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Research Article

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Research on the four-way evolutionary game of taxi market under the background of network reservation

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Abstract With the wide popularization of Internet technology, the rise of new business forms of online car Hailing has brought new experiences to passengers. In this paper, the evolutionary game theory analysis method is used to establish a four-way evolutionary game model of government regulatory departments, passengers, online hailing and traditional taxis, and the simulation analysis is carried out. The theoretical research and simulation results show that encouraging passengers to actively participate in the supervision and building a multi-party cooperative supervision mechanism is conducive to the harmonious and stable development of the taxi market.

Keywords Network reservation; Quadrilateral evolutionary game; Taxi market

Introduction

As a product of the sharing economy, online taxi Hailing competes with the traditional taxi industry in the market. In order to seek more benefits, both parties ignore the government's supervision and conduct illegal operations. Facing the "blowout" development of the industry, it is difficult for the government to effectively regulate it in the short term under the limited resources [1].

In recent years, there have been some related researches at home and abroad on the analysis of taxi market competition based on Game Theory. Fisk applied Stackelberg game model to the traffic field for the first time, realizing the optimization of managers and users in the signal control system and the optimization of user experience [2]. Since the 21st century, domestic scholars have begun to gradually understand the evolutionary game theory, and use the evolutionary game theory to explore the optimal state of the taxi market and passengers under the premise that enterprises pursue profit maximization. Si Yang and others assume that travelers choose their travel mode according to the time value function, and use the two-stage game theory to solve the market equilibrium under each strategy. Finally, through case analysis, it is concluded that the reasonable development of online car Hailing is economically feasible [3]. Yu Yue and others applied evolutionary game theory to analyze travel benefits from the perspective of passengers from the two dimensions of travel utility and travel cost [4]. Jiang Xinguo et al. Studied the impact of illegal costs on the illegal behaviors of taxi drivers, built an evolutionary game model between taxi drivers and traffic law enforcers under different law enforcement strategies, and simulated the changes of illegal strategies of taxi drivers under different law enforcement and license management conditions by simulation [5].

To sum up, there are few studies on the regulation of taxis from the perspective of the relationship between taxi participants. Therefore, in this study, we build a government regulatory department - passengers - online car Hailing - traditional taxi Quartet, analyze the impact of changes in parameters in the Quartet on the overall strategy and conduct simulation analysis to explore the implementation effect of collaborative regulation in the taxi market.

Hypothesis and construction of four party game model of taxi market

Model assumptions

In order to build a game model and analyze the stability of strategies and equilibrium points of all parties and the influence relationship of various factors, the following assumptions are made:

Symbol	Meaning and description
R_1	Basic income of traditional taxi drivers
ΔR_1	Additional income from illegal operation of traditional taxi drivers
C_1	Daily operation cost of traditional taxi
L_1	During passenger supervision, it is found that the traditional taxi drivers violate the rules, and their consumption times are reduced or even returned to zero. The economic losses borne by the traditional taxi.
R_2	Basic income of online car Hailing
ΔR_2	Additional income from illegal operation by online car Hailing drivers
C_2	Daily operating cost of online car Hailing
L_2	During passenger supervision, it is found that the online car Hailing drivers violate the rules, and their consumption times are reduced or even returned to zero. The economic losses borne by the online car Hailing.
C_3	Regulatory costs of government departments
B_1	Under the effective supervision of the government, incentives for the compliance operation of traditional taxi drivers
B_2	Incentives given by the government for the reasonable operation of online taxi Hailing drivers under effective supervision
B_3	Under the effective supervision of the government, if the passengers find that the traditional taxi or online taxi Hailing drivers operate in violation of the rules, the government will pay rewards to the passengers who find the violations
F	Under the effective supervision of the government, the traditional taxi and online taxi Hailing drivers are found to be operating in violation of regulations, and they will be fined
L	The negative impact on the government's reputation caused by the passenger's discovery of violations under the government's ineffective supervision
S	An orderly taxi market environment is conducive to promoting social development and thus increasing social welfare
C_4	Supervision cost of passengers
M	Passengers participated in the supervision and found the psychological effects of the sense of achievement and psychological satisfaction obtained by the compliance operation of traditional taxi and online hire car drivers
r_{21}, r_{12}	In the case of passenger supervision, one of the online hailing and traditional taxis violates the rules and regulations, resulting in damage to its reputation, while the other increases its income
ΔR	The additional income generated by online hailing and traditional taxis choosing illegal operation strategies at the same time

Model construction

According to the above assumptions, the mixed strategy game matrix of government regulatory departments, passengers, online hailing and traditional taxis is shown in Table 1.

Table 1: Quadrilateral game matrix

				Car Hailing			
				Compliance operation		Illegal operation	
				Traditional taxi		Traditional taxi	
				Compliance operation	Illegal operation	Compliance operation	Illegal operation
Government	Effective supervision	passenger	supervise	$-C_3-B_1-B_2+S$ $-C_4+M$ $R_2-C_2+B_2$ $R_1-C_1+B_1$	$-C_3-B_2-B_3+F$ $-C_4+B_3$ $R_2-C_2+B_2+r_{12}$ $R_1+\Delta R_1-C_1-L_1-F$	$-C_3-B_1-B_3+F$ $-C_4+B_3$ $R_2+\Delta R_2-C_2-L_2-F$ $R_1-C_1+B_1+r_{21}$	$-C_3-B_3+2F$ $-C_4+B_3$ $R_2+\Delta R-C_2-L_2-F$ $R_1+\Delta R-C_1-L_1-F$
			Unsupervised	$-C_3-B_1-B_2+S$ 0 $R_2-C_2+B_2$ $R_1-C_1+B_1$	$-C_3-B_2+F$ 0 $R_2-C_2+B_2$ $R_1+\Delta R_1-C_1-F$	$-C_3-B_1+F$ 0 $R_2+\Delta R_2-C_2-F$ $R_1-C_1+B_1$	$-C_3+2F$ 0 $R_2+\Delta R-C_2-F$ $R_1+\Delta R-C_1-F$
	Ineffective supervision	passenger	supervise	$-L+S$ $-C_4+M$ R_2-C_2 R_1-C_1	$-L$ $-C_4$ $R_2-C_2+r_{12}$ $R_1+\Delta R_1-C_1-L_1$	$-L$ $-C_4$ $R_2+\Delta R_2-C_2-L_2$ $R_1-C_1+r_{21}$	$-L$ $-C_4$ $R_2+\Delta R-C_2-L_2$ $R_1+\Delta R-C_1-L_1$
			Unsupervised	S 0 R_2-C_2 R_1-C_1	0 0 R_2-C_2 $R_1+\Delta R_1-C_1$	0 0 $R_2+\Delta R_2-C_2$ R_1-C_1	0 0 $R_2+\Delta R_2-C_2$ $R_1+\Delta R_1-C_1$

2 Model analysis

2.1 Strategic stability analysis of government regulatory departments

According to the Malthusian dynamic equation principle [6], the replication dynamic differential equation describing the regulatory probability of the government can be expressed as:

$$G(x)=\frac{dx}{dt}=x(G_x-\bar{G})=x(1-x)(G_x-G_{1-x})=x(1-x)[znyB_3+yL-z(B_2+F)-n(B_1+F)$$
$$-yB_3+2F-C_3] \quad (1)$$
$$G'(x)=(1-2x)[znyB_3+yL-z(B_2+F)-n(B_1+F)-yB_3+2F-C_3]$$

It can be seen from replicating the dynamic differential equation that when $y>y^*$, the stability strategy of the government supervision department is strong supervision; When $y<y^*$, the stabilization strategy of the government regulatory department is weak regulation; When $y=y^*$, it is impossible to determine the

stabilization strategy of the government regulatory department. Wherein, the threshold value $y^* = \dfrac{z(B_2+F)+n(B_1+F)-2F+C_3}{znB_3\text{-}L+B_3}$.

In the taxi market, passengers, as a third party independent of the government, online taxi hailing and traditional taxis, are the final service objects of online taxi hailing and traditional taxis. They can be a beneficial supplement to government departments and play a supervisory role in whether the government effectively implements the regulatory function. When the participation of passengers is not high, the government will choose weak supervision; With the strengthening of passengers' awareness of supervision and rights protection, the government's stabilization strategy is strong supervision.

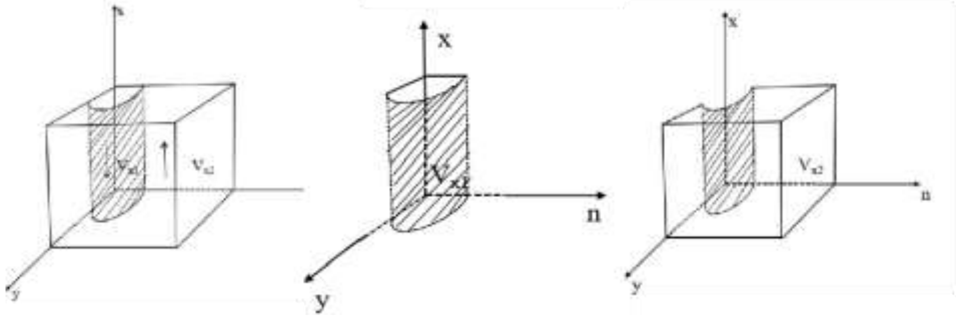

Figure 1: Phase diagram of strategic selection of government regulatory departments

In Figure 1, the volume of Part V_{x1} represents the probability that the government regulatory department adopts the weak regulatory strategy, and correspondingly, V_{x2} represents the probability that the government regulatory department adopts the strong regulatory strategy, which can be obtained through calculation.

$$\begin{aligned} V_{x1} &= \int_0^1\int_0^1 \frac{z(B_2+F)+n(B_1+F)-2F+C_3}{znB_3-L+B_3}dxdn \\ &= \left[\frac{z(B_2+F)\text{-}2F+C_3}{zB_3}+\frac{(B_1+F)(L-B_3)}{(zB_3)^2}\right]\ln\frac{znB_3-L+B_3}{B_3\text{-}L}+\frac{B_1+F}{zB_3} \qquad (2) \\ V_{x2} &= 1-V_{x1} \\ &= 1-\left[\frac{z(B_2+F)\text{-}2F+C_3}{zB_3}+\frac{(B_1+F)(L-B_3)}{(zB_3)^2}\right]\ln\frac{znB_3-L+B_3}{B_3\text{-}L}+\frac{B_1+F}{zB_3} \end{aligned}$$

It is inferred that the probability that the government supervision department chooses strong supervision is positively related to the rewards obtained by the passengers participating in the supervision and finding illegal operation of online taxi Hailing or traditional taxis, and the penalties for the illegal operation of traditional taxis and online taxi Hailing. The rewards for the compliant operation of online taxi hailing and traditional taxis, the cost of government supervision, and the negative impact of the illegal operation on passengers are negatively related.

Strategic stability analysis of passengers

According to the Malthusian dynamic equation principle [6], the replicated dynamic differential equation describing the supervision probability of passengers can be expressed as:

$$P(y)=\frac{dy}{dt}=y(P_y-\bar{P})=y(1-y)(P_y-P_{1-y})=y(1-y)[-xznB_3\text{-}znM+xB_3+C_4]$$
$$P'(y)=(1-2y)[-xznB_3\text{-}znM+xB_3+C_4] \quad (3)$$

According to the copied dynamic equation, when $x>x^*$ the passenger's stability strategy is supervision; When $x<x^*$, the passenger's stability strategy is not regulated; When $x=x^*$, the stability strategy of passengers cannot be determined. Wherein the threshold is $x^*=\frac{znM\text{-}C_4}{B_3-znB_3}$.

With the increase of the supervision probability of the government management department, the probability of passengers choosing the supervision strategy increases. A good taxi market environment is conducive to the more active participation of passengers. The effective supervision of passengers by the government will give certain rewards, and the supervision strategy for passengers will play a certain incentive role.

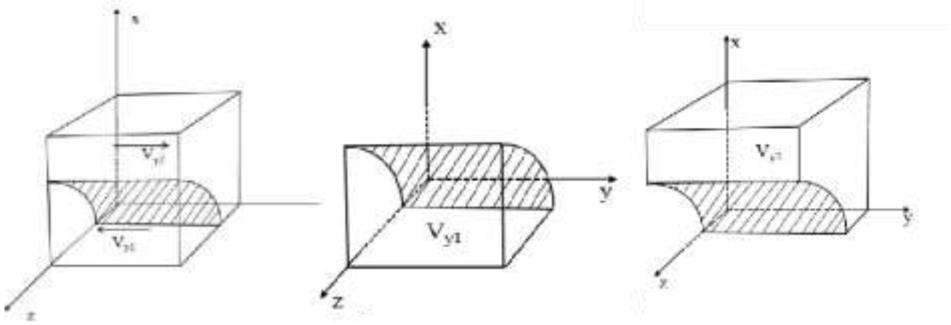

Figure 2: Passenger strategy selection phase diagram

In Figure 2, the volume of V_{y1} represents the probability of passengers adopting the unsupervised strategy, and correspondingly, V_{y2} represents the probability of passengers adopting the supervised strategy, which can be obtained through calculation.

$$V_{y1}=\int_0^1\int_0^1\frac{znM\text{-}C_4}{B_3-znB_3}dydz=\left[\frac{C_4\text{-}M}{nB_3}\right]\ln^{(1\text{-}n)}\text{-}\frac{M}{B_3}$$
$$V_{y2}=1-V_{y1}=1-\left[\frac{C_4\text{-}M}{nB_3}\right]\ln^{(1\text{-}n)}\text{-}\frac{M}{B_3} \quad (4)$$

It is inferred that the probability of passengers choosing supervision is positively related to the rewards paid by the government to the passengers who find violations, and the psychological satisfaction gained by the passengers who participate in the supervision and find that the online taxi hailing and traditional taxis operate in compliance, and negatively related to the cost of passenger supervision.

Strategic stability analysis of online car Hailing

According to the Malthusian dynamic equation principle [6], the replication dynamic differential equation describing the supervision probability of online car Hailing can be expressed as:

$$W(z)=\frac{dz}{dt}=z(W_z-\bar{W})=z(1-z)(W_z-W_{1-z})=$$
$$z(1-z)[xB_2+(y-ny)r_{12}+xF+yl_2-n\Delta R_2-(1-n)\Delta R] \quad (5)$$
$$W'(z)=(1-2z)[xB_2+(y-ny)r_{12}+xF+yl_2-n\Delta R_2-(1-n)\Delta R]$$

According to the replication equation, when $x>x^{**}$ the stable strategy of car Hailing is legal operation; When $x<x^{**}$, the stable strategy of online car Hailing is illegal operation; When $x=x^{**}$, it is impossible to determine the stability strategy of online car Hailing. Wherein the threshold is $x^{**}=\frac{n\Delta R_2+(1-n)\Delta R\text{-}(y-ny)r_{12}\text{-}yl_2}{B_2+F}$.

The increase in the probability of strong supervision by government regulatory departments will change the stable strategy of online car hailing from illegal operation to compliance operation; On the contrary, the probability of strong supervision by government regulatory departments will decrease, which will change the stable strategy of online car hailing from compliance operation to illegal operation. It can be seen that in the taxi market, in order to build a healthy and effective taxi environment and provide protection for passengers' safety, it is necessary for the government regulatory department to take regulatory measures for online taxi Hailing.

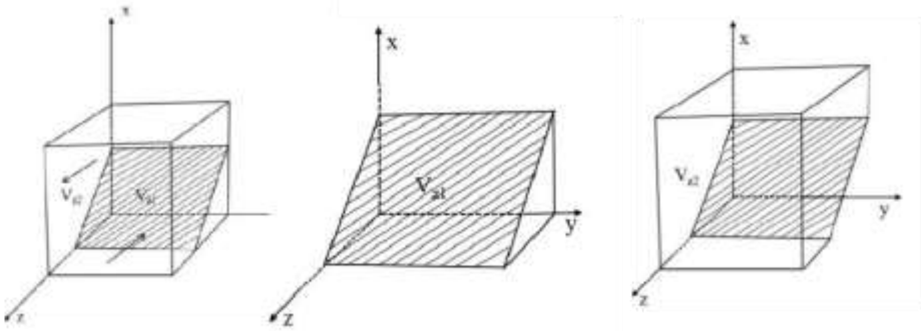

Figure 3: Phase diagram of network car Hailing strategy selection

In Fig. 3, the volume of V_{z1} represents the probability of online car Hailing adopting the illegal operation strategy, and correspondingly, V_{z2} represents the probability of online car Hailing adopting the compliant operation strategy, which can be obtained through calculation

$$V_{z1}=\int_0^1\int_0^1\frac{n\Delta R_2+(1-n)\Delta R\text{-}(y-ny)r_{12}\text{-}yl_2}{B_2+F}dzdy=\frac{2n\Delta R_2+2(1-n)\Delta R\text{-}(1-n)r_{12}\text{-}l_2}{2(B_2+F)} \quad (6)$$
$$V_{z2}=1-V_{z1}=1-\frac{2n\Delta R_2+2(1-n)\Delta R\text{-}(1-n)r_{12}\text{-}l_2}{2(B_2+F)}$$

It is inferred that the probability of online car Hailing choosing legal operation is positively related to the economic loss incurred by the illegal operation of online car hailing, the fines imposed by the government on the illegal operation of online car hailing, and the rewards given by the government to the compliant operation of online car hailing, while it is negatively related to the additional income from the illegal operation.

Stability analysis of traditional taxi strategy

According to the Malthusian dynamic equation principle [6], the replication dynamic differential equation describing the supervision probability of traditional taxis can be expressed as:

$$T(n)=\frac{dn}{dt}=n(T_n-\bar{T})=n(1-n)(T_n-T_{1-n})=$$
$$n(1-n)[xB_1+(y-zy)r_{21}+xF+yl_1-z\Delta R_1-(1-z)\Delta R] \quad (7)$$
$$T'(n)=(1-2n)[xB_1+(y-zy)r_{21}+xF+yl_1-z\Delta R_1-(1-z)\Delta R]$$

According to the copied dynamic equation, when $z>z^*$ the stability strategy of traditional taxis is illegal operation; At present $z<z^*$ the stable strategy of traditional taxis is compliance operation; When $z=z^*$, it is impossible to determine the stability strategy of traditional taxis. Where in the threshold is $z^*=\frac{xB_1+yr_{21}+xF+yl_1-\Delta R}{\Delta R_1-yr_{21}-\Delta R}$.

In the taxi market, online hailing and traditional taxis are in a cooperative or competitive relationship. With the increase of the probability of compliance operation of online hailing, the stability strategy of traditional taxis will change from compliance operation to illegal operation; On the contrary, the rising probability of illegal operation of online taxi Hailing will change the traditional taxi stability strategy from illegal operation to compliance operation.

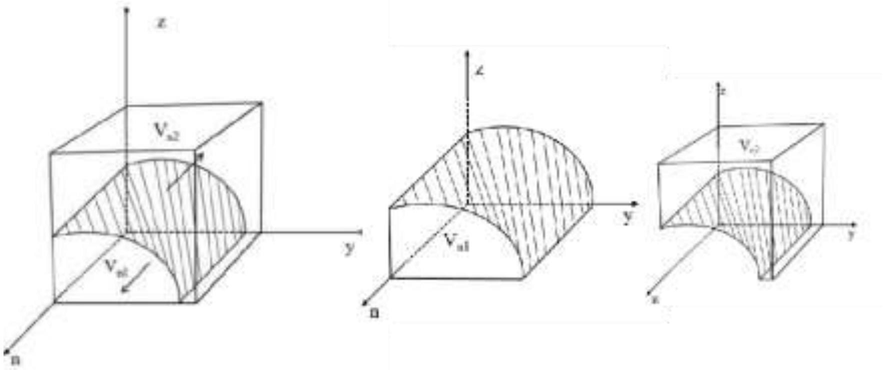

Figure 4: Phase diagram of traditional taxi strategy selection

In Figure 4, the volume of V_{n1} represents the probability that the traditional taxis adopt the compliant operation strategy, and correspondingly, V_{n2} represents the probability that the traditional taxis adopt the illegal operation strategy, which can be obtained through calculation

$$V_{n1}=\int_0^1\int_0^1\frac{xB_1+yr_{21}+xF+yL_1-\Delta R}{\Delta R_1-yr_{21}-\Delta R}dndy=$$
$$\left[\frac{(r_{21}+L_1)(\Delta R-\Delta R_1)}{(r_{21})^2}-\frac{xB_1+xF-\Delta R}{r_{21}}\right]\ln^{\frac{\Delta R_1-r_{21}-\Delta R}{\Delta R_1-\Delta R}}-\frac{r_{21}+L_1}{r_{21}} \quad (8)$$
$$V_{n2}=1-V_{n1}=1-\left[\frac{(r_{21}+L_1)(\Delta R-\Delta R_1)}{(r_{21})^2}-\frac{xB_1+xF-\Delta R}{r_{21}}\right]\ln^{\frac{\Delta R_1-r_{21}-\Delta R}{\Delta R_1-\Delta R}}+\frac{r_{21}+L_1}{r_{21}}$$

It is inferred that the probability of traditional taxis choosing compliance operation is positively related to the rewards for compliance operation of traditional taxis under the supervision of the government, and the additional income obtained when both online taxi hailing and traditional taxis are operating in violation of regulations. The loss suffered by traditional taxis in violation of regulations, the income from illegal operation, and the punishment of traditional taxis operating in violation of regulations under the supervision of the government are negatively related.

Summary

This paper mainly studies the regulation of the taxi market under the background of online car Hailing booking. The conclusions are as follows:

(1) Establish a multi-agent cooperative supervision mechanism. In the regulation of the taxi market, it is one-sided to rely on the government alone. The government needs to increase the incentives for passengers to participate in the regulation and reduce the cost of regulation, so as to increase the benefits of passengers participating in the regulation. Traditional taxis and online Hailing vehicles supervise each other, and a special work verification team is established to deal with the illegal operation problems reported by passengers and drivers in a timely manner. Promote the formation of a long-term development of the government passenger online taxi Hailing traditional taxi collaborative regulatory mechanism.

(2) Appropriately adjust the government's reward and punishment policies. In the process of government supervision, most of them are in the form of fines for violations. It is easy to form a game between fines and illegal operating income. When the government imposes a small amount of punishment on its illegal operation, traditional taxis and online taxi Hailing will still operate in violation of regulations to make up for the amount of fines. Therefore, the government should increase the punishment to promote the evolution of online taxi hailing and traditional taxis towards compliance operation. At the same time, it is also very important to establish corresponding incentive policies. In the taxi market, the phenomenon of low cost of illegal operation and high cost of compliance operation often occurs, which will make some compliant enterprises unable to bear the operating expenses and be expelled from the market. Therefore, giving appropriate subsidies and other preferential policies to compliant vehicles is conducive to encouraging enterprises to operate in compliance.

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