Evolutionary Game Analysis on the Classification Management of Rural Domestic Waste

Xing ZHOU\textsuperscript{1,a,*}, Jing LIU\textsuperscript{2,b} and Yu ZHANG\textsuperscript{1,c}

\textsuperscript{1}SICNU Economics and Management School, Chengdu, Sichuan, China
\textsuperscript{2}PZHU School of Civil and Architectural Engineering, Panzhihua, Sichuan, China
\textsuperscript{a}zhouxing.duoer@outlook.com, \textsuperscript{b}hepiqichou@gmail.com, \textsuperscript{c}1213962088@qq.com

*Corresponding author

Keywords: Classification Management of Waste, Evolutionary Game, Replicator Dynamic Function.

Abstract. In February 2018, the General Office of the CPC Central Committee and the General Office of the State Council issued The Three-year Action Plan for the Rehabilitation of Rural Human Settlements, and in this plan, the classification management of rural domestic waste (CMRDW) was given the priority. Although there has been a successful precedent for the CMRDW model of “collection in household, gathering in village, transshipment in town, treatment in county” created by Jinhua District of Zhejiang Province. However, affected by the quality of rural Chinese residents, related management costs and economic benefits and the government's funds, the CMRDW still hinders. Based on the bounded rationality, this paper constructs a game model of three parties including government, enterprises and rural residents, and establishes an evolutionary stability strategy (ESS) based on the replicator dynamic function to explore a Government-Enterprise-Rural Residents model of waste classification management that tripartite will altogether win and find a development path to form a continuous operation platform.

Introduction

According to the 2016-2018 annual report of China Housing Construction Department 2016-2018, the amount of rural domestic waste removal exceeded 200 million tons, while the waste disposal funds in 2016 was 837 million, accounting for 1.5% of the national construction funds and only 49% of environment sanitation facilities funds. [1] The national rural domestic waste disposal rate is 70%, while the harmless disposal rate is only 17.43%. In the western region, the rate is as low as 7.13% and in township-level area, the rate is 27.39%. The proportion of unified implementation of clearance and transportation from high to low was 38.6% in Jiangsu, 25.4% in Jilin, 13.1% in Hebei, 11.4% in Shaanxi and 7.1% in Sichuan. The highest proportion of arbitrary disposal was 64.6% in Hebei while the lowest was 30.3% in Jiangsu. It can be seen that the classification management of domestic waste is inseparable from the local economic development, the guidance of government departments, the investment of social capital, and the participation of rural residents.[2]

This paper aims to explore how to achieve sustainable partnerships through the evolutionary game model, when government, enterprises and rural residents, affected by various factors, participate in the process of the CMRDW. At the same time, this paper puts forward suggestions on how to implement active and effective guiding policies for government, integrate social responsibility and economic benefits in enterprises' participation in the process of the CMRDW and stimulate the rural residents’ internal motivation to participate in the CMRDW, and explore a sustainable, recyclable model of rural domestic waste disposal.
Model Establishment and Analysis

Relevant Status Analysis

The CMRDW belongs to public services. It is far from being able to meet the financial needs by relying on government financial support only and we find it also difficult to mobilize the enthusiasm of social enterprises and rural residents. From the perspective of the whole society, the introduction of relevant capital can not only provide the stable fund guarantee of CMDW, but also further mobilize the vitality of social funds and establish an actively cooperative relationship. From the perspective of rural residents, as the main body of informal organizations, if they start from their personal rationality to deal with the CMRDW, it is likely to cause the “prisoner's dilemma” of public services, that is, the decision of different residents on whether to actively participate in the CMRDW or not cannot reach the collective optimization even if it achieves a personal one. Therefore, this paper establishes a model from the perspective of the three parties, which is mainly restricted by the government, enterprises and rural residents.[3]

However, the assumptions of this model still have problems as follows:

The government's financial subsidies and the profitability of the project which the bidding enterprises are responsible for are limited.[4] So, it is difficult to attract more enterprises to participate in, and has a strict requirement on the government's guiding policies. As an “economic man”, social enterprise tends to choose projects with higher profitability. The CMRDW project requires enterprises to assume higher social responsibilities. The PPP cooperation mode has regional differences between eastern and western regions in China in the implementation of CMRDW. Affected by negative social capital, rural residents may act contrary to expectations of involving actively in CMRDW.

Hypothesis and Model Construction

The sustainable operation of the CMRDW is bound by the government, social enterprises and rural residents.

Main Body of the Continuous Operation Mechanism of CMRDW. Government has established a competitive market for the CMRDW by investing in financial allocations and setting up a PPP model. To improve relevant laws and regulations, government departments can promote the achievement of the PPP model to supervise, guide and standardize rural residents’ behaviors of the CMRDW, and ultimately realize the unification of economic and social benefits.[5]

Enterprises can obtain opportunities to engage in a certain social service work through competitive bidding, such as recycling, transshipment, and processing of rural domestic waste, and acquire certain benefits with the support of the government. However, when rural residents are not actively involved in it, additional processing costs are incurred, such as the cost of manual reclassification of waste.

It is possible to promote rural residents’ active participation in the CMRDW by increasing the social capital of a rural community. Coleman once mentioned that social capital is a kind of "structural resource", and rural social capital mainly refers to the trust interaction between rural residents due to blood, geography and kinship. Rural residents’ active participation can realize the exchange of point redemption for gifts and government grants, and there is no need to pay management fees directly in the early stage. However, their participation has been influenced by government guidance and the quality of corporate public services.

Behavioral Strategy Hypothesis of the Model. Government departments mainly consider financial subsidies and social credit benefits, and the behavioral strategies are “support” and “nonsupport”; social enterprises mainly consider social responsibility and economic benefits involved in the classification management of domestic waste, and the behavior strategies are “cooperation” and “non-cooperation”. Rural residents mainly consider their income and participation costs, and their behavior strategies are “participation” and “non-participation”.

The probability that the government chooses to support the PPP cooperation mode is $p$, then the
probability of nonsupport is 1 - p. The probability that a social enterprise chooses to cooperate with the government and rural residents is q, then the probability of non-cooperation is 1 - q. The probability that rural residents participate in the CMRDW is r, then the probability of non-participation is 1 - r.

Table 1. Related Parameter Settings of the Model.

<table>
<thead>
<tr>
<th>Issuer</th>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government</td>
<td></td>
<td>Direct income (corporate tax revenue) obtained by the government for providing financial assistance</td>
</tr>
<tr>
<td></td>
<td>$E_{u1}$</td>
<td>Credit benefits that society gives to the government when rural residents actively participate in the CMRDW</td>
</tr>
<tr>
<td></td>
<td>$C_{u1}$</td>
<td>The supervision cost generated by the government in guiding rural residents’ participation and implementation</td>
</tr>
<tr>
<td></td>
<td>$C_{u2}$</td>
<td>Government financial subsidy</td>
</tr>
<tr>
<td>Enterprises</td>
<td>$E_{b}$</td>
<td>Income that enterprises get form the CMRDW</td>
</tr>
<tr>
<td></td>
<td>$C_{b1}$</td>
<td>Extra management cost that enterprises pay when rural residents participate in the CMRDW irregularly.</td>
</tr>
<tr>
<td></td>
<td>$C_{b2}$</td>
<td>Cost that enterprises pay when not engaged in the CMRDW with the policy support.</td>
</tr>
<tr>
<td>Rural Residents</td>
<td></td>
<td>Direct income from rural residents’ when participating in the CMRDW</td>
</tr>
<tr>
<td></td>
<td>$E_{s1}$</td>
<td>Credit benefits given by society to rural residents</td>
</tr>
<tr>
<td></td>
<td>$E_{s2}$</td>
<td>Income of rural residents when not participating in the CMRDW.</td>
</tr>
<tr>
<td></td>
<td>$C_{s1}$</td>
<td>The waste disposal fee that rural residents need to pay when the government no longer gives financial support.</td>
</tr>
<tr>
<td></td>
<td>$I_1$</td>
<td>Point redemption return rate of rural residents when participating in the CMRDW</td>
</tr>
<tr>
<td></td>
<td>$I_2$</td>
<td>Return rate of rural residents not participating in the CMRDW but disposing by themselves.</td>
</tr>
</tbody>
</table>

Figure 1. Three-party Game between Government, Enterprises and Rural Residents.

**Return Matrix of the Model**

We assume the “support”, “nonsupport” and average expectation benefits of the government
departments are $E_p, E_{1-p}, E$

$$E_p = q((E_{a1} + E_{a2} - C_{a1} - C_{a2})r + (E_{a1} - C_{a1})(1-r)) + (1-q)[(-C_{a1} - C_{a2})r - C_{a1}(1-r)]$$

$$= q(E_{a1} + E_{a2}r) - C_{a1} - C_{a2}r. E_{1-p} = q((E_{a1} + E_{a2} - C_{a2})r + E_{a1}(1-r)) + (1-q)(-C_{a2})r + 0* (1-r)]$$

$$= q(E_{a1} + E_{a2}r) - C_{a2}r. \quad (1)$$

$$E_{1-p} = q((E_{a1} + E_{a2} - C_{a2})r + E_{a1}(1-r)] + (1-q)(-C_{a2})r + 0* (1-r))$$

$$= q(E_{a1} + E_{a2}r) - C_{a2}r. \quad (2)$$

$$\bar{E} = pE_p + (1-p)E_{1-p} = p[q(E_{a1} + E_{a2}r) - C_{a1} - C_{a2}r] + (1-p)[q(E_{a1} + E_{a2}r) - C_{a2}r]. \quad (3)$$

We assume the “cooperation”, “non-cooperation” and average expectation benefits of the enterprises are $E_q, E_{1-q}, \bar{E}$

$$E_q = p[E_b r + (E_b - C_b - X)(1-r)] + (1-p)(E_b r + E_b - C_b)(1-r)]$$

$$= p(-XI_1 - X)(1-r) + E_b - C_b (1-r). \quad (4)$$

$$E_{1-q} = p[-C_{b2}r + C_{b2}(1-r)] + (1-p)*0$$

$$= -C_{b2} p. \quad (5)$$

$$\bar{E} = qE_q + (1-q)E_{1-q}$$

$$= q[p(-XI_1 - X)(1-r) + E_b - C_b (1-r)] + (1-q)(-C_{b2}p). \quad (6)$$

We assume the “participation”, “non-participation” and average expectation benefits of rural residents are $E_r, E_{1-r}, \bar{E}$

$$E_r = p((E_{s1} + E_{s2} - XI_1)q + (E_{s1} - C_{s1})(1-q)] + (1-p)[(E_{s1} + E_{s2} - C_{s1} - XI_1)q + (-XI_2)(1-q)]$$

$$= (E_{s1} + E_{s2} - C_{s1} + XI_2 - AI_1 - C_{s1}p)q - XI_2. \quad (7)$$

$$E_{1-r} = p([E_{s1} - E_{s2})q + (E_{s1})(1-q)] + (1-p)[(E_{s1} - E_{s2} - C_{s1})q + (E_{s1})(1-q)]$$

$$= (E_{s1} - E_{s2} - C_{s1} - E_{s3} - C_{s1}p)q + E_{s3}. \quad (8)$$

$$\bar{E} = rE_r + (1-r)E$$

$$= r[(E_{s1} + E_{s2} - C_{s1} + XI_2 - XI_1 - C_{s1}p)q - XI_2] + (1-r)[(E_{s1} - E_{s2} - C_{s1} - E_{s3} - C_{s1}p)q + E_{s3}]. \quad (9)$$

The expectation function and the derivation process

1) Replicator dynamic function when government chooses to support

$$F(p) = \frac{dp}{dt} = p(E_p - \bar{E})$$

$$= p(1-p)[2q(E_{a1} + E_{a2}r) - C_{a1} - 2C_{a2}r]. \quad (10)$$

If $F_p = 0$, then $p = 0, p = 1, q^* = \frac{C_{a1} + 2C_{a2}r}{2(E_{a1} + E_{a2}r)}$

1. If $q = q^*$, $F(p) = 0$ always holds, so all levels are at stable state.
2. If $q \neq q^*$, $F(p) = 0$, so we can get 2 stable points when $p = 0, p = 1$

Derive F(p), the outcome is
\[
f(p) = \frac{dF(p)}{dp} = (1 - 2p)[2q(E_{u1} + E_{u2}r) - C_{u1} - 2C_{u2}r].
\] (11)

ESS requires \( \frac{dF(p)}{dp} < 0 \), \( 2(E_{u1} + E_{u2}r) > 0 \)

When \( q > q^* \), \( \frac{dF(p)}{dp} \bigg|_{p=0} > 0, \frac{dF(p)}{dp} \bigg|_{p=1} < 0 \quad \therefore \) \( p = 1 \) is the local asymptotic equilibrium point

When \( q > q^* \), \( \frac{dF(p)}{dp} \bigg|_{p=0} < 0, \frac{dF(p)}{dp} \bigg|_{p=1} > 0 \quad \therefore \) \( p = 0 \) is the local asymptotic equilibrium point

2) Replicator dynamic function when enterprises choose to corporate

Let \( F(q) = 0 \), the outcome is \( q = 0, q = 1, p^* = \frac{E_b C_h (1 - r) - E_b}{(-XI_1 - X)(1 - r) - C_{b2}} \)

(1) If \( p = p^* \), \( F(p) = 0 \) always holds, so all levels are at stable state.
(2) If \( p \neq p^* \), \( F(p) = 0 \), so we can get 2 stable points when \( p = 0, p = 1 \)

Derive \( F(q) \), the outcome is

\[
f(q) = \frac{dF(q)}{dt} = (1 - 2q)\{p(-XI_1 - X)(1 - r) - C_{b2} + E_b - C_b(1 - r)\}. \] (12)

ESS requires \( \frac{dF(q)}{dq} < 0 \), obviously \( -XI_1 - X)(1 - r) - C_{b2} < 0 \), which can be obtained by known conditions

\( p > p^* \), \( \frac{dF(q)}{dq} \bigg|_{q=0} < 0, \frac{dF(q)}{dq} \bigg|_{q=1} > 0 \), \( \therefore \) \( q = 0 \) is the local asymptotic equilibrium point

\( p < p^* \), \( \frac{dF(q)}{dq} \bigg|_{q=0} > 0, \frac{dF(q)}{dq} \bigg|_{q=1} < 0 \), \( \therefore \) \( q = 1 \) is the local asymptotic equilibrium point

3) Replicator dynamic function when rural residents choose to support

\[
F(r) = \frac{dr}{dt} = r(E_r - E) = r(1 - r)[(2E_{s1} - E_{s3} - 2C_{s1} + XI_2 - I_1 - 2C_{s1}p)q - XI_2 + E_{s3}].
\] (13)

Let \( F(r) = 0 \), the outcome is \( r = 0, r = 1, q = \frac{XI_2 - E_{s3}}{2E_{s1} - E_{s3} - 2C_{s1} + XI_2 - XI_1 - 2C_{s1}p} \)

(1) If \( q = q^* \), \( F(r) = 0 \) always holds, so all levels are at stable state.
(2) If \( q \neq q^* \), \( F(r) = 0 \), so we can get 2 stable points when \( r = 0, r = 1 \)

Derive \( F(r) \), the outcome is

\[
f(r) = \frac{dF(r)}{dr} = (1 - 2r)[(2E_{s1} - E_{s3} - 2C_{s1} + XI_2 - XI_1 - 2C_{s1}p)q + E_{s3} - XI_2]. \] (14)

ESS requires \( \frac{dF(r)}{dr} < 0 \)
We’ve already known \(2E_{x1} - E_{x3} - 2C_{x1} + XI_2 - XI_4 - 2C_{x3}p > 0\)

\[ q > q^*, \left. \frac{d f(r)}{dr} \right|_{r=0} > 0, \left. \frac{d f(r)}{dr} \right|_{r=1} < 0, \therefore r = 1 \] is the local asymptotic equilibrium point

\[ q < q^*, \left. \frac{d f(r)}{dr} \right|_{r=0} < 0, \left. \frac{d f(r)}{dr} \right|_{r=1} > 0, \therefore r = 0 \] is the local asymptotic equilibrium point

**Game Analysis and Suggestions on the Sustainability of China’s CMRDW**

**Asymptotic Stability Analysis and Suggestions to Government Department**

When \( q = q^*, F(p) = 0 \), at this time, no matter what value \( p \) takes, it is in a stable state, that is, the government department’s strategy does not change with time, as shown in the figure, it’s in a strategic stable state;

When \( q < q^* \), \( E(0) < 0 \), \( E(1) > 0 \), \( p = 0 \) is the evolutionary stability point, which indicates that the unsupported strategy chosen by the government department is stable;

When \( q > q^* \), \( E(0) > 0 \), \( E(1) < 0 \), \( p = 1 \) is the evolutionary stability point, which indicates that the supported strategy chosen by the government department is stable;

It can be seen that the probability of the government choosing to support and whether the enterprises and rural residents are engaged in the CMRDW or not will affect the government’s decision-making. On the one hand, the size of the financial subsidies and benefits may be the incentives for the government to support enterprises constantly. On the other hand, the information cost of guiding rural residents to actively participate in and negotiating with enterprises to achieve corporation will also constrain government’s decision-making. Therefore, under the influence of various factors, in order to form a sustainable PPP tripartite partnership under the constraints of credit and other costs, we could learn from the results of the game calculation that the government should continuously provide financial subsidies and seek corporations with enterprises actively. We can use RFID and personal identity-linked spam identification system, then use cloud computing to build a cluster system, and finally establish a deep learning evaluation mechanism to guide and supervise the participation behavior of rural residents.

**Asymptotic Stability Analysis and Suggestions to Enterprises**

When \( p = p^* \), \( E(q) = 0 \), at this time, no matter what value \( q \) takes, it is in a stable state, that is, the enterprises’ strategy does not change with time, as shown in the figure, it’s in a strategic stable state;

When \( p > p^* \), \( E(0) < 0 \), \( E(1) > 0 \), \( q = 0 \) is the evolutionary stability point, which indicates that the uncooperative strategy chosen by enterprises is stable;

When \( p < p^* \), \( E(0) > 0 \), \( E(1) < 0 \), \( q = 1 \) is the evolutionary stability point, which indicates that the cooperative strategy chosen by enterprises is stable;

Considering the benefits, few enterprises in the real world are engaged in the CMRDW. In the early stage, the rural residents’ participation is limited, and the decision-making preference of investing funds in other projects with high and short-term interests may drive the enterprises to make uncooperative behavioral decisions. In order to make rational decision, that is, to actively participate in the CMRDW, it is necessary to use stable financial subsidies and active policy guidance to guarantee benefits and increase the rural residents’ participation. It can also give certain tax incentives for enterprises engaged in the CMRDW and provide preferential policies for the development of related industries to promote the maximization of the benefits for three parties and maintain the sustainability of the cooperative relationship.
Asymptotic Stability Analysis and Suggestions to Rural Residents

When \( q = q^* \), \( F(r) = 0 \), at this time, no matter what value \( r \) takes, it is in a stable state, that is, rural residents’ strategy does not change with time, as shown in the figure, it’s in a strategic stable state;

When \( q < q^* \), \( F'(0) < 0 \), \( F'(1) > 0 \), \( r = 0 \) is the evolutionary stability point, which indicates that the non-participation strategy chosen by rural residents is stable;

When \( q > q^* \), \( F'(0) > 0 \), \( F'(1) < 0 \), \( r = 1 \) is the evolutionary stability point, which indicates that the participation strategy chosen by rural residents is stable;

The benefits obtained by rural residents through the point redemption, the total amount of daily waste generated by themselves which can be used to realize value exchange, and the costs and benefits of self-processing of domestic waste will affect their decision-making. From the calculation results, in order to enable rural residents to actively participate in the CMRDW, the value that can be created by waste disposal should be greater than the value created by unclassified management, and at the same time, the economic cost of the CMRDW should be reduced. Therefore, the government should implement support strategies, for example, by cooperating with enterprises to design a semi-intelligent dustbin that uses AI and depth recognition technology to cultivate users' awareness of participating in waste classification.

Summary

The rural environment is an important issue related to the rural revitalization strategy. The CMRDW is a significant starting point for solving rural environmental problems. By establish game model based on the three parties of government, enterprises and rural residents, the stability of the relevant decision-making is analyzed by using the replicator dynamic function. This paper explores the possibility of implementing the PPP model to promote the CMRDW under the constraints of multiple factors such as economic policy and social capital, and proposes relevant decision-making suggestions. In summary, the government should actively use financial subsidies and related policies to reach cooperation with enterprises, and combine publicity and credit mechanism construction to supervise and guide rural residents to participate in CMRDW. The social funds brought by enterprises have injected capital into this model and guaranteed economic sustainability. As the source of CMRDW, rural residents are a vital subject. Social capital should play a positive role in the informal organization where rural residents are located, and attract more people to actively join in the CMRDW.

References


