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RESEARCH ON OPERATION STRATEGY OF ONLINE TRADING PLATFORM BASED ON STOCHASTIC EVOLUTIONARY GAME

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Abstract. *In view of some illegal issues arising from the development of platform-based e-commerce, it is essential to build a complete regulatory system. Because there are many random disturbance factors in the real society, this requires that we should not be limited to research and analysis in a deterministic environment. Based on this, this paper constructs a stochastic evolutionary game model between government-platform-merchants, and improves the replication dynamic system of the model by adding Gaussian white noise. Then use the stochastic differential equation stability discriminant theorem to analyze the stability of the model, so as to obtain the stability conditions of the system. Finally, the influence of different disturbance intensities on the decision-making behavior of the subject is further discussed through MATLAB simulation. The results showed that random disturbance has had a certain impact on the decision-making of each subject. As the intensity of the disturbance increases, the time for each subject to evolve to a stable strategy will be extended and the volatility of the evolution curve will also increase, but the strategy will evolve to a stable state after a period of time.*
Keywords: Evolutionary game, Stochastic differential equation, Online trading platform, Replication dynamic equation

1. **Introduction.** With the continuous development of platform-based e-commerce, traditional sales models have gradually shifted to online sales models. This major change has given people great convenience in time and space. Against this background, more and more merchants have begun to pour into the platform to expand online business. Coupled with the existence of factors such as the virtuality of the network and information asymmetry, supervision and review have become a major problem. Driven by interests, even if the relevant laws stipulate the regulatory obligations of platform-based enterprises [1], in order to seize market share, it will not only fail to fulfill its obligations of supervision and review of settled businesses in accordance with the law, but it may also cover up illegal acts, or even use its own advantages to force merchants to sign overlord treaties and other illegal acts to seek illegal benefits [2, 3].

Over the years, academic research on platforms has mainly focused on supervision strategies [4-10], power and responsibility issues [11, 12], pricing strategies [13-15] and competitive strategies [16, 17], etc. Because in the actual supervision process, the platform will also have different degrees of illegal phenomena, some scholars have begun to add platform violations to the research process of illegal supervision [18-21]. For example, [18] used evolutionary game theory to study e-commerce market supervision issues, and built a layered supervision model for government supervision illegal platforms and

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platform supervision illegal merchants. Although the illegal problems of the platform are considered, it is still the traditional mode of unilateral government supervision of the platform, and there is also information asymmetry between the government and the platform, which makes the effective supervision of the platform a practical problem that needs to be solved urgently. As a player in the bureau, merchants may become participants in illegal activities, or they may become victims of illegal activities. Encouraging merchants to participate in the process of monitoring whether the platform is operating in compliance with business rules will undoubtedly greatly reduce the high cost caused by information asymmetry. As we all know, there are many random and changeable disturbance factors in the real society, and most of the existing researches are limited to the analysis of the subject's decision in a deterministic environment, which arouses our interest. We consider a class of illegal supervision problems with random disturbances parameters. First, a traditional three-party asymmetric evolutionary game model between government, platform, and merchants is constructed. Then, on the basis of the traditional evolutionary game model, the model's replication dynamic system was improved. By adding Gaussian white noise [22-25], a random evolutionary game model with random disturbance parameters was established. We use the stability discriminant theorem of stochastic differential equations to analyze the stability of the model, and the zero solution moment exponential stability condition of the system is given. Finally, a numerical example verifies the effectiveness of this research.

The rest of this article is arranged as follows. In Section 2, some related definitions and lemmas are briefly reviewed. Section 3 provides a simple statement of the problem and hypothetical description of related parameters in the model, and gives the payment matrix of the model. In Section 4, the model is solved and improved, and the moment exponential stability of the solution is discussed. In Section 5, the stability is verified by numerical simulation. Section 6 provides some conclusions and recommendations, as well as the direction of future work.

2. **Prerequisite Knowledge.** The evolutionary game was first proposed by SMITH in 1973 when studying the phenomenon of biological evolution [26], and later it has been widely used because it is closer to reality. Its core content is evolutionary stability strategy (ESS) and replication dynamics, which respectively represent the steady state and the process of dynamic convergence to this steady state.

Definition 2.1. [27] *If for each mutant $\tau \in \Delta S$, $\exists \bar{\varepsilon} > 0$, such that for $\forall \varepsilon \in (0, \bar{\varepsilon})$ and $\mu = (1-\varepsilon)\sigma + \varepsilon\tau$, there are*

$$E_i(\sigma_i, \mu_{-i}) > E_i(\tau_i, \mu_{-i}), \quad i = 1, 2, \ldots, n$$

then the strategy $\sigma = (\sigma_1, \sigma_2, \ldots, \sigma_n) \in \Delta S$ is ESS. Among them, $E_i(\sigma_i, \mu_{-i})$ and $E_i(\tau_i, \mu_{-i})$ represent the expected return when the ith group adopts strategy σ_i and τ_i respectively, and the other groups adopt strategy μ_{-i}.

Definition 2.2. [28] *Suppose that each individual in the group adopts a pure strategy s (the value of s is $1, 2, \ldots, m$). At t, the number of individuals in the group adopting pure strategy s is $P_s(t)$, and the total number of individuals in the group is $\sum_{i=1}^{m} P_i(t)$. At this time, the proportion of using pure strategy s is $x_s(t) = \frac{P_s(t)}{\sum_{i=1}^{m} P_i(t)}$. When the group status is $X(t) = (x_1(t), \ldots, x_m(t))$, we put the equation:*

$$\frac{dx_s(t)}{dt} = x_s(E(s, X) - E(X, X)), \quad s \in S$$

It is called replication dynamic equation. Among them, $E(s,X)$ represents the income of using pure strategy s when the group status is $X(t)$, and $E(X,X)$ represents the expected return of strategy X.

Lemma 2.1. [29] *Given a stochastic differential equation:*

$$dx(t) = f(t,x(t))dt + g(t,x(t))d\omega(t), \quad x(t_0) = x_0$$

Suppose there is a function $V(t,x(t))$ and positive constants c_1, c_2, which let $c_1|x|^p \leq V(t,x(t)) \leq c_2|x|^p$, $t \geq 0$. If there is a positive constant γ, that lets $LV(t,x(t)) \leq -\gamma V(t,x(t))$, $t \geq 0$, then the pth moment exponential of the zero solution of equation is stable, and $E\,|x(t,x_0)|^p < (c_2/c_1)|x_0|^p e^{-\gamma t}$, $t \geq 0$.

3. **Problem Statement and Basic Assumptions.** It is indispensable for merchants to enter the platform through online sales, and the platform also needs to attract different merchants to settle in if the platform wants to survive. On the one hand, the platform can earn entry fees or take part of the commission. On the other hand, the platform needs merchants to settle in to attract more consumers. Therefore, many platforms may take some coercive measures when seizing market share to disrupt the market order. In this process, merchants are likely to become victims of illegal activities. Encouraging merchants to participate in the process of monitoring whether the platform is operating in compliance or not can undoubtedly greatly reduce the high costs caused by information asymmetry.

Hypothesis: Actively participating merchants may give feedback to the platform during the operation process, and the compliance platform will actively improve the deficiency, and the non-compliance platform will choose short-term benefits to ignore it. The government's supervision work can choose whether to cooperate with other participants. When the government adopts a non-cooperative strategy, it will pay a greater cost of manpower and technology for strict supervision. When the government adopts a cooperative strategy, it can reduce the investment in supervision costs and turn adopt incentive measures to encourage other entities to participate in supervision. In the model, the government, platform, and merchant all have two strategic choices: non-cooperative supervision and cooperative supervision, non-compliance and compliance, non-participation and participation. The relevant parameter settings and meanings of each participant are shown in Table 1.

Based on the above parameter assumptions, the payment matrix of the tripartite game model can be obtained, as shown in Table 2.

4. **Model Construction and Stability Analysis.** First, suppose the probabilities of government non-cooperative supervision and cooperative supervision are x and $1-x$; the probabilities of platform non-compliance and compliance are y and $1-y$; the probabilities of merchants' non-participation and participation are z and $1-z$. If the expected revenue of each strategy of the government, platform, and merchant and the average revenue of each entity are respectively U_{x1}, U_{x2}, U_{y1}, U_{y2}, U_{z1}, U_{z2}, $\bar{U}_x$, $\bar{U}_y$ and $\bar{U}_z$, then you can get government revenue:

$$\begin{aligned} U_{x1} &= yz\left(-C_1 + \alpha F + R_1\right) + y(1-z)\left(-C_1 + R_1 + \alpha F\right) + (1-y)z\left(R_1 - C_1\right) \\ &\quad + (1-y)(1-z)\left(-C_1 + R_1\right) \\ U_{x2} &= yz\left(-M_1\right) + y(1-z)\left(\alpha F - \theta M_2 - M_1\right) + (1-y)z\left(R_1 - M_1\right) \\ &\quad + (1-y)(1-z)\left(R_1 - M_1\right) \\ \bar{U}_x &= xU_{x1} + (1-x)U_{x2} \end{aligned} \tag{1}$$

TABLE 1. Related parameters and their meanings

Parameter	Meaning
C_1	The cost when the government does not cooperate in supervision
F	The government's illegal penalties for non-compliance platforms
R_1	Government reputation gains
M_1	The cost of government cooperative supervision
M_2	Government's capital investment to promote merchant participation in supervision
θ	Investment intensity
α	Punishment intensity
C_2	The compliance cost of the platform
R_2	Reputational benefits of platform compliance
W_1	Losses caused by platform non-compliance
W_2	Losses caused by platform non-compliance to merchants
A_1	Excess returns from vicious platform competition
A_2	The additional revenue earned by the platform when the merchants provide feedback
C_3	Merchant's participation cost
J	Merchants get additional benefits after successful feedback
αF	Penalty fees for platform non-compliance
θM_2	Merchant's participation income

TABLE 2. Game payment matrix

Subject strategy selection and effectiveness		Merchant (non-participation)	Merchant (participation)
Government (non-cooperative supervision)	Platform (non-compliance)	$\alpha F + R_1 - C_1$ $A_1 - \alpha F - W_1$ $-W_2$	$-C_1 + R_1 + \alpha F$ $A_1 - \alpha F - W_1$ $-C_3 - W_2$
	Platform (compliance)	$-C_1 + R_1$ $-C_2 + R_2$ 0	$-C_1 + R_1$ $-C_2 + A_2 + R_2$ J
Government (cooperative supervision)	Platform (non-compliance)	$-M_1$ $A_1 - W_1$ $-W_2$	$\alpha F - \theta M_2 - M_1$ $A_1 - W_1 - \alpha F$ $-C_3 + \theta M_2 - W_2$
	Platform (compliance)	$R_1 - M_1$ $-C_2 + R_2$ 0	$R_1 - M_1$ $-C_2 + A_2 + R_2$ J

Platform revenue:

$$\begin{aligned} U_{y1} &= xz\left(A_1 - \alpha F - W_1\right) + x(1-z)\left(A_1 - W_1 - \alpha F\right) + (1-x)z\left(A_1 - W_1\right) \\ &\quad + (1-x)(1-z)\left(A_1 - \alpha F - W_1\right) \\ U_{y2} &= xz\left(R_2 - C_2\right) + x(1-z)\left(A_2 + R_2 - C_2\right) + (1-x)z\left(R_2 - C_2\right) \\ &\quad + (1-x)(1-z)\left(A_2 + R_2 - C_2\right) \\ \bar{U}_y &= yU_{y1} + (1-y)U_{y2} \end{aligned} \tag{2}$$

Merchant's revenue:

$$\begin{aligned} U_{z1} &= xy\left(-W_2\right)+(1-x)y\left(-W_2\right) \\ U_{z2} &= xy\left(-C_3-W_2\right)+x(1-y)\left(J\right)+(1-x)y\left(\theta M_2-C_3-W_2\right) \\ &\quad +(1-x)(1-y)\left(J\right) \\ \bar{U}_z &= zU_{z1}+(1-z)U_{z2} \end{aligned} \tag{3}$$

From this, the dynamic equation of replication of each participant:

$$\begin{aligned} F(x,y,z) &= \frac{dx}{dt}=x\left(U_{x1}-\bar{U}_x\right) \\ &= x(1-x)\left\{y\left[z\left(\alpha F-\theta M_2\right)+R_1+\theta M_2\right]-C_1+M_1\right\} \end{aligned} \tag{4}$$

$$\begin{aligned} G(x,y,z) &= \frac{dy}{dt}=y\left(U_{y1}-\bar{U}_y\right) \\ &= y(1-y)\left\{z\left[x(-\alpha F)+\alpha F+A_2\right]+A_1-\alpha F-W_1+C_2-A_2-R_2\right\} \end{aligned} \tag{5}$$

$$H(x,y,z)=\frac{dz}{dt}=z\left(U_{z1}-\bar{U}_z\right)=z(1-z)\left[y\left(\theta M_2x+C_3-\theta M_2+J\right)-J\right] \tag{6}$$

Since there is $x,y,z\in[0,1]$ in the model $1-x$, $1-y$, and $1-z$ are all non-negative numbers, which will not affect the evolution of the model. Therefore, we can modify Equations (4)-(6) and change them to:

$$F(x,y,z)=\frac{dx}{dt}=x\left(U_{x1}-U_{x2}\right)=x\left\{y\left[z\left(\alpha F-\theta M_2\right)+R_1+\theta M_2\right]-C_1+M_1\right\} \tag{7}$$

$$\begin{aligned} G(x,y,z) &= \frac{dy}{dt}=y\left(U_{y1}-U_{y2}\right) \\ &= y\left\{z\left[x(-\alpha F)+\alpha F+A_2\right]+A_1-\alpha F-W_1+C_2-A_2-R_2\right\} \end{aligned} \tag{8}$$

$$H(x,y,z)=\frac{dz}{at}=z\left(U_{z1}-U_{z2}\right)=z\left[y\left(\theta M_2x+C_3-\theta M_2+J\right)-J\right] \tag{9}$$

Adding Gaussian white noise to the above equations can be obtained:

$$dx(t)=\left\{y(t)\left[z(t)\left(\alpha F-\theta M_2\right)+R_1+\theta M_2\right]-C_1+M_1\right\}x(t)dt+\sigma x(t)d\omega(t) \tag{10}$$

$$\begin{aligned} dy(t) &= \left\{z(t)\left[x(t)(-\alpha F)+\alpha F+A_2\right]+A_1-\alpha F-W_1+C_2-A_2-R_2\right\}y(t)dt \\ &\quad +\sigma y(t)d\omega(t) \end{aligned} \tag{11}$$

$$dz(t)=\left[y(t)\left(\theta M_2x(t)+C_3-\theta M_2+J\right)-J\right]z(t)dt+\sigma z(t)d\omega(t) \tag{12}$$

When the strategies adopted by the three participating groups are cooperation, compliance, and participation, an initial profit distribution plan is provided. Only when the three groups accept the plan, the system is in a stable state, that is, the original value is $x(t)=0$, $y(t)=0$, $z(t)=0$, Equations (10)-(12) have solutions, which shows that the system will always be in this stable state without external interference. However, the situation of being undisturbed does not exist in reality. Each subject will inevitably be interfered by factors such as emotions, profit-seeking psychology and morality, and then affect the stability of the system. Therefore, we must consider the impact of random disturbances on the system.

According to Lemma 2.1, for Equations (10)-(12), let $V(t,x(t))=x(t)$, $V(t,y(t))=y(t)$, $V(t,z(t))=z(t)$, $x(t)\in[0,1]$, $y(t)\in[0,1]$, $z(t)\in[0,1]$, $c_1=c_2=1$, $p=1$, $\gamma=1$, then

$$\begin{aligned} LV(t,x(t)) &= f(t,x(t))=\left\{y(t)\left[z(t)\left(\alpha F-\theta M_2\right)+R_1+\theta M_2\right]-C_1+M_1\right\}x(t) \\ LV(t,y(t)) &= f(t,y(t)) \\ &= \left\{z(t)\left[x(t)(-\alpha F)+\alpha F+A_2\right]+A_1-\alpha F-W_1+C_2-A_2-R_2\right\}y(t) \end{aligned}$$

$$LV(t, z(t)) = f(t, z(t)) = [y(t)(\theta M_2 x(t) + C_3 - \theta M_2 + J) - J] z(t)$$

If Equations (10)-(12) are exponentially stable with zero solution moment, it must satisfy

$$\{y(t)[z(t)(\alpha F - \theta M_2) + R_1 + \theta M_2] - C_1 + M_1\} x(t) < -x(t) \tag{13}$$

$$\{z(t)[x(t)(-\alpha F) + \alpha F + A_2] + A_1 - \alpha F - W_1 + C_2 - A_2 - R_2\} y(t) < -y(t) \tag{14}$$

$$[y(t)(\theta M_2 x(t) + C_3 - \theta M_2 + J) - J] z(t) < -z(t) \tag{15}$$

Since $x(t) \in [0,1]$, $y(t) \in [0,1]$, $z(t) \in [0,1]$, there will be the corresponding formula reduction and obtain the following conditions: a: $C_1 - M_1 - 1 \geq 0$; b: $-A_1 + \alpha F + W_1 - C_2 + A_2 + R_2 - 1 \geq 0$; c_1: When $C_3 - \theta M_2 + J \geq 0$, $J - 1 \geq 0$, c_2: When $C_3 - \theta M_2 + J < 0$, $C_3 - \theta M_2 + 1 \leq 0$. Therefore, if Equations (10)-(12) satisfy the zero moment exponential stability, the following conditions are satisfied:

$$a \cap b \cap (c_1 \cup c_2)$$

5. **Simulation.** Through the above analysis, we have obtained the stability conditions of the system. In order to more clearly show the influence of different disturbance intensities on the stability of the main body, the results of the above discussion were simulated and verified by MATLAB. Suppose the govemment's non-cooperative supervision cost is $C_1 = 4.3$; the govemment's illegal punishment for non-compliance platforms is $F = 4$; the government's reputation benefit is $R_1 = 3$; the government's investment cost of cooperative supervision is $M_1 = 1.5$; the government's capital investment to promote merchants' participation in supervision is $M_2 = 3.5$; the govemment's investment and penalties are respectively $\theta = 0.5$ and $\alpha = 0.5$; the compliance operating cost of the platform is $C_2 = 2.5$; the reputation benefit of the platform compliance is $R_2 = 2.1$; the losses of the platform's non-compliance operation to itself and the merchant are $W_1 = 4$ and $W_2 = 3$; the excess revenue of the vicious competition of the platform is $A_1 = 5$; the additional revenue obtained by the merchants through information feedback to the platform is $A_2 = 2$; the participation cost of the merchants is $C_3 = 1.8$; the additional revenue obtained by the merchants after successful feedback of information is $J = 2.5$. At this time, the conditions $C_1 - M_1 - 1 \geq 0$, $-A_1 + \alpha F + W_1 - C_2 + A_2 + R_2 - 1 \geq 0$, $C_3 - \theta M_2 + J \geq 0$, $J - 1 \geq 0$ are satisfied, that is, the parameter setting satisfies condition $a \cap b \cap (c_1 \cup c_2)$. By changing the value of random disturbance intensity σ, we can observe the influence of disturbances of different intensities on the decision-making of each group. We take σ as 0, 1, and 2, and set the initial values $x(0)$, $y(0)$, and $z(0)$ as 0.5, and then we can obtain the following diagrams of the evolution of each agent's strategy.

According to Figures 1, 2 and 3, we can get the strategy evolution of each subject under the disturbance of uncertain factors in the "government-platform-merchant" tripartite model. Through the volatility of the curve, we can know that random disturbances have impact on the decision-making of each subject. This shows that in the actual game process of the group, uncertain random factors such as the group's mood, profit-seeking psychology and morality will have an impact on the subject's decision-making behavior. As the intensity of the disturbance increases, the time for each subject to evolve to a stable strategy also increases, and the greater the intensity of the disturbance, the greater the volatility of the evolution curve. It shows that when the intensity of random disturbances to the government, platforms, and merchants increases, the difficulty for the three participants to adopt cooperation, compliance, and participation strategies increases accordingly. Comparing the three graphs, it is found that under the current values, the three participating groups of government, platform, and merchant have evolved to a stable strategy almost simultaneously. When the value of σ is 2, the curve in Figure

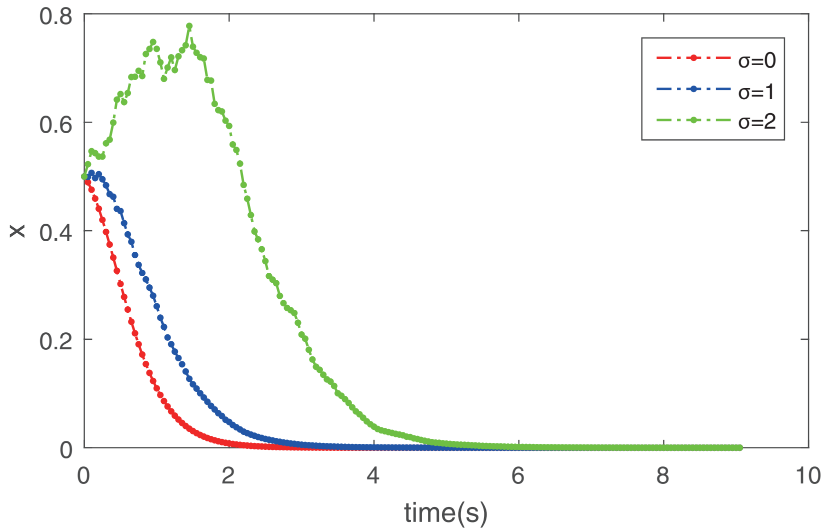

FIGURE 1. The impact of different disturbance intensities on government decision-making

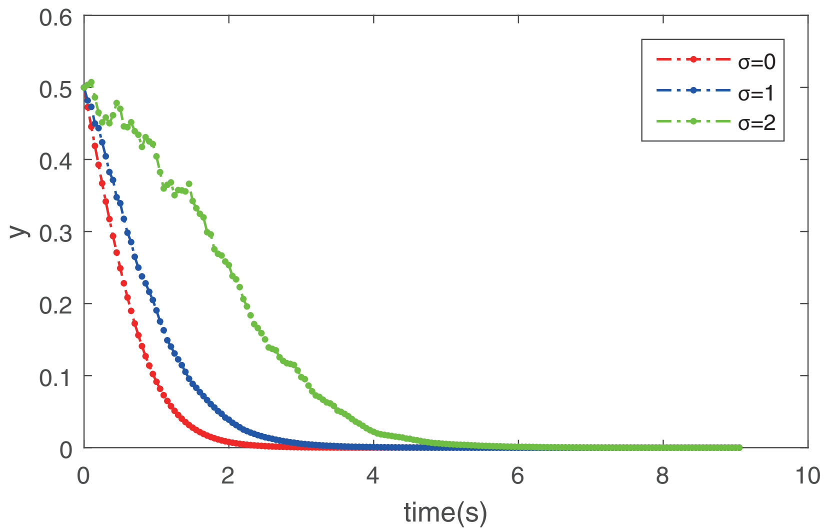

FIGURE 2. The impact of different disturbance intensities on platform decision-making

1 fluctuates more. It shows that in this case, random disturbance has a greater impact on the government's decision-making behavior. In general, the random graph also truly reflects the influence of random disturbance factors on the decision-making of the government, platforms, and merchants groups. This requires that in the actual supervision process, the government supervision department should formulate detailed plans to minimize the influence of uncertain factors such as social conflicts and group emotions on the decision-making of the subject. In addition, the government can improve relevant laws and regulations, clear responsibilities related to the subject, to establish an effective incentive mechanism and other methods to eliminate the presence of opportunism and promote development platform.

6. **Conclusion.** The development of platform-type enterprises has greatly influenced the environment and development of the online sales market. Considering that there are many randomized disturbance factors in the real society, this paper adds Gaussian white noise

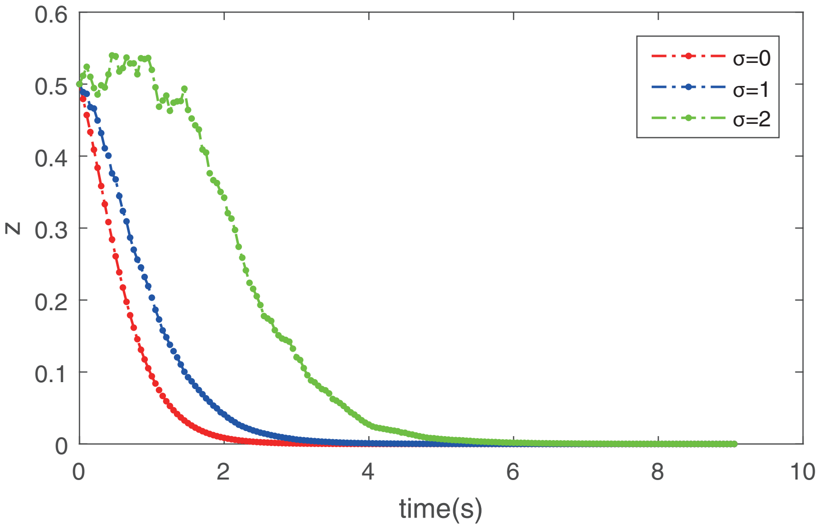

FIGURE 3. The impact of different disturbance intensities on merchant decision-making

on the basis of the evolutionary games to reflect the main decision-making evolution process. The random evolutionary model between government-platform-merchants, analyzes strategic evolutionary stability, and simulates the evolution process. The study found that random disturbance has a certain impact on the decision-making of each subject. As the intensity of the disturbance increases, the time for each agent to evolve to a stable strategy will be extended and the volatility of the evolution curve will also increase, but the strategy will evolve to a stable state after a period of time. It is worth noting that although this article has a certain role in promoting the construction of the platform's illegal supervision system, in reality, the benefits of all parties to online transactions are very complicated. This article is a research on the basis of simplification, and further research is needed for specific cases involving actual benefits.

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