Classification of municipal solid waste based on Game Analysis

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Abstract. With the increasing amount of garbage, every city gradually enforces the implementation of garbage classification. Aiming at the problem of garbage classification, a garbage classification implementation model based on the tripartite game among managers (government), producers (production enterprises) and consumers (residents) is constructed by using the method of dynamic game. Matlab is used to simulate and analyze the dynamic equation of tripartite replication, and find out the optimal strategy suitable for the three parties, then put forward measures to improve the way of waste classification, so as to reduce the amount of waste in a real sense and improve people's living standards.

1. Introduction
With the improvement of people's living standards and the increase of various consumption, garbage is increasing. According to the data of the statistical yearbook of urban and rural construction in 2018, the amount of domestic garbage removed and transported in China has gradually increased, exceeding 200 million tons in 16 years, reaching 216 million tons in 17 years and 228 million tons in 18 years, with an increase ratio of 5.56%. In the face of such a huge amount of data, garbage classification has become an urgent task [1-3].

At present, scholars at home and abroad have done a lot of research on waste classification [4-6]. Wang Wei [7] played games with residents, collection and transportation enterprises and processing enterprises as the main body, and analyzed the responsibility ratio among the three parties; Xu Zhenxiao [8] and Wang Dandan [9] played games with residents, government and processing enterprises as the main body, and analyzed the behavior of the three parties. But at present, few literatures take production enterprises into account. As producers of products, producers are the source of waste, and they are also important participants in waste classification. In this regard, this paper analyzes the decision-making behavior of the three main bodies of waste classification, producers, consumers and managers, explores the dynamic game between the main bodies with the help of evolutionary game theory, and uses MATLAB to simulate the evolution process to find out the optimal solution of the three parties, so as to realize waste classification in the maximization of the three parties’ interests, improve environment and realize sustainable development.

2. Tripartite game model

2.1. Model Assumption And Parameter Setting
Three main subjects are selected: government, production enterprises and residents.
Hypothesis 1: The three players in the game are all bounded rational and maximize their own interests. The behavioral strategy sets of government, production enterprises and residents are (supervision, non supervision), (responsible production, irresponsible production) (participate in waste classification, not participate in waste classification).

Hypothesis 2: Set the probability of government group choosing to supervise is x; the probability of enterprise group choosing responsible production is y; the probability of residents group choosing to participate in waste classification is z. At the same time, \( x, y, z \in [0,1] \).

Hypothesis 3: The behaviors of the three parties influence each other. When one party adjusts the strategy, the other two participants will adjust the strategy accordingly.

Based on the above assumptions, the relevant parameter symbols are set, as shown in Table 1.

### Table 1. The assumption of related parameter

| Symbol | Meaning |
|--------|---------|
| a      | The cost of the government's supervision on residents and the production enterprises |
| b      | The government give the incentive subsidies to production enterprises have the responsibility to produce |
| b      | Remedial cost taken by government caused by the failure of residents to classify garbage due to the irresponsible production of production enterprises |
| d      | Incentives and subsidies of government departments for residents to classify garbage |
| e      | Comprehensive income from the government's regulation of waste classification and recycling and regular treatment |
| f      | When enterprises are responsible for production, the cost of they design products and increase classification identification. |
| g      | The increased operating cost of recycling waste materials after the enterprise has the responsibility to produce, and the residents need to classify the garbage |
| h      | The increased operating cost of recycling waste materials after the enterprise has the responsibility to produce when the residents do not classify the garbage |
| i      | Income from recycling of enterprises |
| j      | Producers who do not recycle their products will be punished by the government |
| k      | The time and physical cost for residents to adopt classification behavior when they design products and add classification labels to production enterprises |
| l      | The time and physical cost for residents to adopt classification behavior when the production enterprise does not design products or add classification labels |
| m      | The cost of government punish when Residents do not classify the garbage and discard it directly |
| n      | Residents choose garbage classification, which brings positive effects |

According to the relevant parameter setting, the decision-making behavior of the three parties in the game and the income matrix are shown in Table 2.

### Table 2. Gain matrix

| Symbol | Meaning |
|--------|---------|
|    a   | The cost of the government's supervision on residents and the production enterprises |
|    b   | The government give the incentive subsidies to production enterprises have the responsibility to produce |
|    b   | Remedial cost taken by government caused by the failure of residents to classify garbage due to the irresponsible production of production enterprises |
|    d   | Incentives and subsidies of government departments for residents to classify garbage |
|    e   | Comprehensive income from the government's regulation of waste classification and recycling and regular treatment |
|    f   | When enterprises are responsible for production, the cost of they design products and increase classification identification. |
|    g   | The increased operating cost of recycling waste materials after the enterprise has the responsibility to produce, and the residents need to classify the garbage |
|    h   | The increased operating cost of recycling waste materials after the enterprise has the responsibility to produce when the residents do not classify the garbage |
|    i   | Income from recycling of enterprises |
|    j   | Producers who do not recycle their products will be punished by the government |
|    k   | The time and physical cost for residents to adopt classification behavior when they design products and add classification labels to production enterprises |
|    l   | The time and physical cost for residents to adopt classification behavior when the production enterprise does not design products or add classification labels |
|    m   | The cost of government punish when Residents do not classify the garbage and discard it directly |
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2.2. Evolution model analysis

The expected return of the government's choice of supervision and non supervision is \( E_s \) and \( E_{s'} \), and the average expected return is \( E_s \), which can be obtained from table 2,
\[ E_{a_1} = yz(-a-b+d+e) + y(1-z)(-a-b+e+m) + z(1-y)(-a-d+j) + (1-y)(1-z)(-a-c+j+m) \]  
(1)

\[ E_{a_2} = (1-y)(1-z)(-c) \]  
(2)

\[ E_{a} = xE_{a_2} + (1-x)E_{a_2} \]  
(3)

If the manufacturer chooses responsible production and irresponsible production, the expected revenue is \( E_{b_1} \) and \( E_{b_2} \), and the average expected revenue is \( E_{b} \), the same can be obtained.

\[ E_{b_1} = xz(b-f-g+i) + x(1-z)(b-f-h+i) + z(1-x)(-f-g+i) + (1-x)(1-z)(-f-h+i) \]  
(4)

\[ E_{b_2} = xz(-j) + x(1-z)(-j) \]  
(5)

\[ E_{b} = yE_{b_1} + (1-y)E_{b_2} \]  
(6)

The expected income of residents who choose to participate in waste classification or not is set as \( E_{c_1} \) and \( E_{c_2} \), and the average expected income is \( E_{c} \), the same can be obtained.

\[ E_{c_1} = xy(d-k+n) + x(1-y)(d-l+n) + y(1-x)(-k+n) + (1-x)(1-y)(-l+n) \]  
(7)

\[ E_{c_2} = xy(-m) + x(1-y)(-m) \]  
(8)

\[ E_{c} = zE_{c_1} + (1-z)(E_{c_2}) \]  
(9)

According to the evolutionary game theory, the replication dynamic equations of government, production enterprises and residents are as follows.

\[ F(x) = \frac{d}{dt}x(E_{a_1} - E_{a_2}) = x(1-x)(E_{a_1} - E_{a_2}) = x(1-x)[y(-b+e-j) + z(-d-b+m) - a + j + m] \]  
(10)

\[ F(y) = \frac{d}{dt}y(E_{b_1} - E_{b_2}) = y(1-y)(E_{b_1} - E_{b_2}) = y(1-y)[z(-g+h) + x(b+j) - f-h+i] \]  
(11)

\[ F(z) = \frac{d}{dt}z(E_{c_1} - E_{c_2}) = z(1-z)(E_{c_1} - E_{c_2}) = z(1-z)[y(-k+l) + x(d+m) + l-n] \]  
(12)

### 2.3. Stability Analysis

#### 2.3.1. The Stability Of The Tripartite Strategy

According to the conclusion of Ritzberger and Weibull (1996), we only need to analyze the stability of eight equilibrium points, such as \( X_1 = (0,0,0) \), \( X_2 = (0,1,0) \), \( X_3 = (0,0,1) \), \( X_4 = (0,1,1) \), \( X_5 = (1,0,0) \), \( X_6 = (1,0,1) \), \( X_7 = (1,1,0) \), \( X_8 = (1,1,1) \), which achieve Jacobian:

\[
J = \begin{bmatrix}
(l-2d)[(-b+e-f)+x(-d-m)-a+j+i] & x(1-x)(-b+e-f) & x(1-x)(d-m) \\
\lambda(1-y)(b+g) & (1-2y)[(g+h)+x(b+j)-f-h+i] & \lambda(1-y)(g+h) \\
x(1-z)(d+m) & x(1-z)(-k+l) & (1-2z)[(-k+l)+x(d+m)+l-n]
\end{bmatrix}
\]

Substitute 8 equilibrium points into Jacobian matrix to obtain corresponding eigenvalues, as shown in Table 3.

| Equilibrium point | characteristic value \( \lambda_1 \) | characteristic value \( \lambda_2 \) | characteristic value \( \lambda_3 \) |
|-------------------|-----------------|-----------------|-----------------|
| \( X_1 = (0,0,0) \) | \(-a+j+m\) | \(-f-h+i\) | \(-l-n\) |
| \( X_2 = (0,1,0) \) | \(-b+e-f-a+j+m\) | \(f+h-i\) | \(-k+2l-n\) |
| \( X_3 = (0,0,1) \) | \(d+j-a\) | \(-g-f+i\) | \(n-l\) |
| \( X_4 = (0,1,1) \) | \(-b+e-f-d-a+j\) | \(f+i-g\) | \(k+n-2l\) |
| \( X_5 = (1,0,0) \) | \(a-j\) | \(b+j-f-h+i\) | \(d+m+n-1\) |
| \( X_6 = (1,0,1) \) | \(d+a\) | \(-g+b+j+f+i\) | \(-d-m-l+n\) |
| \( X_7 = (1,1,0) \) | \(d+a\) | \(-g+b+j+f+i\) | \(-d-m-l+n\) |
| \( X_8 = (1,1,1) \) | \(d+a\) | \(-g+b+j+f+i\) | \(-d-m-l+n\) |
2.3.2. Stability Analysis In Different Situations. By using Friedman's equilibrium strategy stability judgment method, the stability of each equilibrium point is further judged. The fact shows that \( g < h \) and \( k < l \). Assuming \( b + f - e < 0, d + a - j < 0 \), so \( a - j - m < 0 \). If \( i < g + f < h + f < j \), that is, the comprehensive income of enterprises with responsibility for production is greater than irresponsibility for production, the stability of equilibrium point can be discussed in three situations, as shown in Table 4.

### Table 4: The stability analysis for balance point under different situations

| Equilibrium point | Scenario 1 | Scenario 2 | Scenario 3 |
|------------------|------------|------------|------------|
|                  | \( \lambda_1 \), \( \lambda_2 \), \( \lambda_3 \) | \( \lambda_1 \), \( \lambda_2 \), \( \lambda_3 \) | \( \lambda_1 \), \( \lambda_2 \), \( \lambda_3 \) |
| \( X_1 = (0, 0, 0) \) | Unstable point | Unstable point | Unstable point |
| \( X_2 = (0, 1, 0) \) | Unstable point | Unstable point | Unstable point |
| \( X_3 = (0, 0, 1) \) | Unstable point | Unstable point | Unstable point |
| \( X_4 = (0, 1, 1) \) | Unstable point | Unstable point | Unstable point |
| \( X_5 = (1, 0, 0) \) | Unstable point | Unstable point | Unstable point |
| \( X_6 = (1, 0, 1) \) | Unstable point | Unstable point | Unstable point |
| \( X_7 = (1, 1, 0) \) | Unstable point | Unstable point | Unstable point |
| \( X_8 = (1, 1, 1) \) | Unstable point | Unstable point | ESS |

3. Evolution Simulation Analysis

The evolution process of the system depends on the change of relevant parameters. MATLAB is used to solve the replication dynamic equation. Because the parameters are extremely complex and difficult to quantify, the parameters are assigned according to the setting of relevant parameters, as shown in Table 4, so as to obtain the dynamic evolution of the system. The horizontal axis shows the evolution time of the system, and the vertical axis shows the proportion of government supervision \( x(t) \) and the proportion of enterprises responsible for production \( y(t) \) and the proportion of residents participating in waste classification \( y(t) \).

### Table 5: Model parameter assignment

| parameter | \( a \) | \( b \) | \( d \) | \( e \) | \( f \) | \( g \) | \( h \) | \( i \) | \( j \) | \( k \) | \( l \) |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| numerical value | 3 | 0.8 | 0.3 | 5 | 1 | 1.2 | 1.8 | 0.8 | 3.5 | 2 | 2.5 |

State 1: when \( m < k < l < n \), it is difficult to determine the sign of eigenvalue in \( X_1 \) and \( X_8 \), if \( -k + 2l + d + m - n < 0 \), then set \( n = 5.5 \) and \( m = 1.5 \), and the simulation results are shown in Figure 1. The equilibrium stability condition is satisfied in \( X_8 = (1, 1, 0) \), the system evolution strategy is (supervision; responsible production; not participating in garbage classification); if \( -k + 2l + d + m - n > 0 \), \( n = 3 \), \( m = 1.5 \), and the simulation results are shown in Figure 2. The equilibrium stability condition is satisfied in \( X_8 = (1, 1, 1) \), the system evolution strategy is (supervision; responsible production; participating in garbage classification).
State 2: when \( k<l<m< n \), it is difficult to determine the sign of eigenvalues in \( X^s_1 \) and \( X^s_2 \), if \(-k+2l+d+m-n<0\), then set \( n = 6.5, m = 2.8\), and the simulation results are shown in Figure 3. The system evolution strategy is (supervision; responsible production; not participating in waste classification). If \(-k+2l+d+m-n>0\), let \( n = 5.5, m = 2.8\), and the simulation results obtained at this time are shown in Figure 4. The system evolution strategy is (supervision; responsible production; participation in waste classification).

State 3: when \( m<n<k<l \), the evolutionary stability result of the system is \( X^s_8 = (l, l, 1) \), let \( n = 1.5, m = 1\), and the simulation result is shown in Figure 7. It can be seen from the figure that the system evolution strategy is (supervision; responsible production; participation in waste classification).

State 4: when \( n<k<l<m \), the evolutionary stability result of the system is \( X^s_8 = (l, l, 1) \), let \( n = 1.5, m = 3\), and the simulation result is shown in Figure 3. It can be seen from the figure that the system evolution strategy is (supervision; responsible production; participation in waste classification).

State 5: when \( k<l<m< n \), the evolutionary stability result of the system is \( X^s_8 = (l, l, 1) \), let \( n = 3, m = 4\), and the simulation result is shown in Figure 7. It can be seen from the figure that the system evolution strategy is (supervision; responsible production; participation in waste classification).
State 6: when $n < m < k < l$, the evolutionary stability result of the system is $X^*_1 = (1,1,1)$, let $n = 1$, $m = 1.5$, and the simulation result is shown in Figure 8. It can be seen from the figure that the system evolution strategy is (supervision; responsible production; participation in waste classification).

Figure 6. n=3 m=4 System Evolution.  Figure 7. n=1 m=5 System Evolution

4. Conclusion
According to the above model and simulation, the behavior of the three parties in waste classification is restricted by many factors. Under different restrictions, the three players will evolve in different directions with the influence of various factors.

As a manager, the government of course hopes that enterprises can produce responsibly and residents can classify garbage, so as to reduce the cost of taking remedial measures. As producers, production enterprises hope that the government can give more incentives and subsidies, and at the same time, they hope that the residents can classify the garbage, so as to reduce the cost of their own responsible production for some garbage collection. As consumers, residents also hope that the government can give more incentives and subsidies. At the same time, they also hope that manufacturers can increase relevant labels when designing products, so as to reduce the time and physical cost of their participation in waste classification.

It can be seen that the most ideal situation is that the government takes supervision, the production enterprises are responsible for production, the residents participate in waste classification, and the three parties work together to build a green life and create a beautiful homes.

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