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# Research on Urban Construction Waste-Based on Evolutionary Game Analysis

Qingfen He

Business School, East China University of Political Science and Law, Shanghai 201620, China

## Abstract

**With the vigorous development of China's construction industry, while promoting the modernization, it also brings the increasingly serious construction waste pollution problem. The effective treatment of construction waste is conducive to improving people's quality of life and promoting the sustainable development of the construction industry. Therefore, this paper constructs an evolutionary game model of construction waste collaborative treatment based on the condition of finite rationality and the evolutionary game theory, and analyzes the behavior choice of each subject under different situations. The results show that based on the principle of maximizing their own interests, when the income exceeds the loss, they tend to actively deal with the problem, and the cooperative treatment of each subject can maximize to solve the pollution problem of construction waste.**

## Keywords

**Construction Waste Disposal; Evolutionary Game; Collaborative Treatment.**

## 1. Introduction

Under the background of the continuous promotion of new urbanization in China, the construction industry has been growing and becoming the pillar industry of China's national economic development. At the same time, a large number of construction activities such as new construction, reconstruction, expansion and demolition will produce a large number of construction wastes. In order to save costs, enterprises generally adopt extensive methods such as stacking, burning and burying to deal with construction wastes, which will inevitably cause environmental pollution and waste of resources[1]. According to relevant statistical data of the National Bureau of Statistics, the amount of construction waste generated in China is increasing year by year, increasing from 812 million tons in 2010 to 1.85 billion tons in 2018. According to the Ministry of Housing and Urban-Rural Development, China's annual construction waste may exceed 3 billion tons[2]. Improper disposal of construction waste will not only bring great potential safety hazard, but also cause serious environmental pollution. For example, some construction sites dump construction waste directly near the site for their own convenience without taking any safety measures. Affected by extreme weather, a large amount of accumulated construction waste may collapse, causing road congestion and even endangering the lives and property of workers. Moreover, some construction wastes may contain a large amount of heavy metals, which are difficult to be degraded by themselves. If they are buried without any treatment, they will cause great pollution to the surrounding surface water and groundwater through fermentation, rain washing and groundwater infiltration, and cause great damage to the environment[3]. In order to reduce the production of construction waste, properly handle construction waste, protect and improve the ecological environment, China has issued the Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste, the Regulations on the Management of Urban Construction Waste and the Law of the People's Republic of China on the Promotion of Circular Economy.

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President Xi Jinping pointed out in the report of the 19th National Congress that the construction of an environmental governance system with the government as the leading role, enterprises as the main body and social organizations and the public participating in various aspects is beneficial to promoting the reform of the ecological civilization system. However, the government, enterprises and the public have their own behavior strategies. Clarifying the behavior strategies of each subject under different circumstances is conducive to the construction of collaborative treatment system, promoting the collaborative treatment of construction waste and realizing efficient utilization of resources. However, most of the current studies focus on the relationship between government and enterprises, and few studies consider the public. Wang Yixin et al. (2022) believed that the enthusiasm of social capital participation could contribute to the recycling of construction waste by constructing an evolutionary game model between government and social capital[4]. Promoting the recycling level of construction waste in enterprises can effectively integrate resources and improve the utilization rate of construction waste [5]. Moreover, Chen Wanting et al. (2019) believe that the government 's increase in rewards and punishments can encourage producers to actively recycle[6]. The collaborative treatment of construction waste by various subjects can alleviate the pollution problem caused by construction waste to a certain extent[7], and the public, as the main victim of improper treatment of construction waste and one of the beneficiaries of proper treatment, plays an important role in the process of pollution control by the government[8,9]. Therefore, in order to give full play to the synergistic effect of government, enterprises, law enforcement personnel and the public, and promote the efficient disposal of construction waste[10].this paper will analyze the behavior choice of government, construction waste emission enterprises, law enforcement personnel and the public under different conditions by constructing the four-party evolutionary game model, aiming at providing some suggestions for the effective disposal of construction waste, thus promoting the sustainable development of construction industry.

## 2. Strategy Selection under Different Circumstances of Each Subject

The government is not only the policy maker of environmental regulation, but also the regulator of proper disposal of construction waste. The effective disposal of construction waste plays a vital role in saving social resources, protecting ecological environment and improving people's living quality. The government will give certain rewards to the enterprises that correctly dispose of construction waste, and punish the enterprises that wrongly dump construction waste accordingly. A strong reward and punishment system will help standardize the treatment of construction waste and promote the recycling of construction waste. But in the process of construction waste disposal supervision, the government needs to invest a lot of manpower, material resources and financial resources. Therefore, the government expects to regulate construction waste emission enterprises at a lower cost, so as to encourage the public to participate actively and promote the sustainable development of the construction industry. As the main body of construction waste discharge, construction waste discharge enterprise is an important target of government supervision. If enterprises treat construction waste in strict accordance with the requirements of the government, it will increase the cost of enterprises and reduce the profits of enterprises. Therefore, in order to pursue the maximization of benefits, enterprises tend to dispose of construction waste at a smaller cost. Law enforcement personnel play an important role in the supervision of construction waste discharge, but always carry out strong supervision will greatly increase the supervision cost of law enforcement personnel. Therefore, law enforcement officials usually want companies or the public to legally dispose of construction waste and supervise it autonomously. The public is the main victim of improper management of construction waste pollution and the main beneficiary of efficient treatment. However, as a whole, public participation in supervision often requires certain costs, such as

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time. Therefore, if the proper disposal of construction waste is not related to the interests of the public, the public generally has low enthusiasm for the supervision of the legal and compliant disposal of construction waste.

## 3. Analysis of the Quadripartite Evolutionary Game of Four-Paties

### 3.1. Model Assumptions

The subjects involved in the game are the government, construction waste discharge enterprises, law enforcement personnel and the public, and they are all bounded rational. First, it is assumed that there are only two behavioral strategies for the government, construction waste discharge enterprises, law enforcement personnel and the public, namely {strict supervision, loose supervision},{legal treatment, illegal treatment},{active law enforcement, passive law enforcement} and {participation, non-participation}. Based on this, the following assumptions are made:

Hypothesis 1: The probability that the government will adopt strict regulation on construction waste discharge enterprises is $x$ $(0 \leq x \leq 1)$, and the probability that the government will adopt loose regulation is 1- $x$.

Hypothesis 2: The probability that the construction waste discharging enterprise chooses to dispose the construction waste legally is $y$ $(0 \leq y \leq 1)$, and the probability that the construction waste is disposed illegally is 1- $y$.

Hypothesis 3: The probability of active law enforcement by law enforcement officers is $g$ $(0 \leq g \leq 1)$, and the probability of passive law enforcement is 1- $g$.

Assumption 4: The probability of the public actively participating in the supervision of construction waste disposal by construction waste discharging enterprises and the supervision of the government is $z$ $(0 \leq z \leq 1)$, and the probability of the public not participating in the supervision of construction waste disposal by construction waste discharging enterprises and the supervision of the government is 1- $z$.

Assumption 5: Suppose that the government 's basic return, whatever its choice, is $B_1$. When the government chooses to strictly supervise the construction waste discharge, the construction waste discharge enterprise chooses to legally dispose the construction waste, the law enforcement officer actively enforces the law and the public chooses to participate in the supervision, the government strictly supervises the effective disposal of the construction waste, the law enforcement officer actively enforces the law according to the requirement, which can enhance the public 's favorable opinion to the government and increase the government' s reputation$U = (P_1 + P_3)$. The legal disposal of the construction waste by the enterprise can save certain supervision cost for the government, thus increasing the government 's income $R_1$. The cost of active government regulation is correspondingly high$W_1$. If the enterprise chooses to dispose of the construction waste illegally, the government will impose a corresponding fine, and the government will obtain corresponding income $m_1$. At the same time, if the law enforcement personnel enforce the law passively, the government will also give corresponding punishment, and the government will obtain benefits $m_2$. So, when the strategy set is {strict regulation, legal treatment, active enforcement, participation}, the government 's payoff is $B_1 + R_1 + U - W_1 - S_1 - S_2 - S_3$. When the government chooses loose supervision and the strategy chosen by enterprises, law enforcement officers and the public remains unchanged, the government passively deals with the problem of improper discharge of construction waste, the government 's reputation will be damaged $N_1$, and the government' s loose supervision will also produce certain costs. Thus, when the strategy set is {light regulation, legal treatment, active enforcement, participation}, the government 's payoff is$B_1 + R_1 + P_3 - W_2 - N_1$.

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Hypothesis 6: Suppose that no matter what choice is made, the basic profit of the construction waste discharging enterprise is $B_2$. When the construction waste discharging enterprise chooses to dispose the construction waste legally according to the regulations, the government chooses strict supervision, the law enforcement personnel strictly enforce the law and the public chooses to participate in the supervision, the government will give corresponding rewards $S_1$, and the law enforcement personnel will increase their favorable opinion of the enterprise $O$. The enterprises that dispose the construction waste legally reduce the local garbage pollution to a certain extent, which will increase the reputation of the enterprise among the public. Increase the corresponding income $P_2$, but the enterprise cost will also increase accordingly $\Delta C$. Therefore, when the policy set is {strict regulation, legal treatment, active enforcement, participation}, the profit of the enterprise is $B_2 + S_1 + P_2 + \mathrm{O} - \Delta C$. When the construction emission enterprise chooses to illegally dispose the construction waste for its own interests, and the choice of the government, law enforcement personnel and the public remains unchanged, the public will report the enterprise illegally disposing the construction waste. If the illegal disposal behavior is true, the enterprise will face the fine of the government $F_1$, and the law enforcement personnel will strengthen the law enforcement to the enterprise$l$. At the same time, the company 's reputation in society will also be damaged $N_2$. Therefore, when the policy set is {strict regulation, illegal treatment, active enforcement, participation}, the profit of the enterprise is $B_2 - F_1 - N_2 - l$.

Hypothesis 7: Suppose that whatever choice is made, the law enforcement officer 's basic benefit is $B_3$. When the law enforcement personnel actively enforce the law, the government adopts strict supervision, the construction waste discharge enterprise legally handles the construction waste and the public participates in the supervision, the government will give certain rewards to the active law enforcement personnel $S_2$, the construction waste problem concerned by the public is effectively responded, which can improve the prestige of the law enforcement personnel in the public $P_3$, strict law enforcement will produce higher cost $W_3$, and the enterprise legally handles the construction waste can reduce the law enforcement cost to a certain extent and increase the income $R_2$. Therefore, when the policy set is {strict regulation, legal treatment, active enforcement, participation}, the benefit of the law enforcement officer is $B_3 + P_3 + S_2 + R_2 - W_3$. When the law enforcement personnel carry out negative law enforcement, the choice of the government, enterprises and the public remains unchanged, the public actively participates in the supervision of whether the construction waste is legally disposed, and will complain about the negative behavior of the law enforcement personnel. If it is true, the law enforcement personnel will be punished $F_2$, the prestige of the law enforcement personnel will decrease accordingly $N_3$, and the negative law enforcement will also produce corresponding costs $W_4$. Therefore, when the policy set is {strict regulation, legal treatment, passive enforcement, participation}, the revenue of the law enforcement officer is$B_3 + R_2 - F_2 - N_3 - W_4$.

Hypothesis 8: When the public chooses to participate in supervision, construction waste discharge enterprises dispose construction waste legally, the government chooses strict supervision and law enforcement personnel actively enforce the law, the public participation in supervision can improve the quality of life and obtain benefits $I_1$; under the strong supervision of the government or strict law enforcement personnel, the legal disposal of construction waste can improve the environment to a certain extent, and the public can obtain benefits $I_2$; In order to more actively encourage the public to participate in the supervision of whether the construction waste discharge is reasonable, The government will give corresponding subsidies to the public who actively participate in the supervision $S_3$, but the public participation in the supervision will also produce corresponding costs$C$. So when the strategy set is {strict regulation, legal treatment, active enforcement, participation}, the public 's benefit is $I_1 + I_2 + S_3 - C$. When the public choose not to participate in the supervision.

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**Table 1.** Relevant Parameters and Meanings of Model

| participant | parameter | express meaning |
|---|---|---|
| Government | $B_1$ | Basic income of local government |
| | $P_1$ | Public participation in monitoring and government active supervision of gains |
| | $R_1$ | Government gains from legal disposal of construction waste by enterprises |
| | $W_1$ | Costs of active government regulation |
| | $m_1$ | Part of the fine of the enterprise shall be used as the revenue of the government |
| | $m_2$ | Part of the fines imposed by law enforcement officers are used as government revenue |
| | $N_1$ | Public participation in supervision, losses caused by government's failure to fulfill its responsibilities |
| enterprise | $B_2$ | basic income of an enterprise |
| | $S_1$ | Rewards given by the government to enterprises for legal disposal of construction waste |
| | $O$ | Enterprises legally dispose construction waste to gain the favor of law enforcement personnel |
| | $P_2$ | Public participation in supervision, and income obtained by enterprises from legal treatment |
| | $\Delta C$ | Incremental costs incurred by the business in legal processing |
| | $F_1$ | Fines arising from illegal handling by enterprises |
| | $l$ | Losses caused by strict law enforcement by law enforcement personnel and illegal handling by enterprises |
| | $N_2$ | The public reports the losses caused by illegal handling of enterprises |
| Law enforcement officers | $B_3$ | Basic income of law enforcement officers |
| | $S_2$ | Rewards given by the government for active law enforcement by law enforcement personnel |
| | $P_3$ | Public participation in oversight, gains to law enforcement officers |
| | $W_3$ | Costs of strict enforcement |
| | $R_2$ | Proceeds obtained by law enforcement personnel from legal treatment by enterprises |
| | $F_2$ | Losses from passive enforcement (fines) |
| | $N_3$ | Public reporting of losses from passive law enforcement |
| | $W_4$ | Costs of passive enforcement |
| Public | $I_1$ | Benefits of public participation in monitoring |
| | $I_2$ | Proceeds from legal disposal by enterprises or strict government supervision |
| | $S_3$ | Public participation in monitoring, government subsidies |
| | $C$ | Costs of public participation in monitoring |
| | $H$ | Losses caused by illegal handling by the enterprise or non-participation of the public in supervision |

The government, law enforcement officers and enterprises`s strategies remain unchanged, the public will not participate in the supervision of whether the construction waste will be disposed

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reasonably, which will cause corresponding losses$H$. Thus, when the strategy set is {strict regulation, legal treatment, active enforcement, non-participation}, the public 's benefit is$I_2 - H$.

The Table 1 are the model parameters and the expression meanings.

**Table 2.** Payoff Matrix for Different Choices

| Decision combination | payoff matrix | | | |
|---|---|---|---|---|
| | Government | enterprise | Law enforcement officers | Public |
| {Strict supervision, legal handling, active law enforcement, participation} | $B_1 + R_1 + U - W_1 - S_1 - S_2 - S_3$ | $B_2 + S_1 + P_2 + 0 - \Delta C$ | $B_3 + P_3 + S_2 + R_2 - W_3$ | $I_1 + I_2 + S_3 - C$ |
| {Strict supervision, legal handling, active law enforcement, non-participation} | $B_1 + R_1 - W_1 - S_1 - S_2$ | $B_2 + S_1 + 0 - \Delta C$ | $B_3 + S_2 + R_2 - W_3$ | $I_2 - H$ |
| {Relaxed regulation, legal treatment, active enforcement, participation} | $B_1 + R_1 + P_3 - W_2 - N_1$ | $B_2 + P_2 + 0 - \Delta C$ | $B_3 + P_3 + R_2 - W_3$ | $I_1 + I_2 - C$ |
| {Relaxed regulation, legal treatment, active enforcement, non-participation} | $B_1 + R_1 - W_2$ | $B_2 + 0 - \Delta C$ | $B_3 + R_2 - W_3$ | $I_2 - H$ |
| {Strict supervision, illegal handling, active law enforcement, participation} | $B_1 + U + m_1 - W_1 - D - S_2 - S_3$ | $B_2 - F_1 - N_2 - l$ | $B_3 + P_3 + S_2 - W_3$ | $I_1 + I_2 + S_3 - C - H$ |
| {Strict supervision, illegal handling, active law enforcement, non-participation} | $B_1 + m_1 - W_1 - D - S_2$ | $B_2 - F_1 - l$ | $B_3 + S_2 - W_3$ | $I_2 - H$ |
| {lax regulation, illegal handling, active enforcement, participation} | $B_1 + P_3 - W_2 - D - N_1$ | $B_2 - N_2 - l$ | $B_3 + P_3 - W_3$ | $I_1 + I_2 - C - H$ |
| {Loose regulation, illegal handling, active enforcement, non-participation} | $B_1 - W_2 - D$ | $B_2 - l$ | $B_3 - W_3$ | $I_2 - H$ |
| {lax regulation, lawful treatment, passive enforcement, participation} | $B_1 + R_1 + P_1 + m_2 - W_1 - S_1 - S_3$ | $B_2 + S_1 + P_2 - \Delta C$ | $B_3 + R_2 - F_2 - N_3 - W_4$ | $I_1 + I_2 + S_3 - C$ |
| {Strict supervision, legal handling, passive law enforcement, non-participation} | $B_1 + R_1 + m_2 - W_1 - S_1$ | $B_2 + S_1 - \Delta C$ | $B_3 + R_2 - F_2 - W_4$ | $I_2 - H$ |
| {lax regulation, lawful treatment, passive enforcement, participation} | $B_1 + R_1 - W_2 - N_1$ | $B_2 + P_2 - \Delta C$ | $B_3 + R_2 - N_3 - W_4$ | $I_1 + I_2 - C$ |
| {Relaxed regulation, legal treatment, passive enforcement, non-participation} | $B_1 + R_1 - W_2$ | $B_2 - \Delta C$ | $B_3 + R_2 - W_4$ | $I_2 - H$ |
| {Strict regulation, illegal handling, passive enforcement, participation} | $B_1 + P_1 + m_1 + m_2 - W_1 - \mathrm{D} - S_3$ | $B_2 - F_1 - N_2$ | $B_3 - F_2 - N_3 - W_4$ | $I_1 + I_2 - C - H$ |
| {Strict regulation, illegal handling, passive enforcement, non-participation} | $B_1 + m_1 + m_2 - W_1 - \mathrm{D}$ | $B_2 - F_1$ | $B_3 - F_2 - W_4$ | $I_2 - H$ |
| {lax regulation, illegal handling, passive enforcement, participation} | $B_1 - W_2 - D - N_1$ | $B_2 - N_2$ | $B_3 - N_3 - W_4$ | $I_1 - C - H$ |
| {lax regulation, illegal handling, passive enforcement, non-participation} | $B_1 - W_2 - D$ | $B_2$ | $B_3 - W_4$ | $-H$ |

The Table 2 is a payoff matrix for different behavioral choices between government, business, law enforcement, and the public.

## 3.2. Model Construction

According to the above assumptions and the return matrix, we can get the expected return of the government for strict supervision and loose supervision $E_{X1}, E_{X2}$ the average expected return of the government $E_x$.

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$E_{X1} = \mathrm{yg}[z(B_1 + R_1 + U - W_1 - S_1 - S_2 - S_3) + (1 - \mathrm{z})(B_1 + R_1 - W_1 - S_1 - S_2)] + (1 - y)g[z(B_1 + U + m_1 - W_1 - D - S_2 - S_3) + (1 - z)(B_1 + m_1 - W_1 - D - S_2)] + \mathrm{y}(1 - \mathrm{g})[\mathrm{z}(B_1 + R_1 + P_1 + m_2 - W_1 - S_1 - S_3) + (1 - \mathrm{z})(B_1 + R_1 + m_2 - W_1 - S_1)] + (1 - y)(1 - g)[z(B_1 + P_1 + m_1 + m_2 - W_1 - \mathrm{D} - S_3) + (1 - z)(B_1 + m_1 + m_2 - W_1 - \mathrm{D})];$

$E_{X2} = \mathrm{yg}[z(B_1 + R_1 + P_3 - W_2 - N_1) + (1 - \mathrm{z})(B_1 + R_1 - W_2)] + (1 - y)g[z(B_1 + P_3 - W_2 - D - N_1) + (1 - z)(B_1 - W_2 - D)] + \mathrm{y}(1 - \mathrm{g})[\mathrm{z}(B_1 + R_1 - W_2 - N_1) + (1 - \mathrm{z})(B_1 + R_1 - W_2)] + (1 - y)(1 - g)[z(B_1 - W_2 - D - N_1) + (1 - z)(B_1 - W_2 - D)]$

$$E_x = \mathrm{x}E_{X1} + (1 - \mathrm{x})\, E_{X2}$$

In the same way, we can get the expected income of legal disposal and illegal disposal of construction waste $E_{\mathrm{y}1}$ and $E_{y2}$ the average expected income of construction waste disposal enterprises $E_y$.

$E_{\mathrm{y}1} = xg[z(B_2 + S_1 + P_2 + \mathrm{O} - \Delta C) + (1 - z)(B_2 + S_1 + \mathrm{O} - \Delta C)] + (1 - x)g[z(B_2 + P_2 + \mathrm{O} - \Delta C) + (1 - z)(B_2 + \mathrm{O} - \Delta C)] + x(1 - g)[z(B_2 + S_1 + P_2 - \Delta C) + (1 - z)(B_2 + S_1 - \Delta C)] + (1 - x)(1 - g)[z(B_2 + P_2 - \Delta C) + (1 - z)(B_2 - \Delta C)];$

$E_{y2} = xg[z(B_2 - F_1 - N_2 - l) + (1 - z)(B_2 - F_1 - l)] + (1 - x)g[z(B_2 - N_2 - l) + (1 - z)(B_2 - l)] + x(1 - g)[z(B_2 - F_1 - N_2) + (1 - z)(B_2 - F_1)] + (1 - x)(1 - g)[z(B_2 - N_2) + (1 - z)(B_2)];$

$$E_y = \mathrm{y}E_{\mathrm{y}1} + (1 - \mathrm{y})E_{y2}$$

In that same way, we can also get the expect income of active enforcement $E_{g1}$, passive enforcement $E_{g2}$ and the average expected income of decision-making behavior $E_g$.

$E_{g1} = xy[z(B_3 + P_3 + S_2 + R_2 - W_3) + (1 - z)(B_3 + S_2 + R_2 - W_3)] + (1 - x)y[z(B_3 + P_3 + R_2 - W_3) + (1 - z)(B_3 + R_2 - W_3)] + x(1 - y)[z(B_3 + P_3 + S_2 - W_3) + (1 - z)(B_3 + S_2 - W_3)] + (1 - x)(1 - y)[z(B_3 + P_3 - W_3) + (1 - z)(B_3 - W_3)];$

$E_{g2} = xy[z(B_3 + R_2 - F_2 - N_3 - W_4) + (1 - z)(B_3 + R_2 - F_2 - W_4)] + (1 - x)y[z(B_3 + R_2 - N_3 - W_4) + (1 - z)(B_3 + R_2 - W_4)] + x(1 - y)[z(B_3 - F_2 - N_3 - W_4) + (1 - z)(B_3 - F_2 - W_4)] + (1 - x)(1 - y)[z(B_3 - N_3 - W_4) + (1 - z)(B_3 - W_4)];$

$$E_g = \mathrm{g}E_{g1} + (1 - \mathrm{g})E_{g2}$$

Similarly, we can also get the expected return of the public choosing to participate $E_{z1}$, the expected return of choosing not to participate $E_{z2}$ and the average expected return of the public decision-making behavior $E_z$.

$E_{z1} = yg[x(I_1 + I_2 + S_3 - C) + (1 - x)(I_1 + I_2 - C)] + (1 - y)g[x(I_1 + I_2 + S_3 - C - H) + (1 - x)(I_1 + I_2 - C - H)] + y(1 - g)[x(I_1 + I_2 + S_3 - C) + (1 - x)(I_1 + I_2 - C)] + (1 - y)(1 - g)[x(I_1 + I_2 - C - H) + (1 - x)(I_1 - C - H)];$

$E_{z2} = yg[x(I_2 - H) + (1 - x)(I_2 - H)] + (1 - y)g[x(I_2 - H) + (1 - x)(I_2 - H)] + y(1 - g)[x(I_2 - H) + (1 - x)(I_2 - H)] + (1 - y)(1 - g)[x(I_2 - H) + (1 - x)(-H)];$

$$E_z = zE_{z1} + (1 - z)\, E_{z2}$$

Based on the evolutionary game theory, following is the replication dynamic equation of construction waste discharge enterprises, government and the public :

$F(x) = F_x(x, y, \mathrm{g}, z) = \frac{dx}{dt} = x(\mathrm{E_{X1}} - \mathrm{E_x}) = x(1 - x)(E_{X1} - E_{X2}) = x(1 - x)[\mathrm{y}(R_1 - S_1) + \mathrm{gz}(P_1 - S_3 + N_1) + (1 - \mathrm{y})(m_1 - \mathrm{D} + 1) - (1 - \mathrm{g})(B_1 - W_2 - \mathrm{z}\mathrm{N}_1)];$

$F(y) = F_y(x, y, \mathrm{g}, z) = \frac{dy}{dt} = y\left(E_{\mathrm{y}1} - \mathrm{E_y}\right) = y(1 - y)\left(E_{\mathrm{y}1} - E_{y2}\right) = y(1 - y)[z(P_2 + N_2) + g(O + l - zN_2) + xF_1 - \Delta C];$

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$$F(g) = F_g(x, y, \mathrm{g}, z) = \frac{dg}{dt} = g\left(E_{g1} - E_g\right) = g(1-g)\left(E_{g1} - E_{g2}\right) = g(1-g)[x(S_2 + F_2) - yR_2 + z(P_3 + N_3) + W_4 - W_3];$$

$$F(z) = F_z(x, y, \mathrm{g}, z) = \frac{dz}{dt} = z(E_{z1} - E_z) = z(1-z)(E_{z1} - E_{z2}) = z(1-z)[xgS_3 + xy(1-g) + Hy + I_1 - C]$$

Passing through solve the above$F_x(x, y, \mathrm{g}, z) = 0$,$F_y(x, y, \mathrm{g}, z) = 0$, $F_z(x, y, \mathrm{g}, z) = 0$ ,we can get the corresponding pure strategy equilibria, which are F1 (0,0,0,0), F2 (0,0,0,1), F3 (1,0,0,0), F4 (1,0,0,1), F5 (0,1,0,0), F6 (0,1,0,1), F7 (1,1,0,0), F8 (1,1,0,1), F9 (0,0,1,0), F10 (0,0,1,1), F11 (1,0,1,0), F12 (1,0,1,1), F13 (0,1,1,0), F14 (0,1,1,1), F15 (1,1,1,0), F16 (1,1,1,1)

## 3.3. The Analysis of Model

Through the above analysis, in order to further judge whether the equilibrium point is a stable point, a Jacobian matrix will be constructed:

$$J = \begin{bmatrix} \frac{\partial F_x(x,y,\mathrm{g},z)}{\partial x} & \frac{\partial F_x(x,y,\mathrm{g},z)}{\partial y} & \frac{\partial F_x(x,y,\mathrm{g},z)}{\partial g} & \frac{\partial F_x(x,y,\mathrm{g},z)}{\partial z} \\ \frac{\partial F_y(x,y,\mathrm{g},z)}{\partial x} & \frac{\partial F_y(x,y,\mathrm{g},z)}{\partial y} & \frac{\partial F_y(x,y,\mathrm{g},z)}{\partial g} & \frac{\partial F_y(x,y,\mathrm{g},z)}{\partial z} \\ \frac{\partial F_g(x,y,\mathrm{g},z)}{\partial x} & \frac{\partial F_g(x,y,\mathrm{g},z)}{\partial y} & \frac{\partial F_g(x,y,\mathrm{g},z)}{\partial g} & \frac{\partial F_g(x,y,\mathrm{g},z)}{\partial z} \\ \frac{\partial F_z(x,y,\mathrm{g},z)}{\partial x} & \frac{\partial F_z(x,y,\mathrm{g},z)}{\partial y} & \frac{\partial F_z(x,y,\mathrm{g},z)}{\partial g} & \frac{\partial F_z(x,y,\mathrm{g},z)}{\partial z} \end{bmatrix}$$

According to the Jacobian matrix, the stability of the pure strategy equilibrium obtained by copying the dynamic equation is analyzed, and the stability conditions are obtained, as shown in Table 3.

Table 3 shows that three of the sixteen equilibrium strategy points are not stable, and the remaining thirteen are stable when the conditions are met. The following two cases, F1 (0,0,0,0) and F16 (1,1,1,1), are analyzed emphatically. (1) The stable point is F1 (0,0,0,0)$m_1 + W_2 + 1 < D + B_1$, which means that the government conducts loose supervision and the law enforcement personnel will adopt passive law enforcement. Due to the poor social environment for legal disposal of construction waste, the cost of public participation in supervision is often higher than the benefits brought. At the same time, in this stage, the profits obtained by illegal disposal of construction waste by construction waste discharge enterprises are relatively high, and due to the limited scope of public capacity, the illegal disposal of construction waste by enterprises will not be discovered with high probability, so most enterprises will directly dump the construction waste near the construction site or bury it nearby, and choose illegal disposal. The optimal strategy in the four-way game is {loose regulation, illegal treatment, passive enforcement, no participation}. (2) The stable point F16 (1,1,1,1) shall be satisfied$P_1 + R_1 > S_1 + S_3 - N_1; S_2 + F_2 + P_3 + N_3 + W_4 - W_3 > R_2$, that is, the public actively participates in the supervision. If the government passively responds to the complaints related to construction waste, the reputation of the government will be reduced, and the government will also face the complaints from the public against the government. The cost incurred will make the government take strict supervision measures. Strict government supervision will encourage law enforcement officers to actively deal with illegal construction waste, and will increase the frequency of spot checks on construction waste discharge enterprises, so that enterprises will spontaneously and legally dispose of construction waste. So the best strategy in the four-way game is {strict supervision, legal treatment, active law enforcement, participation}.

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**Table 3.** Stability Analysis

| Equilibrium point | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\lambda_4$ | Stability Conditions |
|---|---|---|---|---|---|
| F1 (0,0,0,0) | $m_1 + W_2 + 1 - D - B_1$ | $-\Delta C$ | $W_4 - W_3$ | $I_1 - C$ | $m_1 + W_2 + 1 < D + B_1;$ |
| F2 (0,0,0,1) | $m_1 + W_2 + N_1 + 1 - D - B_1$ | $P_2 + N_2 - \Delta C$ | $P_3 + N_3 + W_4 - W_3$ | $-(I_1 - C)$ | $m_1 + W_2 + N_1 + 1 < D + B_1; P_2 + N_2 < \Delta C; P_3 + N_3 + W_4 < W_3;$ |
| F3 (1,0,0,0) | $-(m_1 + W_2 + 1 - D - B_1)$ | $F_1 - \Delta C$ | $S_2 + F_2 + W_4 - W_3$ | $I_1 - C$ | $m_1 - B_1 > D - W_2 - 1; S_2 + F_2 + W_4 < W_3;$ |
| F4 (1,0,0,1) | $-(m_1 + W_2 + N_1 + 1 - D - B_1)$ | $P_2 + N_2 + F_1 - \Delta C$ | $S_2 + F_2 + P_3 + N_3 + W_4 - W_3$ | $-(I_1 - C)$ | $B_1 - m_1 < W_2 + N_1 + 1 - D; N_2 + F_1 < \Delta C - P_2; S_2 + F_2 + P_3 + N_3 + W_4 < W_3$ |
| F5 (0,1,0,0) | $R_1 - S_1 - B_1 + W_2$ | $\Delta C$ | $W_4 - W_3 - R_2$ | $H + I_1 - C$ | unstable point |
| F6 (0,1,0,1) | $R_1 - S_1 - B_1 + W_2 + N_1$ | $-(P_2 + N_2 - \Delta C)$ | $-R_2 + P_3 + N_3 + W_4 - W_3$ | $-(H + I_1 - C)$ | $W_2 + N_1 - B_1 < S_1 - R_1; \Delta C < N_2 + P_2; N_3 + W_4 < W_3 + R_2 - P_3;$ |
| F7 (1,1,0,0) | $-(R_1 - S_1 - B_1 + W_2)$ | $-(F_1 - \Delta C)$ | $S_2 + F_2 + W_4 - W_3 - R_2$ | $1+H + I_1 - C$ | unstable point |
| F8 (1,1,0,1) | $-(R_1 - S_1 - B_1 + W_2 + N_1)$ | $-(P_2 + N_2 + F_1 - \Delta C)$ | $S_2 + F_2 + P_3 + N_3 + W_4 - W_3 - R_2$ | $-(1+H + I_1 - C)$ | unstable point |
| F9 (0,0,1,0) | $m_1 - D + 1$ | $O + L - \Delta C$ | $-(W_4 - W_3)$ | $I_1 - C$ | $D < m_1 + 1; O + L < \Delta C;$ |
| F10 (0,0,1,1) | $P_1 - S_3 + N_1 + m_1 - D + 1$ | $P_2 + O + L - \Delta C$ | $-(P_3 + N_3 + W_4 - W_3)$ | $-(I_1 - C)$ | $N_1 - D < S_3 - P_1 - m_1 - 1; P_2 + O + L < \Delta C;$ |
| F11 (1,0,1,0) | $-(m_1 - D + 1)$ | $O + L + F_1 - \Delta C$ | $-(S_2 + F_2 + W_4 - W_3)$ | $S_3 + I_1 - C$ | $m_1 > D - 1;\ O + L + F_1 < \Delta C;$ |
| F12 (1,0,1,1) | $-(P_1 - S_3 + N_1 + m_1 - D + 1)$ | $P_2 + O + L + F_1 - \Delta C$ | $-(S_2 + F_2 + P_3 + N_3 + W_4 - W_3)$ | $-(S_3 + I_1 - C)$ | $P_1 + m_1 > S_3 - N_1 - m_1 + D - 1; P_2 + O + L + F_1 < \Delta C;$ |
| F13 (0,1,1,0) | $R_1 - S_1$ | $-(O + L - \Delta C)$ | $-(W_4 - W_3 - R_2)$ | $H + I_1 - C$ | $R_1 < S_1; \Delta C < O + L; R_2 < W_4 - W_3; H + I_1 < C;$ |
| F14 (0,1,1,1) | $R_1 - S_1 + P_1 - S_3 + N_1$ | $-(P_2 + O + L - \Delta C)$ | $-(P_3 + N_3 + W_4 - W_3 - R_2)$ | $-(H + I_1 - C)$ | $R_1 + P_1 + N_1 < S_1 + S_3; P_2 + O + L > \Delta C; P_3 + N_3 + W_4 - W_3 > R_2;$ |
| F15 (1,1,1,0) | $-(R_1 - S_1 + P_1 - S_3 + N_1)$ | $-(O + L + F_1 - \Delta C)$ | $-(S_2 + F_2 + W_4 - W_3 - R_2)$ | $S_3 + H + I_1 - C$ | $P_1 + R_1 > S_1 + S_3 - N_1; S_2 + F_2 + W_4 - W_3 > R_2; S_3 + H + I_1 < C$ |
| F16 (1,1,1,1) | $-(R_1 - S_1 + P_1 - S_3 + N_1)$ | $-(P_2 + O + L + F_1 - \Delta C)$ | $-(S_2 + F_2 + P_3 + N_3 + W_4 - W_3 - R_2)$ | $-(S_3 + H + I_1 - C)$ | $P_1 + R_1 > S_1 + S_3 - N_1; S_2 + F_2 + P_3 + N_3 + W_4 - W_3 > R_2;$ |

## 4. Conclusion and Recommendations

Under the condition of bounded rationality, this paper studies the evolutionary game problem of urban construction waste collaborative treatment, and constructs the relevant game model, with the construction waste emission enterprises, the government and the public as the game

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subjects. 1. Only 13 of the 16 equilibrium points obtained by copying the dynamic equation are stable under the relevant conditions through Jacobian matrix; 2. In different situations, each subject will make the best choice from their own interests; 3. The cooperative treatment of each subject is the most ideal strategy to solve the pollution problem of construction waste.

In order to promote the co-treatment of construction waste, the following suggestions are put forward: 1. As the main supervisor of construction waste disposal, the government should perfect the corresponding laws and regulations, implement powerful reward and punishment system, and improve the disposal efficiency of construction waste; 2. As the main producer of construction waste, construction waste discharge enterprises should cooperate with the corresponding policies of the government, improve the treatment technology of construction waste, dispose construction waste reasonably and legally, and promote the sustainable development of construction industry; 3. As the executors of relevant environmental regulation policies, the law enforcement personnel should give full play to the bridge role between the government and the construction waste discharge enterprises, actively implement the relevant policies of the government, convey the spirit of the relevant policies to the enterprises, increase the frequency of spot check on the illegal disposal of construction waste by enterprises, and urge the enterprises to discharge construction waste legally consciously; 4. As the main victim of construction waste pollution, the public should enhance their environmental awareness and consciously strengthen the supervision of construction waste disposal.

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