Research on the Monitoring of Drivers' Hygiene Behavior by Online Car-Hailing Platforms During the Epidemic

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Abstract. In recent years, the online car-hailing industry has shown a rapid development trend, and the demand for online car-hailing and the number of floating populations will continue to grow. In this context, strengthening the nationwide supervision of online car-hailing epidemic prevention and control can reduce the risk of the spread of the epidemic to a certain extent. This paper establishes a principal-agent game model between the car-hailing platform and the driver, and obtains the optimal monitoring density, punishment intensity of the car-hailing platform, and the driver's optimal rule compliance probability; through numerical simulation, the driver's rule compliance cost and platform benefits are analyzed. The impact of the apportionment ratio on the optimal platform punishment intensity, monitoring density and driver compliance probability; finally, the SIS infectious disease model is used to simulate the changes in the number of sick people over time when drivers comply with the rules and do not comply with the rules.

Keywords: Car-hailing service supply chain · Principal-agent · Infectious disease model

1 Introduction

With the rapid development of information technologies such as the Internet, big data, and cloud computing, online car-hailing has developed rapidly due to its many advantages, such as convenience, speed, low price, and the ability to fully utilize idle resources. According to data from the Ministry of Transport, as of July 31, 2021, a total of 241 online car-hailing platform companies across the country have obtained online car-hailing platform business licenses, and a total of 3.51 million online car-hailing driver's licenses and 1.357 million vehicle transport licenses have been issued in various regions. However, in early 2020, a sudden new crown epidemic posed a huge threat to people's lives and health. Due to the small and closed space inside the car, online car-hailing can easily become the carrier of the spread of the epidemic. For example, on December 28, 2020, an online car-hailing driver in Shunyi District, Beijing was diagnosed with a confirmed case, and then several online car-hailing drivers who had dinner with him were diagnosed one after another, which caused great harm to social public health. The

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confirmed patients in Shenyang and other places are also closely related to online car-hailing. Therefore, the supervision of the hygienic behavior of online car-hailing drivers is not only related to the platform's reputation for service quality, but also to the effective control of the epidemic in the whole society.

At present, some platforms have taken prevention and control measures in accordance with relevant national policies, such as requiring drivers and passengers to wear masks, registering a health code to ride, disinfection and ventilation in each vehicle, and drivers uploading photos and videos of vehicle disinfection. Platforms conduct random inspections through in-vehicle cameras and strictly enforce penalties for violations. However, due to the large number of online car-hailing platforms, insufficient supervision and implementation capabilities, and the prevention and control effect is difficult to guarantee, it has formed a major hidden danger to epidemic prevention and control. Therefore, in order to solve the balance between the cost of platform monitoring and the monitoring effect, the research on the monitoring of drivers' hygiene behavior by the car-hailing platform is particularly important.

At present, the research on the supervision of enterprises on the platform mainly focuses on the government, the platform and the enterprise as participants. It is believed that the government can increase the supervision and control of the platform to achieve the "strict management rate" of the platform and the "legal operation rate" of the enterprise [1][4]; other studies believe that increasing customer supervision and improving the authenticity and influence of customer online word-of-mouth can promote strict supervision of platforms and improve service quality of enterprises [2][9]. These research methods are mainly principal-agent [3][5][6] and evolutionary games, and the research objects are mostly e-commerce platforms and enterprises [7]. There are few studies on online car-hailing [8]. On the basis of the above research, this paper will focus on the study of the new crown epidemic. First, the principal-agent model is used to study the monitoring of drivers' hygiene behavior by the car-hailing platform. Second, the infectious disease model is used to simulate the development of the epidemic under different monitoring efforts. Condition. It is intended to provide decision support for monitoring and management of relevant platforms.

2 The Online Car-Hailing Platform's Monitoring Model for Drivers' Hygiene Behavior During the Epidemic

2.1 Basic Assumptions and Parameter Settings

In this model, it is assumed that the car-hailing platform is the principal and the driver is the agent. There are two types of behavior of drivers, one is to comply with hygiene rules to provide safe and good service, and the other is to provide poor quality service without complying with hygiene rules. The cost of the driver in compliance and non-compliance is different, assuming C_1 and C_2 respectively, and $C_1 > C_2$, the service price in both cases is ω. The probability of driver compliance is q, and due to the limited supervision resources, the monitoring density of the platform is p, and the punishment intensity is α. The supervision cost of the platform is C_3, and $C_3 = \frac{1}{2}kp^2, k > 0$. If the driver does not comply with the monitoring, the probability of being discovered is 100%. The

Table 1. Parameter settings

Parameter	Meaning	Parameter	Meaning
C_1	Costs for drivers to comply	ω	service fee
C_2	Costs incurred by drivers when they do not comply	α	Punishment for non-compliance detected
C_3	Regulatory costs of ride-hailing platforms	β	Platform share profit ratio
p	Monitor density	Q	Order volume
q	Probability of driver compliance	Q_0	Order volume when drivers don't comply
K	The platform's unit marginal monitoring cost factor	N	number of drivers
a	Order volume influence factor for driver compliance		

apportionment ratio of the car-hailing platform is β, and the initial registration fee is ignored here.

Assumption: There is a linear relationship between the order volume and the probability that the driver will comply with the regulations: $Q = Q_0 + aqQ_0$.

2.2 The Game Process Between the Car-Hailing Platform and the Driver

In this game, both parties know their own benefits, but the platform does not know the driver's behavior, so this game is a dynamic game with incomplete information. Analyze the game process:

The first is that the driver abides by the regulations, and the platform supervises the driver. Since the driver abides by the contract and provides good service, it does not involve the platform to punish it.

The second is that the driver does not comply, and the online car-hailing platform is supervised. At this time, because the driver's unqualified behavior was discovered by the platform, he was punished by the platform with α.

The third is that the driver obeys, and the platform does not supervise it. Although the platform did not supervise it, because the drivers obeyed the regulations and provided good services, they did not cause harm to the society.

The fourth type is that the driver does not comply, and the platform does not supervise it. Because the driver did not comply with the regulations, but because the platform did not supervise it, the driver obtained excess profits and escaped punishment, which had a negative impact on society.

The strategic expressions of the car-hailing platforms and drivers under different strategies are as follows:

Table 2. Policy expressions under different strategies

		Online car-hailing platform	
		Supervision	Not Supervision
driver	obey	$N(\omega - C_1)Q\beta - C_3$ $(1-\beta)(\omega - C_1)Q$	$N(\omega - C_1)Q\beta$ $(1-\beta)(\omega - C_1)Q$
	Not obey	$N[(\omega - C_1)Q\beta + \alpha] - C_3$ $[(1-\beta)(\omega - C_2)Q - \alpha]$	$N(\omega - C_1)Q\beta$ $(\omega - C_2)Q(1-\beta)$

2.3 Model Building and Analysis

According to the policy expression, the expected revenue function of the car-hailing platform and the driver is established:

The expected revenue of the car-hailing platform is expressed as follows:

$$E\pi_{Onlinecar-hailingplatform} = pqN\beta(\omega - C_1)Q + (1-p)qN\beta(\omega - C_1)Q + p(1-q)N\left[\beta(\omega - C_1)Q + \alpha\right] + (1-P)(1-q)N\beta(\omega - C_1)Q - 2C_3 \tag{1}$$

The expected revenue of the driver is expressed as:

$$\mathrm{E}\pi_{\mathrm{driver}} = pq(1-\beta)(\omega - C_1)Q + (1-\beta)(\omega - C_1)Q(1-p)q + \left[(1-\beta)(\omega - C_2)Q - \alpha\right]p(1-q) + (1-\beta)(\omega - C_2)Q(1-q)(1-p) \tag{2}$$

To maximize the expected benefit of the driver, the specific model is as follows:

$$q^* = argmax\mathrm{E}\pi_{\mathrm{driver}}$$

Proposition 1: For the driver, there is a compliance probability q^* that maximihgft zes its expected return, and its value is:

$$q^* = \frac{AQ_0 - BQ_0 - AaQ_0 - \alpha p}{(B-A)2aQ_0} \tag{3}$$

Assume $(1-\beta)(\omega - C_2) = A$,

$$(1-\beta)(\omega - C_1) = B$$

Prove:

Find the first derivative of the driver's revenue function, as shown in the following equation:

$$\frac{d\mathrm{E}\pi_{\text{driver}}}{dq} = (1-\beta)(\omega - C_1)(Q_0 + aqQ_0) + (1-\beta)(\omega - C_1)aqQ_0 - (1-\beta)(\omega - C_2)(Q_0 + aqQ_0) + (1-\beta)(\omega - C_2)(1-q)aQ_0 + \alpha p \quad (4)$$

The second derivative of the driver's expected revenue with respect to q is given by:

$$\frac{d^2 E\pi_{\text{driver}}}{dq^2} = 2(1-\beta)aQ_0(C_2 - C_1) \quad (5)$$

Because $C_2 - C_1 < 0$, so $\frac{d^2 E\pi_{\text{driver}}}{dq^2} < 0$.

If the second derivative is a constant less than 0, the driver's expected revenue function is strictly convex, so there is a unique q^* that maximizes the driver $E\pi_{\text{driver}}$. The value of q^* is the solution when the first derivative is equal to 0:

The solution to q^* is as follows:

$$q^* = \frac{AQ_0 - BQ_0 - AaQ_0 - \alpha p}{(B-A)2aQ_0}$$

Proposition 2: There is a functional formula about p^* and α^*, which makes the expected benefit of the car-hailing platform optimal. The functional formula needs to be satisfied:

$$F(p) = \left(1 - \frac{Z - \alpha p}{M}\right)N\alpha - N\beta(\omega - C_1)\frac{\alpha}{2(B-A)} + Np\alpha^2\frac{1}{(B-A)2aQ_0} - 2Nkp = 0 \quad (6)$$

Prove:

$$\begin{cases} \frac{\partial E_{\pi\text{Onlinecar-hailingplatform}}}{\partial p} = \\ (1-q)N\alpha + N\beta(\omega - C_1)\frac{-\alpha}{2(B-A)} + \\ Np\frac{\alpha^2}{(B-A)2aQ_0} - 2kp = 0 \\ \frac{\partial E_{\pi\text{Onlinecar-hailingplatform}}}{\partial \alpha} = \\ \frac{p^2 N\alpha}{(B-A)2aQ_0} + N\beta(\omega - C_1)\frac{-p}{2(B-A)} + \\ p(1-q)N = 0 \end{cases} \quad (7)$$

The solution of α^* is as follows:

$$\alpha^* = \frac{2\beta(\omega - C_1)(B-A)a^2{Q_0}^2 - 2(B-A)aQ_0 + (A - B - Aa)Q_0}{\left[1 + (B-A)2aQ_0\right]p} \quad (8)$$

Substitute α^* into the system of equations to get the functional formula for p:

Assume $M = 4(B-A)$,$Z = 18A - 20B$,$X = \frac{2500}{B-A}$,$Y = -\frac{15000}{B-A}$

Proposition 2 is proved.

Table 3. Numerical simulation

N	10000
β	0.2
ω	30
C_1	15
Q_0	20
a	0.1
K	5
C_3	0.002003
C_2	13.13
p	0.028308
q	0.512032
α	211.6716
$E\pi_{\text{Onlinecar-hailingplatform}}$	659961.2
$\text{E}\pi_{\text{driver}}$	264.7124

3 Numerical Simulation

Assumption: The price ω of an online car-hailing platform express car that normally travels 10km during the day is 30 yuan. Assume that the cost C_1 of car-hailing drivers complying with the platform rules is 15 yuan/unit, and the cost C_2 when they do not comply with the rules is 13.13–13.3 yuan/unit. Suppose that when the platform is supervised and found that the supplier sells fake products, the punishment for it α =20000 yuan; the platform's profit sharing ratio β=0.2, the number of drivers N for the car-hailing platform is 10,000, and when the driver does not follow the rules all day long.The order quantity $Q_0 = 20$; assume $a = 0.1$, $K = 0.5$.

It can be seen that as the monitoring density p increases, the driver compliance probability q increases; at the same time, the punishment intensity α and the monitoring density p change in the opposite direction. As the monitoring density p increases, the punishment intensity α decreases.

Now assume that the city has a total population of 200,000, 10,000 online car-hailing drivers, and 10 initially infected drivers. If each driver does not follow the rules, the daily exposure rate is 0.5, but if each driver obeys the rules, the daily exposure rate is 0.5. 0.1 to simulate 200 days.

As you can see from the graph above, after about 30 days, the city's population will become infected (regardless of the daily cure rate). Because drivers do not follow the rules, the platform's supervision and punishment are not in place, which is very harmful to the society and a waste of social resources. Therefore, the platform should assume the responsibility of supervision and safeguard the interests of the entire social community. If drivers follow the rules, it will take about 150 days for the entire population to become infected. (Does not consider the daily cure rate). By comparing with the previous results,

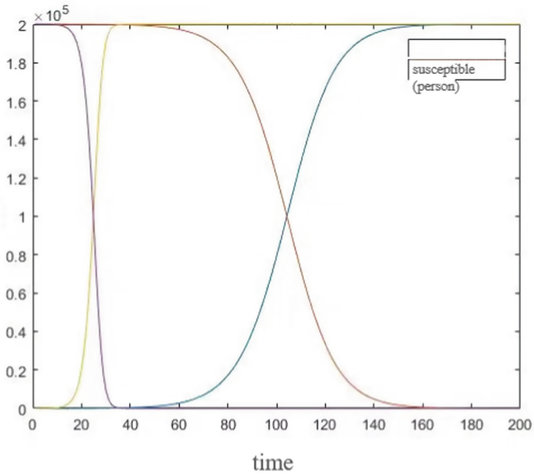

Fig. 1. SIS infectious disease model

if the driver did not follow the rules, all the people were infected within 30 days, but when the driver followed the rules, the contact infection rate was reduced, and the infection time of the entire group was pushed back to 150 days, which is still a big gap. Moreover, the number of sick people in the first 50 days is still equivalent to the initial sick number, and measures can be used to effectively control the situation and prevent the spread of the epidemic.

From the above two simulation results, we can see the importance of platform supervision in this epidemic. If drivers strictly abide by the rules, regularly disinfect and sterilize, and wear masks throughout the process, it will reduce the pressure on the government and give the public peace of mind. In the sharing economy model of car-hailing, special attention should be paid to hygiene and ventilation in a confined space. Providing good and reliable services to the society cannot be separated from the supervision of the platform. The lack of supervision in the incident of the infection of car-hailing drivers is the main reason.

4 Sensitivity Analysis

a). The figure shows the cost of non-compliance gradually increases, the probability of drivers to comply also increases, the monitoring density of the platform increases slightly, and the punishment decreases. In view of this situation, the higher the cost of the driver's non-compliance, the more the driver will choose to comply and provide quality service.

b). As the costs of compliance and non-compliance are getting closer and closer, the probability of drivers complying is greater, and for online car-hailing platforms, the monitoring density of the platform is maintained at a low level, and the penalties are also decreasing. That is, when drivers pay similar costs when they comply with non-compliance, drivers will choose to comply with relevant regulations, and the platform will

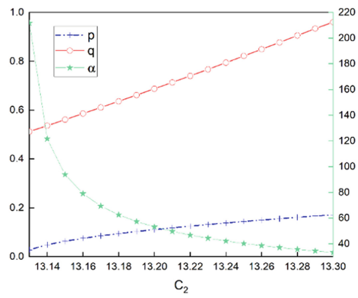

Fig. 2. Effects of 2F Effects of 2Figure 2. Effects of C_2 on p、α and q

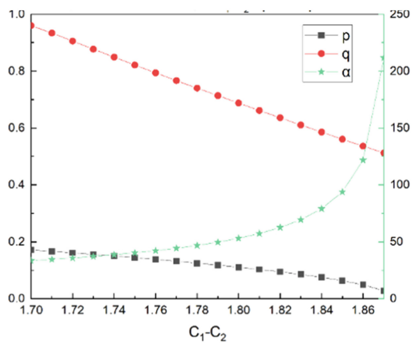

Fig. 3. Effects of $C_1 - C_2$ on p、α and q

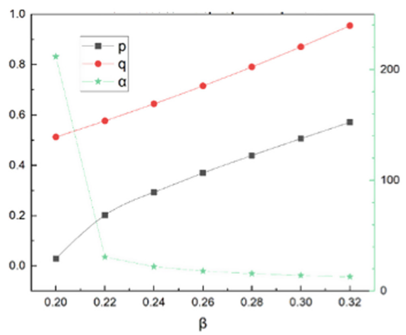

Fig. 4. Effects of β on α and

also implement lower monitoring density and penalties. During the epidemic, the cost of masks, gloves, alcohol, disinfectant, etc. required by drivers for epidemic prevention is the difference between compliance and non-compliance. If platform can provide some materials, the cost difference will be smaller, and online car-hailing drivers will comply with relevant regulations to provide High-quality services to reduce the risk of epidemic spread.

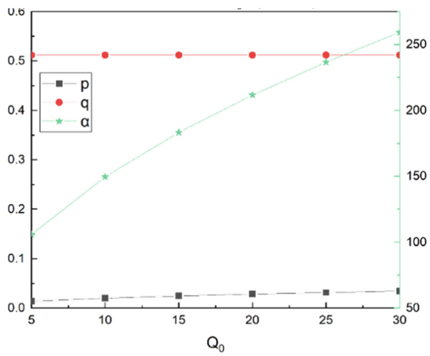

Fig. 5. Effects of 0**Figure5** Effects of Q_0 on p、α and q

c). As can be seen from the above chart, with the increase of the platform's share ratio, the monitoring density of the platform has increased significantly, the probability of drivers' compliance will increase significantly, and the corresponding punishment will decrease. The platform's apportionment ratio is slightly increased, from 0.2 to 0.3, and the probability of drivers' compliance will be greatly increased. The apportionment ratio can be adjusted to increase the monitoring density to ensure drivers' compliance.

d). If the order volume increases when the driver does not comply, the platform will strengthen the punishment, but the monitoring density does not increase significantly, and the change in the order volume when the driver does not comply will hardly affect the driver's behavior. For the platform, the product of the corresponding monitoring density and the punishment intensity for each order is unchanged.

5 Conclusions and Recommendations

In the car-hailing service supply chain, car-hailing platforms can choose to supervise or not supervise, and drivers can choose to comply or not. The risks in the service supply chain are different from other traditional supply chains, and the spread of risks during the epidemic is more harmful to society. This paper establishes the game model between the car-hailing platform and the driver through the principal-agent theory. Through the calculation, it is concluded that the optimal monitoring density and punishment intensity of the car-hailing platform should satisfy the following relationship, and the optimal compliance probability of the driver is obtained. Through sensitivity analysis, it is found that the smaller the cost difference between the driver's compliance and the non-compliance, the greater the probability that the driver chooses to comply, indicating that the driver's choice is related to the rules that need to be complied with. Relevant rules, less risk.

In response to this situation, the platform can give drivers corresponding subsidies. For example, during the epidemic, relevant epidemic prevention supplies are distributed: masks, disinfectants, temperature detectors, gloves, etc., to reduce the cost difference and ensure their compliance. At the same time, the platform's share ratio has an impact on both drivers and online car-hailing platforms. Increasing the platform's share ratio will increase the platform's monitoring efforts, and the driver's compliance probability will also be greatly improved. The platform can appropriately increase its share ratio to reduce drivers' non-compliance behavior to control this supply chain risk.

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