteed. The peculiar state is named State 5.

This study selects IP and PD to characterize the impact of social media participation on the safety regulation of ridesharing passengers. The range of values corresponding to IP and PD in States 1–5 is calculated as follows.

State 1: Because of $(H - C + \gamma L) = H - \left(C_0 + \frac{(1-\beta)}{k}\right) + \gamma L < 0$ and $\gamma F - \Delta C = \gamma \alpha R - \Delta C < 0$, it could get that $0 < \alpha < \frac{\Delta C}{R\gamma}$ and $0 < \beta < 1 - k(H - C_0 + \gamma L)$.

Similar to the calculation process of State 1, results can be shown as follows.

State 2: $0 < \alpha < \frac{\Delta C}{\gamma}$, $1 - k(H - C_0 + \gamma L) < \beta < 1$.

State 3: $\frac{\Delta C}{R\gamma} < \alpha < 1$, $0 < \beta < 1 - k(H - C_0)$.

State 4: $\frac{\Delta C}{R} < \alpha < 1$, $1 - k(H - C_0) < \beta < 1$.

State 5: $\frac{\Delta C}{R} < \alpha < \frac{\Delta C}{R\gamma}$, $1 - k(H - C_0 + \gamma L) < \beta < 1 - k(H - C_0)$.

By observing the above results, it is interesting that the system's evolutionary state is closely related to the value range of α and β. In other words, the evolution state is related to the participation situation of social media in regulation.

To precisely analyze the impact of social media participation on the evolutionary process between governments and platform companies, this study divides IP and PD into high, medium, and low levels, respectively.

According to the upper and lower limits of the value range concerning α and β corresponding to above the five states, we set $\alpha_0 = \frac{\Delta C}{R}$, $\alpha_1 = \frac{\Delta C}{R\gamma}$, $\beta_0 = 1 - k(H - C_0 + \gamma L)$, $\beta_1 = 1 - k(H - C_0)$. The levels classification of IP and PD are shown in Table 4.

Table 4. The definition of different levels of impact power (IP) and participation degree (PD).

Social Media Metrics	Range of Corresponding Parameters	Levels
IP	$0 < \alpha < \alpha_0$	Low
	$\alpha_0 < \alpha < \alpha_1$	Medium
	$\alpha_1 < \alpha < 1$	High
PD	$0 < \beta < \beta_0$	Low
	$\beta_0 < \beta < \beta_1$	Medium
	$\beta_1 < \beta < 1$	High

This study constructs a two-dimensional space coordinate system to research the states of evolution in different combinations between different levels of IP and PD. Specifically, it is divided into nine evolution scenarios, as shown in Figure 2.

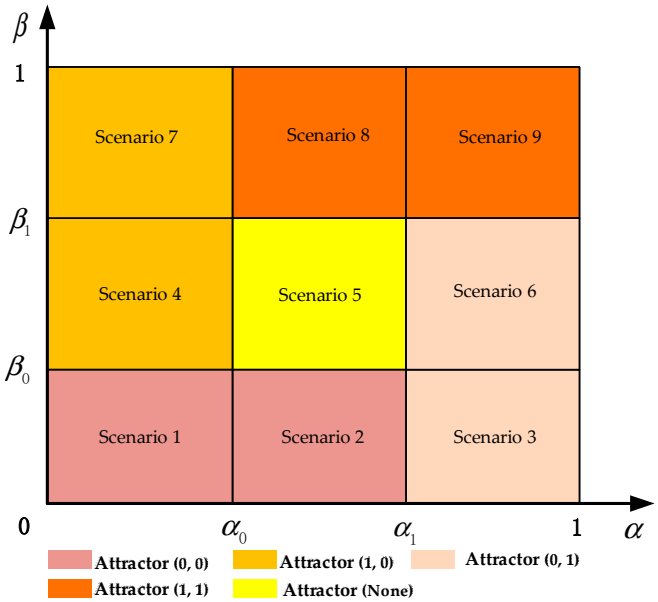


Figure 2. Scenarios division according to the levels of impact power (IP) and participation degree (PD).

The stability analysis of nine scenarios are shown in Table 5.

Table 5. Stability analysis of each scenario.

Attractors	Scenario 1			Scenario 2			Scenario 3		
	detJ	trJ	Results	detJ	trJ	Results	detJ	trJ	Results
(0,0)	+	-	Stable	+	-	Stable	-	Uncertain	Saddle
(1,0)	-	Uncertain	Saddle	-	+	Unstable	+	+	Unstable
(0,1)	-	Uncertain	Saddle	+	Uncertain	Saddle	+	-	Stable
(1,1)	+	+	Unstable	-	Uncertain	Saddle	-	Uncertain	Saddle
Attractors	**Scenario 4**			**Scenario 5**			**Scenario 6**		
	detJ	trJ	Results	detJ	trJ	Results	detJ	trJ	Results
(0,0)	-	Uncertain	Saddle	-	Uncertain	Saddle	+	+	Unstable
(1,0)	+	-	Stable	-	Uncertain	Saddle	-	Uncertain	Saddle
(0,1)	-	Uncertain	Saddle	-	Uncertain	Saddle	+	-	Stable
(1,1)	+	+	Unstable	-	Uncertain	Saddle	-	Uncertain	Saddle
Attractors	**Scenario 7**			**Scenario 8**			**Scenario 9**		
	detJ	trJ	Results	detJ	trJ	Results	detJ	trJ	Results
(0,0)	-	Uncertain	Saddle	-	Uncertain	Saddle	+	+	Unstable
(1,0)	+	-	Stable	-	Uncertain	Saddle	-	Uncertain	Saddle
(0,1)	+	+	Unstable	+	+	Unstable	-	Uncertain	Saddle
(1,1)	-	Uncertain	Saddle	+	-	Stable	+	-	Stable

4. The Influence Analysis for Safety Regulation

According to the above definition concerning different levels of IP and PD, the social media participation situation in each scenario is shown in Table 6.

Table 6. The scenarios corresponding levels of impact power (IP) and participation degree (PD).

Scenarios	Social Media		Attractors
	IP	PD	
Scenario 1	Low		(0,0)
Scenario 2	Medium	Low	(0,0)
Scenario 3	High		(0,1)
Scenario 4	Low		(1,0)
Scenario 5	Medium	Medium	None
Scenario 6	High		(0,1)
Scenario 7	Low		(1,0)
Scenario 8	Medium	High	(1,1)
Scenario 9	High		(1,1)

4.1. Evolution State Influence Analysis at Different Scenarios

(1) Influence analysis at low PD levels (Scenario 1, Scenario 2, Scenario 3).

In Scenarios 1–3, the PD is at a low level. Therefore, whatever strategy platform companies choose, governments do not adopt the SR strategy because of the excessive regulatory cost.

In Scenario 1, due to the low level of IP, platform companies' losses from the ISI strategy are less than the security cost. Therefore, platform companies must choose the ISI strategy. The IP reaches a medium level in Scenario 2. At this time, the security costs saved are less than the losses under the strict regulation of governments. However, all platform companies adopt the ISI strategy driven by interests without the strict regulation of governments. In Scenario 3, due to the losses from the ISI strategy are already higher than the savings of security costs with high-level IP, all platform companies choose the ESI strategy. The evolution phase diagram of these scenarios is shown in Figure 3.

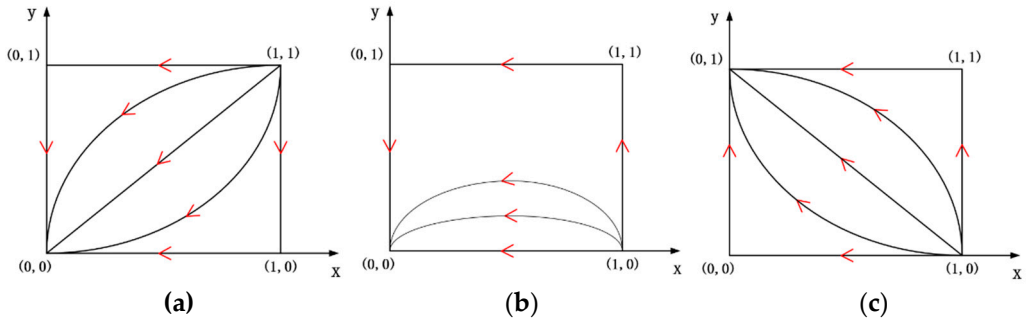


Figure 3. Evolution phase diagram of the scenarios:(**a**) Scenario 1; (**b**) Scenario 2; (**c**) Scenario 3.

In the absence of governments regulation, the platform company's choice just depends on the level of IP. Both Scenario 1 and 2 are negative states, in which no platform company chooses the ESI strategy. It does not reflect the positive impact of social media on regulation. By comparing the scenarios above, the social media play an active role in this regulation when the IP reaches a high level.

(2) Influence analysis at low IP levels (Scenario 1, Scenario 4, Scenario 7).

In these three scenarios, due to the low level of IP, the losses of platform companies from ISI strategy are less than the security investments. No matter what strategy governments choose, the best choice for platform companies is ISI strategy.

The analysis of Scenario 1 refers to the previous paragraph. In Scenario 4, the medium level PD slightly reduces the government's regulatory cost. The governments choose the SR strategy in response. The same result appears in Scenario 7, because of a higher level of PD. The evolution phase diagram of these scenarios is shown in Figure 4.

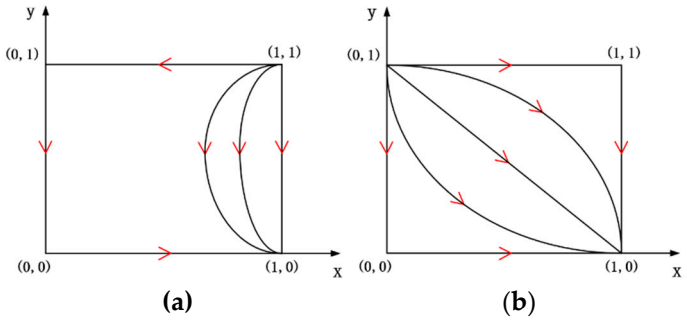


Figure 4. Evolution phase diagram of the scenarios: (**a**) Scenario 4; (**b**) Scenario 7.

In these scenarios, the involvement of social media promotes governments to choose the SR strategy as PD increases gradually. It reflects the positive impact of social media on regulation. However, the low level of IP fails to constrain platform companies from the ISI strategy.

(3) Influence analysis at a medium level of IP and PD (Scenario 5).

In this scenario, both governments and platform companies could adjust their strategy on the basis of opponent strategies to get more payoffs. There is no ESS of the game system. The evolution phase diagram of Scenario 5 is shown in Figure 5.

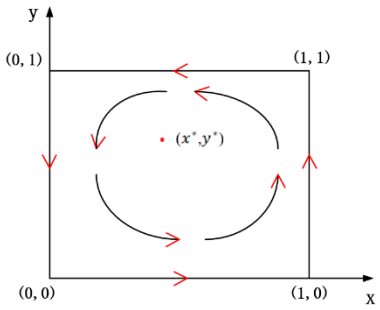


Figure 5. Evolution phase diagram of Scenario 5.

In this scenario, the system cannot evolve to any stable state, and the travel safety of ridesharing passengers cannot be guaranteed in the long run.

(4) Influence analysis at medium level of PD and high level of IP (Scenario 6).

To some extent, the regulatory costs of governments have been reduced, but it is still greater than the payoffs from the SR strategy. As the same analysis of Scenario 3, governments would keep the LR strategy. The system evolves from State 5 to State 3, due to the high level of IP. At this point, the ridesharing passengers' travel safety situation has been improved and reached a good state.

The evolution phase diagram of Scenario 6 is shown in Figure 6.

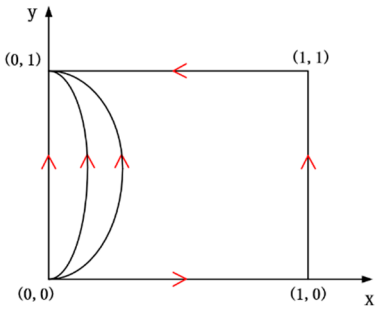


Figure 6. Evolution phase diagram of Scenario 6.

(5) Influence analysis at medium level of IP and high level of PD (Scenario 8).

The security investments are less than the losses from the ISI strategy in Scenario 8. Therefore, platform companies would rather choose the ESI strategy than the ISI strategy. According to the analysis of Scenario 7, governments would keep the SR strategy. The evolution phase diagram of Scenario 8 is shown in Figure 7. The system evolves from State 5 to State 4. The safety of ridesharing passengers is better protected.

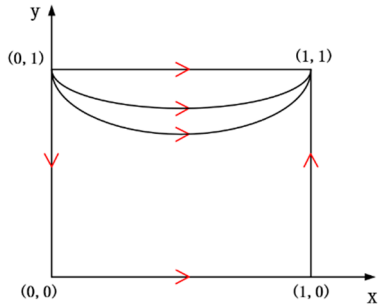


Figure 7. Evolution phase diagram of Scenario 8.

(6) Influence analysis at high level of IP and PD (Scenario 9).

Compared to Scenario 8, the IP achieves a high level. Referring to the analysis of Scenario 3, platform companies inevitably choose the ESI strategy. With a high level of PD, governments could adopt the SR strategy at a lower cost. The evolution phase diagram of Scenario 9 is shown in Figure 8. It is consistent with Scenario 8, the ESS of the system is (1,1). The safety of ridesharing passengers' safety is well protected.

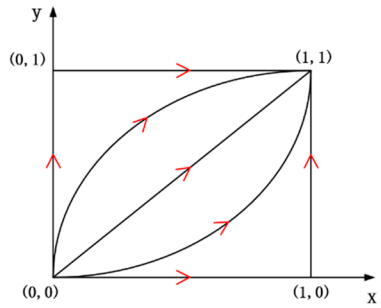


Figure 8. Evolution phase diagram of Scenario 9.

4.2. Simulation Experiment

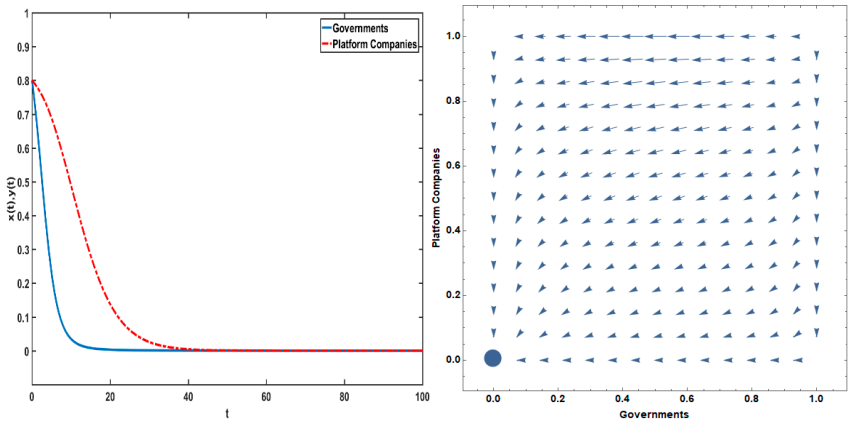
In this section, we use Mathematica and Matlab to carry out numerical experiments of different scenarios to verify the previous analysis. It offers a clearer and more comprehensive reflection of the safety regulation game's evolution under different situations where social media participates.

Taking the ridesharing market in China as an example, the relevant parameters are calibrated. Assuming that the revenues (H) of governments from the SR strategy are equal to the losses (L) from the LR strategy, and the value of both is 1, $H = L = 1$. At present, the ridesharing market of China is still at a stage of continuous improvement. Therefore, the government's regulatory capacity (k) and the fixed regulatory cost (C_0) are at the medium level separately. Referring to relevant literature [62], this study sets $k = 0.6$. The fixed regulatory cost (C_0) is about half of H, where sets $C_0 = 0.5$. According to the investigation of platform companies in China, their revenues are close to H, where $R = 1$. The results of the survey also show that security costs of platform companies are about 30 percent of revenues, where $\Delta C = 0.3$. Referencing the current situation of social media participation in the regulation of ridesharing passengers, the exposure rate (γ) is also at the medium level, which means it is only exposed to relatively serious events. Therefore, this study sets $\gamma = 0.6$.

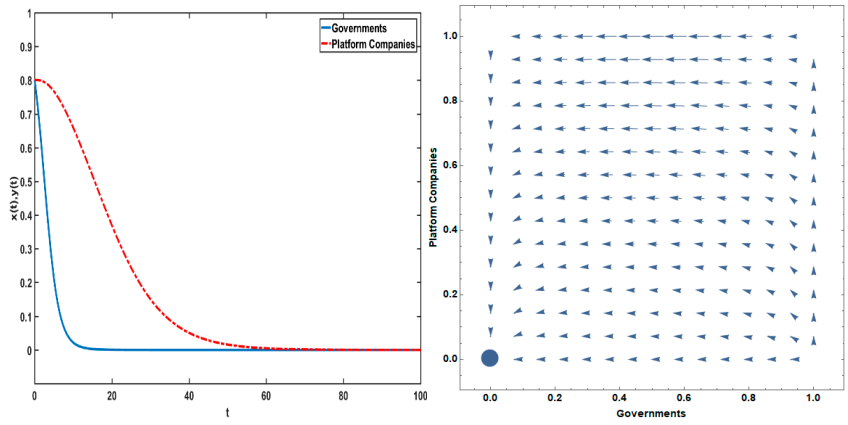
According to $\alpha_0 = \frac{\Delta C}{R}$, $\alpha_1 = \frac{\Delta C}{R\gamma}$, $\beta_0 = 1 - k(H - C_0 + \gamma L)$, and $\beta_1 = 1 - k(H - C_0)$, $\alpha_0 = 0.30$, $\alpha_1 = 0.50$, $\beta_0 = 0.34$, and $\beta_1 = 0.70$ are obtained by calculation.

Then, according to the values of these parameters, the values of α and β are selected to meet the requirements of nine scenarios for simulation experiments, respectively.

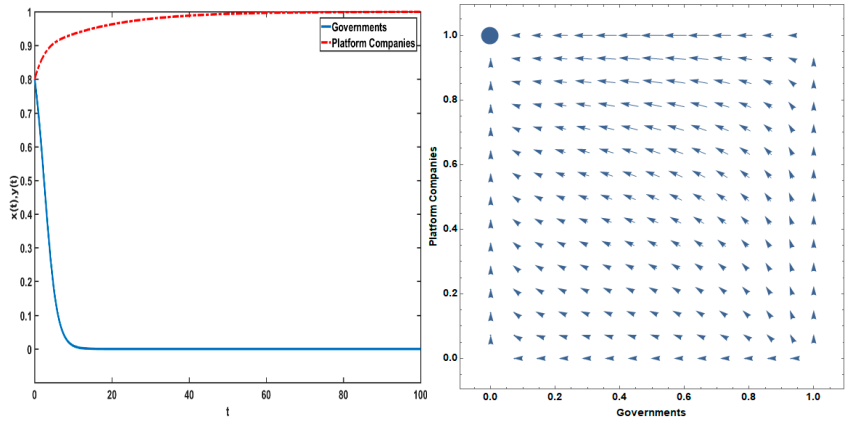
The simulation experiments include linear and 2-D trajectory flows formats. The experimental results are shown in Figures 9–12.



(**a**)



(**b**)



(**c**)

Figure 9. Evolutionary process of the scenarios: (**a**) Scenario 1; (**b**) Scenario 2; (**c**) Scenario 3.

When PD is at a low level, the evolution processes of these three scenarios are shown in Figure 9. The governments choose the LR strategy regardless of the IP level. Once the IP achieves a high level in Scenario 3, all platform companies choose the ESI strategy. The ESS of the system also evolves from (0,0) to (0,1).

When IP is at a low level, the evolutionary process of Scenario 4 and Scenario 7 are shown in Figure 10. The governments choose the SR strategy as PD increases to the medium level in Scenario 4. The ESS of the system changes from (0,0) to (1,0). However, even if PD reaches a high level, platform companies still choose the ISI strategy in Scenario 7. It shows that social media with a low level of IP only has a positive impact on governments. However, it cannot effectively prevent platform companies from adopting the ISI strategy.

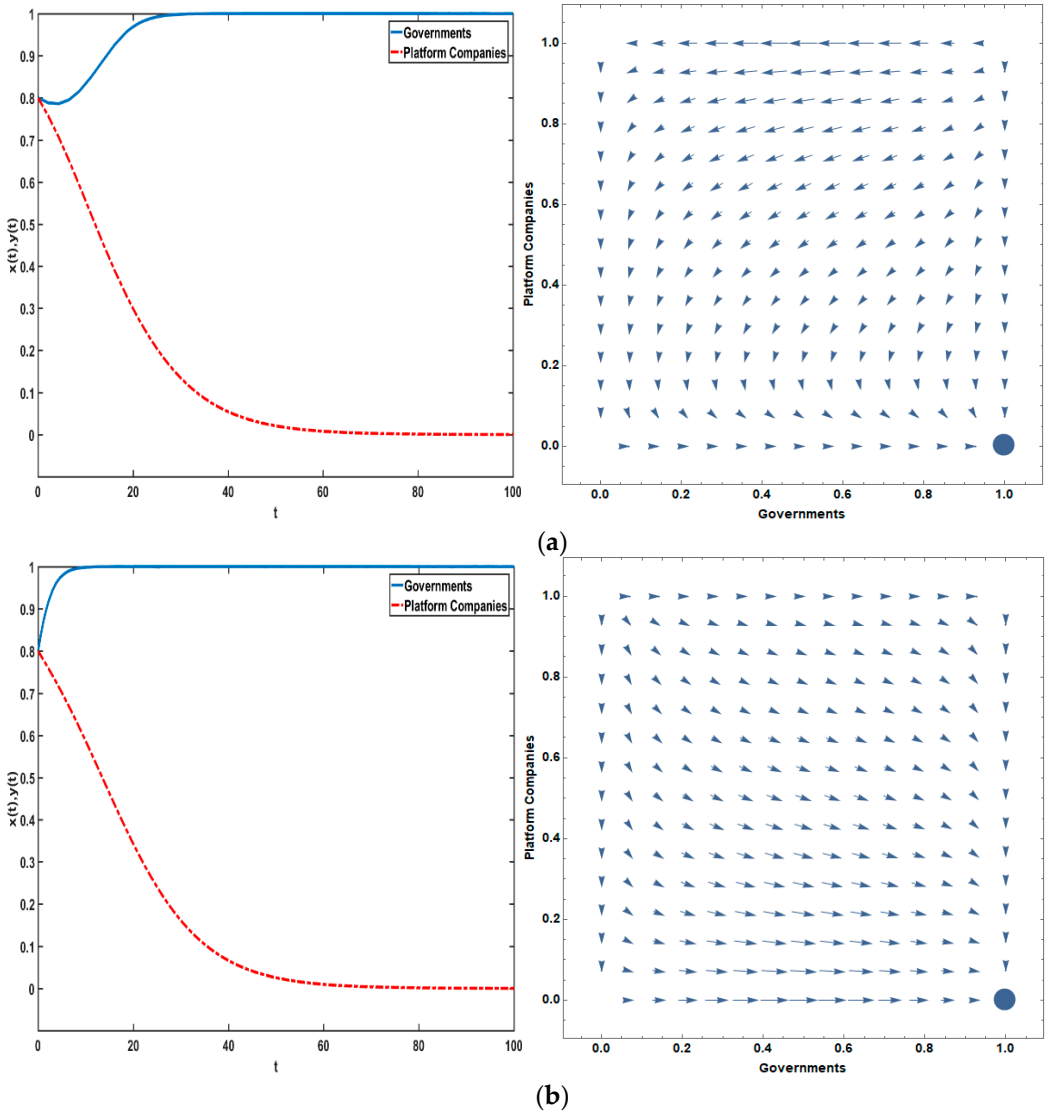


Figure 10. Evolutionary process of the scenarios: (**a**) Scenario 4; (**b**) Scenario 7.

Two scenarios with a medium level of PD are shown in Figure 11. It can be seen from Figure 11a that there is no ESS in Scenario 5. The ratio of governments' and platform companies' strategy choice is constantly changing. As the proportion of platform companies choosing the ISI strategy gradually increases, the proportion of governments choosing the SR strategy gradually increases. In this scenario, the game system could not evolve to a stable state. This confirms the previous analysis concerning Scenario 5, that both governments and platform companies can adjust the strategy according to each

other's strategy to maximize the interests. As shown in Figure 11b, the system evolves to stable State 3, due to the promotion of IP. In this stage, all platform companies choose the ESI strategy and the safety of ridesharing passengers is improved.

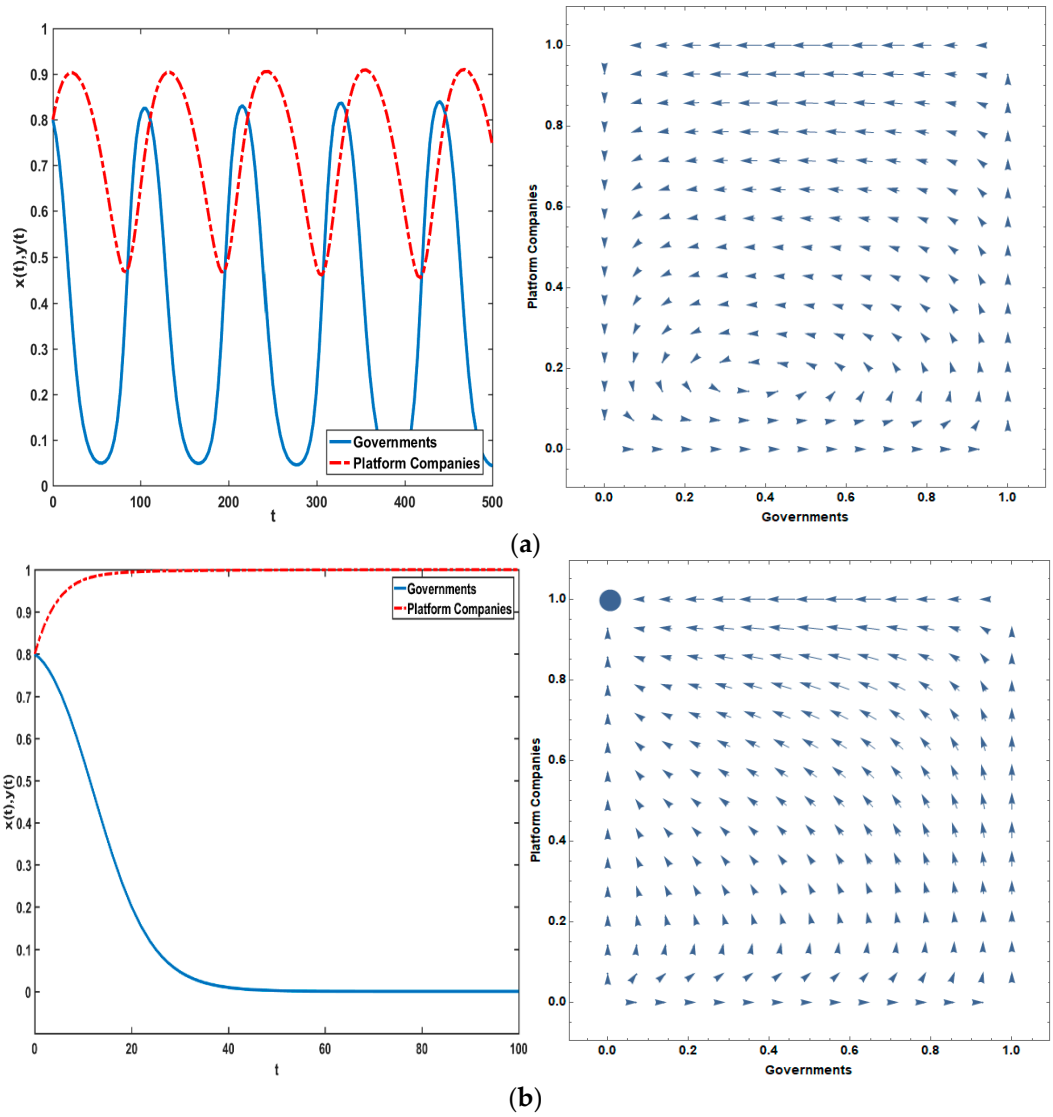


Figure 11. Evolutionary process of the scenarios: (**a**) Scenario 5; (**b**) Scenario 6.

The evolution of two scenarios with a high level of PD is shown in Figure 12. It shows that the evolution time of Scenario 9 to a stable state is less than Scenario 8. Meanwhile, the same rule can be found in the comparison of Figure 9a,b, Figure 10a,b, Figures 9c and 11b, respectively. This confirms the analysis of Scenarios 1, 3, 7, and 9 in the previous chapter. In these four scenarios, governments and platform companies choose strategies only on the basis of their own payoffs. In the game, neither side will adjust its strategy on the basis of the other's strategy choices. It means that the evolutionary time required for system evolution to a stable state is relatively shorter.

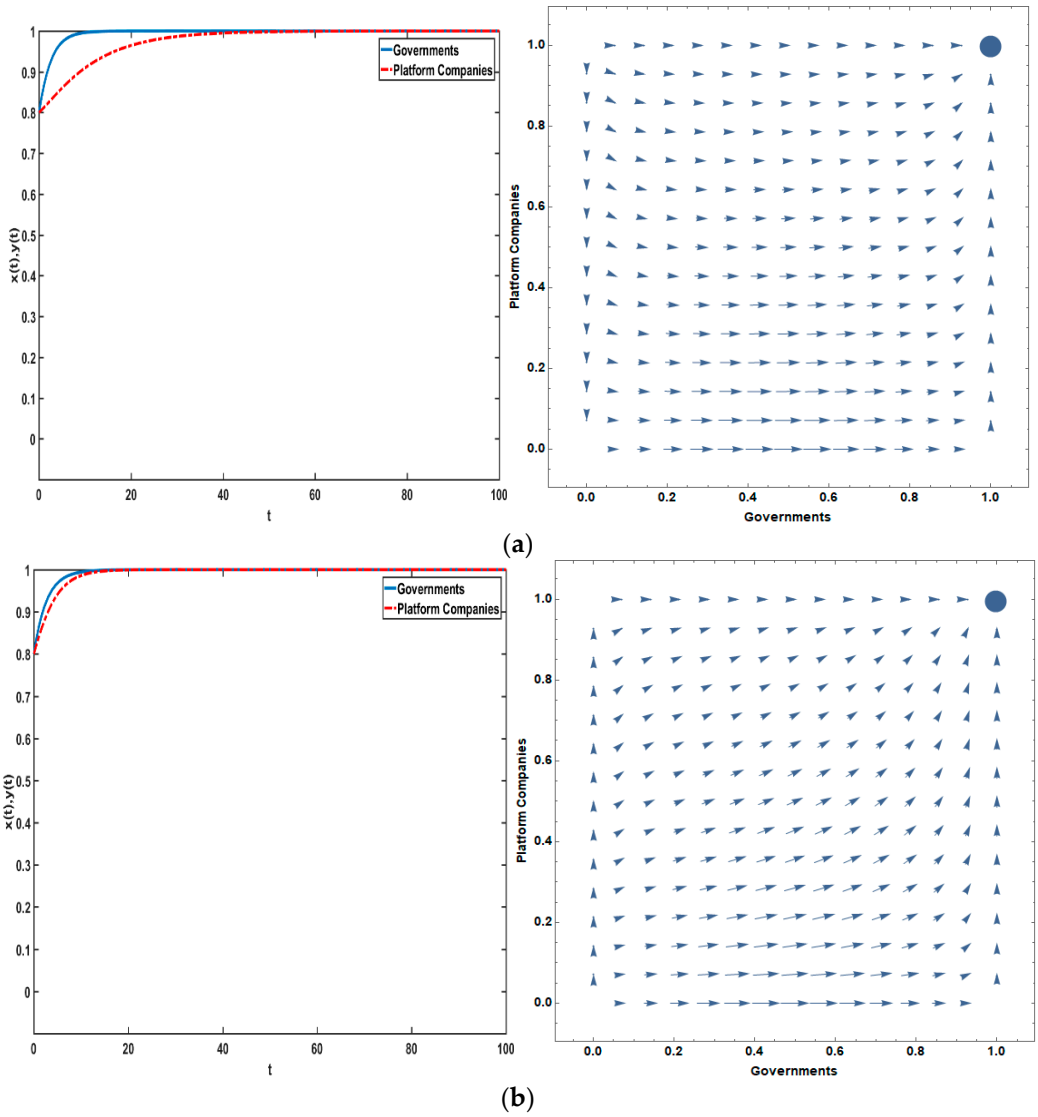


Figure 12. Evolutionary process of the scenarios: (**a**) Scenario 8; (**b**) Scenario 9.

The results of the numerical simulation are consistent with the previous analysis. It offers vivid displays of evolutionary results in different scenarios under social media participation. As IP and PD increase, the safety of ridesharing passengers could be better protected. Meanwhile, it reflects the positive effect of social media participation on the regulation of ridesharing industry.

4.3. Futher Discussion about State 3 and State 4

The system evolves to State 3 under Scenario 3 or 6 and evolves to State 4 under Scenario 8 or 9. Simultaneously, the safety of ridesharing passengers is well protected in these two states, which could be labeled as good states. However, in these two states, the government's strategy is different under social media participation in regulation.

It is worth noting that the game system relies heavily on the high level of IP to achieve State 3. This means that social media is the only regulatory force. Thus, the governments' choice of LR strategy can be regarded as "lazy management" [62]. Due to the lack of governments participation, there are great risks in this regulatory model [30]. Unlike the role of governments, social media platforms generally aim to gain more revenues by increasing their IP. The coverage of social media tends to meet public preference and seek sensational effects [63]. There exist widespread biases and exaggerations

in social media reports [64,65]. In the long run, relying heavily on social media in regulation may bring some serious consequences, such as the unscrupulous social media may pose a potentially unfair threat to the companies [66]. For example, if one of the platform companies adopts the ESI strategy, it is likely to suffer significant losses, due to false reports from social media with high-level IP. If that happens, the participation of social media may not improve ridesharing passengers' safety. It eventually undermines the development of the ridesharing industry. Therefore, State 3 could not be regarded as the optimal scenario.

In contrast, there are two forces (governments and social media) in the safety regulation of the ridesharing industry in State 4. The governments are the dominant force, and social media are the complementary force. A higher level of PD allows governments to strictly regulate ridesharing industry at a lower cost. It will no longer be "sloth administration." At the same time, the medium level of IP is enough to effectively constrain platform companies to choose the ISI strategy, such as the analysis of Scenario 8. If the PD is at a medium or low level, a high-level IP is required to effectively exert the regulatory effect of social media, such as Scenario 3 or Scenario 6. In fact, it is difficult for IP to reach a high level. However, it is easier for social media to reach a medium level of PD to effectively regulate the ridesharing industry. In other words, the conditions of social media participation in Scenario 8 are easier to be satisfied in the real world.

The involvement of governments circumvents the potential risks of relying entirely on social media forces in this safety regulation. The safety of the ridesharing industry is expected to achieve long-term improvements. To some extent, State 4 could be seen as the optimal state of the game system in this study.

5. Conclusions

The purpose of this study is to explore whether social media could improve the safety of ridesharing passengers. Therefore, this study constructs an evolutionary game model between governments and platform companies under social media participation. Then, this study analyzes the evolution states of the game system in different situations where social media participates in regulation. It further analyzes the influence of social media on safety regulation of ridesharing passengers and verifies the analysis results through simulation experiments. Finally, the two good states of safety regulation are discussed. The following conclusions were obtained.

The ESS of the system is closely related to the levels of IP and PD. In different scenarios with various levels of IP and PD were combined, the system may evolve to different states. The results showed that the participation of social media had the potential to improve safety regulation.

Specifically, the involvement of social media with high-level IP and PD could guide governments and platform companies to take a positive strategy. It may allow the safety of ridesharing passengers in the game to evolve to the optimal State 4 (1, 1). To do this, however, IP must be at least at a medium level and PD must be at a high level. In this state, governments strictly regulate at a lower cost and platform companies emphasize safety investment. The travel safety of ridesharing passengers is guaranteed over time.

It is an important public safety and social issue. In order to develop ridesharing continuously, it is important to create a safe travel environment. How governments could effectively take advantage of social regulation force may be the key to solving this issue. On the basis of the above research, this study proposes the following suggestions.

The governments should support and guide the development of social media to ensure that its own IP is at least at a medium level in the safety issues exposed in the ridesharing industry. The active participation of social media should be rewarded. It could ensure social media achieves a high level of PD in the safety regulation of ridesharing industry. In addition, governments should establish a joint regulation mechanism between themselves and social media or other social forces.

This study also has some limitations. First, social media is introduced in the form of parameters. It is still limited to the modeling analysis of the game relationship and evolution process between

governments and platform companies. For future research, social media could be considered as a player in the game. Second, due to the limitation of data collection (e.g., the costs of government's regulation), we used the numerical simulation method in this study. In future research, studies could be further enriched by adding more survey data into the model.

Author Contributions: Q.S. established the research framework; T.L. drafted the manuscript and contributed to the materials and analysis; T.L., X.G., and S.W. carried out the result calculations; Q.S., T.L., and F.M. revised the manuscript together. All authors have read and agreed to the published version of the manuscript.

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