Evolutionary Game Analysis of Supervisory Decision Behavior of Third-party Trading Platform

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Abstract. This paper constructs an asymmetric evolutionary game model between the “government-platform-consumer” three parties, uses Jacobian matrix and Lyapunov’s first method to analyze its replication dynamic equation, and discusses the influence of the main parameters on the agent’s decision-making behavior. Then, MATLAB simulation was used to demonstrate the gradual trend in different situations, with a view to providing a decision-making reference for the benign development of the third-party trading platform.

1. Introduction
With the development of electronic commerce, illegal behaviors such as false propaganda, counterfeiting, and fraudulent transactions caused by factors such as network virtualization and information asymmetry have become more serious. Although the state has perfected the relevant legal system and clarified the platform’s regulatory obligations to the merchants [1], for the sake of its own interests and development, the platform not only cannot effectively supervise, but it may even appear to cover merchants and other illegal laws. [2].

At present, more and more scholars apply evolutionary game theory to the illegal supervision of network economy. The core content of evolutionary game theory is evolutionary stability strategy and replication dynamics. It mainly uses dynamic methods to study the strategy selection process of individuals in a group. Replication dynamics is an important method for studying the selection process during evolution. It describes the frequency of a specific strategy being adopted in a population.

In recent years, most scholars have focused on the platform’s research on illegal supervision of settled businesses [3-11], and few people have paid attention to the effectiveness of platform supervision. In order to urge the platform to be carefully regulated, literature [12] constructed a two-party game between the government and the platform, but in actual supervision, there is information asymmetry between the government and the platform, and its supervision requires high costs, while consumers as a direct user of goods or services and a victim of illegal behavior, it has a unique advantage in monitoring the illegality of the network economy. Therefore, this paper builds an evolutionary game model between “government-platform-consumer” and draws on the analysis methods in [13-14] to study the supervision of third-party trading platforms from the perspective of social co-governance.

2. The Basic Assumptions and Model Building
Assume that the three participants are all limited rational economic agents. In the model, the government, platform, and consumers all have two strategic choices: supervision and non-supervision, feasance and non-feasance, participation and non-participation. Assume that the relevant parameters of each subject are as follows:

B : Policy support or financial subsidy given by the government to the platform;
$E$: Rewards for information feedback given to consumers by the platform;
$C$: Cost of government regulation; $F$: Government punishment for non-feasance platforms;
$R$: Improvement of government credibility; $A$: Platform non-feasance Loss of revenue;
$C + C$ and $U + U$: Cost and psychological benefits of consumer participation in information feedback and reporting;
$J$: The beneficial impact of government regulatory decisions on consumers;
$J$ and $J$: The negative effects of platform non-feasance on the government and consumers.

Generally, we think that the above parameters are all positive, and $F + R > C_1$, $F + A > C_2$. From this, we can get the payment matrix of the tripartite game model, as shown in Table 1.

### Table 1. Game payment matrix.

| Subject strategy selection and effectiveness | Consumer (Participation) | Consumer (Non-participation) |
|---------------------------------------------|--------------------------|-------------------------------|
| Platform (Feasance)                         | $A_1 - C_1 - B + R$      | $A_1 - B - C_1 + R$          |
|                                             | $A_2 + A_1 + B - E_1 - C_2$ | $A_2 + B - C_2$              |
|                                             | $E_1 - C_3 + J_1 + U_1$  | $J_1$                        |
| Government (Supervision)                    | $A_1 - B - C_1 + F - E_2 - J_2 + R$ | $A_1 - B - C_1 + F - J_2 + R$ |
| Platform (Non-feasance)                     | $A_2 - A_1 + A_1 + B - F - E_1$ | $A_2 + B - F - A_3$          |
|                                             | $E_1 + E_2 - C_3 - C_4 - J_1 - J_3 + J_1 + U_1 + U_2$ | $J_1 - J_3$               |
| Government (Feasance)                       | $A_1 - B + R$             | $A_1 - B + R$                |
| Platform (Non-feasance)                     | $A_2 + A_1 + B - C_1$     | $A_2 + B - C_1$              |
|                                             | $E_1 - C_3 + U_1$         | $0$                          |
| Government (Non-supervision)                | $A_1 - B + F - E_2 - J_2$ | $A_1 - B - J_2$              |
| Platform (Feasance)                         | $A_2 - A_1 + A_1 + B - + E_1 - F$ | $A_1 + B - A_3$              |
|                                             | $E_1 + E_2 - C_3 - C_4 - J_3 + U_1 + U_2$ | $-J_3$                      |

### 3. Analysis of the Stability of the Main Body Evolution
Suppose the probability of government supervision and non-supervision is $x$ and $1 - x$; The probability of platform feasance and non-feasance is $y$ and $1 - y$; The probability of consumer participation and non-participation is $z$ and $1 - z$.

#### 3.1. Dynamic Analysis of the Replication of the Three Parties Involved
The expected benefits $U_{s_1}$ and $U_{s_2}$ of the government’s “supervision” and “non-supervision” strategies are:

$$U_{s_1} = y (-C_1 - B + R) + (1 - y) (-E_2 z - B - C_1 + F - J_2 + R)$$

$$U_{s_2} = y (-B + R) + (1 - y) [z (F - E_2) + B - J_2]$$

The expected benefits $U_{s_1}$ and $U_{s_2}$ of the platform’s “feasance” and “non-feasance” strategies are:
\[ U_{s1} = (1 - z)(B - C_z) + z(A_i + B - E_i - C_z) \]
\[ U_{s2} = (1 - z)(-Fx + B - A_i) + z(-A_i + A_i - E_i + B - F) \]

The expected benefits \( U_{s1} \) and \( U_{s2} \) of consumers’ “participation” and “non-participation” strategies are:

\[ U_{s1} = -y(E_z - C_z - J_z + U_z) + xJ_l + E_i + E_z - C_z - C_i - J_z + U_i + U_z \]
\[ U_{s2} = xJ_l + yJ_z - J_z \]

From the above analysis, the replication dynamic equations of the government, platform, and consumers are:

\[ F(x) = x(1 - x)(U_{s1} - U_{s2}) = x(1 - x)\left[ -y(-zF + F + R) + (-zF - C_i + F + R) \right] \]

(1) Analysis of the government’s replication dynamics:

(i) When \(-y(-zF + F + R) + (-zF - C_i + F + R) = 0\), we have \( F(x) \equiv 0 \), no matter what value \( x \) takes at this time, the government’s decision is stable.

(ii) When \(-y(-zF + F + R) + (-zF - C_i + F + R) \neq 0\), let \( F(x) = 0 \), we get \( x = 0 \), \( x = 1 \) two equilibrium points.

Differentiate \( F(z) \):

\[ F'(x) = (1 - 2x)\left[ -y(-zF + F + R) + (-zF - C_i + F + R) \right] \]

When \( F + R - C_i / F + R < y \leq 1 \), we have \( F'(x) \big|_{x>0} < 0 \), \( F'(x) \big|_{x<1} > 0 \), then \( x = 0 \) is a stable point, that is, the government will tend to adopt a unsupervised strategy due to the comprehensive consideration of costs and benefits.

When the above conditions are not met, the government’s decision-making will have the following two situations: if \( y <-Fz + F + R - C_i / -Fz + F + R \), then \( F'(x) \big|_{x>0} > 0 \), \( F'(x) \big|_{x<1} < 0 \), so \( x = 1 \) is a stable point, and the government will eventually tend to adopt a supervised strategy; if \( y > -Fz + F + R - C_i / -Fz + F + R \), then \( F'(x) \big|_{x>0} < 0 \), \( F'(x) \big|_{x<1} > 0 \), so \( x = 0 \) is a stable point, and the government will eventually tend to adopt an unsupervised strategy.

It can be seen that the evolutionary stable state of government group supervision decision-making is closely related to the platform and consumer group decision-making. The government’s strategic choice is the result of a three-party game.

Similarly, the decision-making evolution of the platform can be proved.

(2) Unlike the government and platforms, the consumer replication dynamics are only related to \( y \).

The specific analysis is as follows:

(i) When \(-y(E_z - C_z + U_z) + E_i + E_z - C_z - C_i + U_i + U_z = 0\), we have \( F(z) \equiv 0 \), no matter what value \( z \) takes, the consumer’s decision is stable.

(ii) When \(-y(E_z - C_z + U_z) + E_i + E_z - C_z - C_i + U_i + U_z \neq 0\), let \( F(z) = 0 \), we get \( z = 0 \), \( z = 1 \) two equilibrium points.

Differentiate \( F(z) \):

\[ F'(z) = (1 - 2z)\left[ -y(E_z - C_z + U_z) + E_i + E_z - C_z - C_i + U_i + U_z \right] \]

According to the game payment matrix, we know that \( E_i - C_z + U_i \) and \( E_i + E_z - C_z - C_i + U_i + U_z \)
are the relative net income of consumer participation when the platform feasance and non-feasance. If they are both negative, the consumer’s income is negative and tends to take non-participation decisions, so at least one of the relative net income must be positive. The specific analysis is as follows:

When \( E_i - C_i + U_i > 0 \) and \( E_i + E_z - C_3 - C_4 + U_1 + U_2 > 0 \), there are \( F'(z)|_{z>0} > 0 \) and \( F'(z)|_{z<0} < 0 \), then \( z = 1 \) is the stable point.

When \( E_i - C_i + U_i < 0 \) and \( E_i + E_z - C_3 - C_4 + U_1 + U_2 > 0 \), there are two cases: if \( y < E_i + E_z - C_3 - C_4 + U_1 + U_2 / E_z - C_4 + U_2 \), then \( F'(z)|_{z>0} > 0 \), \( F'(z)|_{z<1} < 0 \), so \( z = 1 \) is the stable point; if \( y > E_i + E_z - C_3 - C_4 + U_1 + U_2 / E_z - C_4 + U_2 \), then \( F'(z)|_{z<0} < 0 \), \( F'(z)|_{z=1} > 0 \), so \( z = 0 \) is the stable point.

Similarly, we can get the stability of the decision when \( E_i - C_3 + U_i > 0 \) and \( E_i + E_z - C_3 - C_4 + U_1 + U_2 < 0 \).

3.2. Evolutionary Stability Analysis of the Three-party Game System

Due to the long-term interest game between the government, platform and consumers, the equations (1)-(3) are combined to establish a replication dynamic system of the three parties:

\[
\begin{align*}
F(x) &= x(1-x)\left[ -y(-zF + F + R) - zF - C_i + F + R \right] \\
F(y) &= y(1-y)\left[ x(F - zF) + zF + A_3 - C_i \right] \\
F(z) &= z(1-z)\left[ -y(E_2 - C_4 + U_1 + U_2) + E_i + E_z - C_3 - C_4 + U_1 + U_2 \right]
\end{align*}
\]

From this, the equilibrium point of the system is obtained, and only the stability analysis of points \( P_1(0,0,0), P_2(1,0,0), P_3(0,1,0), P_4(1,1,0), P_5(0,1,1), P_6(1,0,1), P_7(1,1,1) \) is needed[15]. The Jacobian matrix of the system is:

\[
J = \begin{bmatrix}
(1-2x)(U_{11} - U_{22}) & x(1-x)(zF - F - R) & x(1-x)(yF - F) \\
y(1-y)(F - zF) & (1-2y)(U_{11} - U_{22}) & y(1-y)(-xF + F) \\
0 & z(1-z)(C_4 - E_2 - U_2) & (1-2z)(U_{11} - U_{22})
\end{bmatrix}
\]

Among them: \( U_{11} - U_{22} = -y(-zF + F + R) - zF - C_i + F + R \);

\[
U_{11} - U_{22} = x(F - zF) + zF + A_3 - C_2 - 1;
\]

\[
U_{11} - U_{22} = -y(E_2 - C_4 + U_1 + U_2) + E_i + E_z - C_3 - C_4 + U_1 + U_2 .
\]

Therefore, we can get the characteristic roots corresponding to each point:

The characteristic roots of \( P_1 \) are: \(-C_i + F + R, A_3 - C_3, E_i + E_z - C_4 + U_1 + U_2;\)

The characteristic roots of \( P_2 \) are: \( C_i - F - R, F + A_3 - C_2, E_i + E_z - C_4 + U_1 + U_2;\)

The characteristic roots of \( P_3 \) are: \(-C_i, C_2 - A_i, E_i - C_3 + U_1;\)

The characteristic roots of \( P_4 \) are: \(-C_i + R, F + A_3 - C_2, C_3 + C_4 - E_i - E_z - U_1 - U_2;\)

The characteristic roots of \( P_5 \) are: \( C_1, C_2 - F - A_i, E_i - C_3 + U_1;\)

The characteristic roots of \( P_6 \) are: \( C_1 - R, F + A_3 - C_2, C_3 + C_4 - E_i - E_z - U_1 - U_2;\)

The characteristic roots of \( P_7 \) are: \(-C_i, C_2 - F - A_i, C_3 - E_i - U_1;\)

The characteristic roots of \( P_8 \) are: \( C_1, C_2 - F - A_i, C_3 - E_i - U_1.\)
According to Lyapunov’s first method, since \( F + R > C_1 \), \( F + A_1 > C_2 \), \( C_i > 0 \), so that \( P_1, P_2, P_4, P_5, P_6, P_8 \) are unstable points.

When \( C_i < E_i + U_i \), point \( P_i(0,1,1) \) is the asymptotically stable point of the replication dynamic system, that is, when the cost of satisfying consumer participation in information feedback is lower than the benefit, the three-party game model will evolve into an ideal state, and the government does not need to pay a lot of effort. During supervision, the platform has adopted serious supervision strategies to make a difference, and consumers have also actively participated in the development of the e-commerce market and the process of illegal supervision.

When \( C_i > E_i + U_i \) and \( C_j < A_j \), point \( P_j(0,1,0) \) is the asymptotically stable point of the replication dynamic system. Explain that when the cost of consumer participation in information feedback is higher than the benefit, although consumers will tend not to urge, but by reducing the regulatory cost of the platform and increasing its inaction, it can also be carefully monitored by the platform.

4. Simulation

For the system can evolve to an ideal state eventually, the parameter setting needs to satisfy the conditions \( F + A_j < C_2 \) and \( C_j < E_i + U_i \). This article assumes: \( F = 5 \), \( R = 6 \), \( C_i = 4 \), \( A_j = 3.8 \), \( C_2 = 4.3 \), \( E_i = 3.5 \), \( E_2 = 4.1 \), \( C_j = 3.5 \), \( C_4 = 4.5 \), \( U_i = 2 \), \( U_2 = 3 \).

Based on the above conditions, the initial \( x = 0.5 \) is fixed, and by adjusting the values of \( y \) and \( z \), the evolution graph of \( x \) with time \( t \) under different initial conditions is obtained, as shown in Figure 1. In the evolution process, \( x \) is not monotonic, and the larger the initial values of \( y \) and \( z \), the faster \( x \) evolves to 0, indicating that the higher the proportion of active participation by the platform and consumers, the time it takes for the government to evolve to a non-supervision strategy shorter.

Fixing the initial \( y = 0.3 \), by adjusting the values of \( x \) and \( z \), the evolution graph of \( y \) with time \( t \) under different initial conditions is obtained, as shown in Figure 2. The function curve is monotonically increasing, and the larger the initial values of \( x \) and \( z \), the faster \( y \) will converge. It shows that the higher the proportion of government and consumer supervision is, the faster the platform will evolve to the feasance strategy, until all evolve into the feasance strategy.

**Figure 1.** Evolution of \( x \) with time \( t \) when the initial values of \( y \) and \( z \) change.

**Figure 2.** Evolution of \( y \) with time \( t \) when the initial values of \( x \) and \( z \) change.

Fixing the initial \( z = 0.3 \), by adjusting the values of \( x \) and \( y \), the evolution graph of \( z \) with time
$t$ under different initial conditions is obtained, as shown in Figure 3. Similarly, the values of $x$ and $y$ only affect the convergence rate of $z$, and will not change its monotonicity. With the increase in the proportion of the government and the platforms, the evolution of consumers toward the participation strategy slows down, and eventually all evolve into participation strategy. Taking the initial values $x = 0.3$, $y = 0.4$, $z = 0.5$; $x = 0.2$, $y = 0.7$, $z = 0.4$; $x = 0.5$, $y = 0.3$, $z = 0.8$ as an example, the evolution of the three-party game system is demonstrated in a three-dimensional coordinate system the trend eventually stabilized at point $P(0,1,1)$, as shown in Figure 4.

5. Conclusions and Recommendations

Through the analysis of this paper, it is found that the three parties will have an influence on each other. The active participation of consumers and the strengthen supervision of the government can effectively supervise the platform, and fully mobilizing the enthusiasm of consumers can effectively compensate for the lack of government supervision; Measures such as improving consumer’s rights protection awareness and social responsibility, and reducing the difficulty and cost of rights protection are conducive to promoting the evolution of the platform’s behavior towards a serious feasance strategy.

The government should further refine the relevant laws and regulations, urge the platform to improve its internal evaluation system as soon as possible, establish a complete information sharing mechanism and reporting channel, increase the penalties for violations and non-feasance, reduce feasance costs, and guide the platform to actively effective supervision of business activities, reasonable use of media and other effective ways to increase publicity of relevant laws and regulations, cultivate public awareness of law and social responsibility, and fully mobilize the enthusiasm of consumers to protect their rights and supervision, so that consumer participation has become a deterrent to crime. The main force.

The limitation of this article is that it only considers the two strategic choices of the three groups of government, platform and consumer. However, in the actual supervision process, there are other participating groups and various strategic choices of each participating subject, which needs to be continued the study.

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