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Evolutionary Game Analysis of the Utilization of Construction Waste Resources Based on Prospect Theory

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Abstract: Strengthening the resource utilization of construction waste can improve the environment, alleviate resource shortage, and build a harmonious ecological environment between man and nature. Prospect theory was integrated into trilateral evolutionary game theory to analyze the processes of resource utilization of construction waste among local government, construction enterprises, and the public by establishing the perceived payoff matrix of the three players in the game and using the replication dynamic equation to analyze their strategy choices and evolution path. The results showed that the strategies of the three players depended on the strategies chosen by the other side, the perceived value of the relevant parameters, and the numerical relations among them. Under the conditions that the local government reasonably controlled the supervision cost and the degree of rewards and punishments, the construction enterprise promoted the resource-based technology and management means, and the public enhanced the sense of social responsibility, the game model would evolve toward the ideal state of (1,1,1), to realize the resource utilization of construction waste.

Keywords: prospect theory; construction waste; trilateral game; evolutionary game

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1. Introduction

Under the accelerating pace of Chinese urbanization, infrastructure construction is thriving, and large amounts of natural resources are constantly being consumed. Meanwhile, construction waste is growing at an annual rate of billions of tons. Most construction waste is directly transported to the suburbs or buried in landfill without being used, which has brought enormous pressure on the social environment and natural resources. As we know, construction garbage is a potentially renewable resource, so establishing a scientific and effective utilization system for construction garbage is an urgent problem in our country for its control and management issues [1].

At present, many scholars have studied the stakeholders of construction waste resource utilization. Some have studied it from the single subject [2], some from the two-party subject [3], some from the three-party subject [4], and others from the multi-party subject [5]. In the study of the behavioral decision-making choices of various rights subjects, scholars often use the idea of evolutionary game theory for analysis. For example, Yang et al. [6] studied the game equilibrium of construction solid waste logistics operation by constructing a tripartite game model of the government, enterprises, and the public. In the three stages of construction waste management, Yao [7] respectively established the static game model of complete information between the government and the central stakeholder (the construction units, transportation companies, and recycling enterprises) to analyze the stability of the evolutionary game. Yuan and Wang [8] built an evolutionary game model to analyze the decision-making evolution process of construction enterprises and building materials production enterprises under the two situations of government intervention and non-intervention, and to identify the factors that promote the utilization of construction waste resources.

The existing research mainly adopted the traditional evolutionary game model, focused on the pairwise game, and limited to the static or dynamic game. In the conventional evolutionary game model, the profit and loss affecting the game players are determined, and the theoretical income calculation is based on the objective income of the expected utility theory, which fails to reflect the psychological value of the game players, and it is not completely consistent with the hypothesis of bounded rationality [9,10]. In fact, the relevant subjects of construction waste recycling are not completely rational when choosing whether to utilize construction waste as resources. When the loss and benefit are uncertain, they tend to make choices based on the perceived cost and value of construction waste recycling rather than the objective actual cost, and there is a deviation between perceived value and actual utility [11]. This value perception feature is in line with the research category of prospect theory. Prospect theory can consider the rational deficiency and preference of game players and measure the prospect value under dynamic, uncertain conditions, which is more objective and more consistent with the strategy choice of game players under real conditions [12].

This paper applied the prospect theory to the strategic evolution game of construction waste resourcization for a construction waste resourcization system composed of local governments, construction enterprises, and the public. The value function and subjective probability weight function in the prospect theory are used to replace the return function in the evolutionary game return matrix, to construct the perception return matrix. Based on the benefit matrix, this paper used the replication dynamic equation to analyze the evolutionary game of the strategy of the local government, construction enterprises, and the public for the resource utilization of construction waste and provides countermeasures and suggestions for the resource utilization of construction waste.

2. Subject Analysis

2.1. Local Government

In the early stage of using construction waste resources, the local government is in the leading position and is the helmsman of the utilization of construction waste resources [13]. Local governments formulate policies and measures according to local conditions to standardize the behaviors of each subject of the construction waste resource utilization system, and at the same time confer punishment or reward according to the behaviors of each subject, to encourage each subject to play an active role in the construction waste resource utilization.

2.2. Construction Enterprises

Construction enterprises are the source of construction waste. Through effective management of the construction site and secondary utilization of on-site materials, they can realize the resource utilization of construction waste [14]. They are the key performers of source control and reduction and are also the users of recycled products.

2.3. The Public

Whether or not the resource utilization of construction waste is related to the public's perception of social environment comfort and natural environment safety, and the public's perceived value judgment, is a strong force affecting the resource utilization of construction waste [15].

3. Model Hypothesis and Parameter Description

3.1. Model Assumptions

According to prospect theory, when people evaluate objective things, it is mainly based on their perception of the cost and benefit value of the strategy, rather than the direct profit and loss value of the strategy itself [16]. Prospect value is determined by value function and decision weight, in which value function reflects the actual evaluation of objective things, and decision weight reflects the psychological evaluation of perceived bias. Prospect theory breaks with the conventional expected utility hypothesis and overcomes the expected utility hypothesis that policymakers are perfectly rational.

Hypothesis 1. *The players of the game are local governments, construction enterprises, and the public, all of which are bounded, rational decision-makers. Local government aims to ensure the stable development of the local economy under the condition of comprehensive treatment of construction waste and avoiding the occurrence of environmental events. Construction enterprises aim to maximize their economic interests. The public expects the social and environmental benefits of living comfortably free of construction waste. According to the prospect theory, the psychological perception of the payment value of the three game players is set as prospect value, V, which is composed of value function, U(Δω), and weight function, π(p) [17], as shown in Equation (1):*

$$\begin{cases} V = \sum_i \pi(p_i)U(\Delta\omega_i) \\ U(\Delta\omega) = \begin{cases} (\Delta\omega)^\alpha, (\Delta\omega \geq 0) \\ -\lambda(-\Delta\omega)^\beta, (\Delta\omega < 0) \end{cases} \\ \pi(p) = \frac{p^\gamma}{\left(p^\gamma + (1-p)^\gamma\right)^{\frac{1}{\gamma}}} \end{cases} \tag{1}$$

where p_i represents the perceived probability of the game player when situation i occurs, and π(0) = 0, π(1) = 1 [18] and $\Delta\omega_i$ represents the difference between the actual payment value and the reference point value of the three-party game players after the occurrence of scenario i. When Δω = 0, U(0) = 0. The parameters α and β represent the risk pursuit coefficient (0 < α, β < 1) and respectively represent the marginal diminishing degree of the perceived "gain" and "loss" value of the game subject. The greater the value, the greater the marginal diminishing degree of the perceived value, the weaker the sensitivity of the game subject to this value, the less susceptible the decision of the game subject to its influence, and the more inclined the game subject is to take risks. The parameter λ represents the loss avoidance coefficient (λ > 1), and the larger the value is, the more sensitive the game players are to the strategy loss.

Under the model assumption, the perceived value of the game subject will change with the change of the reference points of gain and loss, rather than the objective absolute value level. According to the value function curve of prospect theory (as shown in Figure 1), the curve is concave in the return interval and convex in the loss interval, indicating that game players tend to avoid risks when facing returns and seek risks when facing losses [19]. The curve is steeper in the loss interval than in the gain interval, indicating that the sensitivity of game players to losses is much higher than that of gains of the same scale [20].

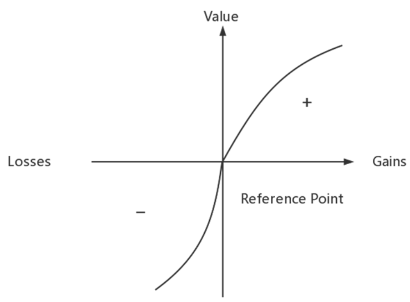

Figure 1. Value function curve of prospect theory.

Hypothesis 2. *The local government is responsible for guiding, supervising, and managing the recycling of local construction waste. Through the formulation of relevant regulations and management methods, supplemented by economic measures such as rewards and fines, the local government will conduct interventional management of the recycling of construction waste within its jurisdiction. Based on considering the benefits and costs of recycling construction waste, local governments can choose two strategies "supervision" and "non-supervision."*

Hypothesis 3. *As the producer of construction waste, construction enterprises are the source of the resource management of construction waste. However, as an economy, construction enterprises maximize their economic benefits. In recycling construction waste, construction enterprises can choose to transport the construction waste generated from the construction site to a landfill without classification or simple classification, or choose to implement the recycling of construction waste under the economic incentive of the local government. The two strategies of construction enterprises are "resource utilization and non-resource utilization."*

Hypothesis 4. *As a social unit, the public has the right and obligation to maintain a harmonious living environment, but the public, as a limited rational subject, pursues the maximization of its interests. In the face of recycling construction waste, the public can choose not to supervise so that they do not have to pay the cost of supervision. Therefore, the power source of supervision is mainly economic or spiritual rewards from the government. The public's two strategies are "monitor and do not monitor."*

Hypothesis 5. *The positive behaviors of three players in the game have a synergistic effect. When the local government adopts the supervision strategy, the public actively supervises, and the construction enterprise implements the resource management of the construction waste generated in the process of project construction, and the chance of the flood of construction waste is small. Under this condition, the probability of construction waste threatening natural harmony is 0. When only one or two parties adopt a positive strategy, the probability of construction waste threatening the natural harmony will increase, and the probability is* $0 < p < 1$*. When all three parties adopt negative strategies (no supervision, no recycling, no supervision), the probability of construction waste threatening the harmony of nature is 1.*

Hypothesis 6. *When the local government actively supervises, but the construction enterprise does not recycle, the threat risk of construction waste to the environment will not be eliminated, which will not lead to the increase of public support for the local government and the improvement of the sense of social benefit. Only when both the local government and the construction enterprise take positive measures can the public's sense of local government and social benefits be enhanced. Only when the public participates in the supervision of the utilization of construction waste resources can the government efficiency and social benefits be perceived. Therefore, this parameter is reflected in the public participation in the supervision. When both the local government and the construction enterprise adopt active strategies, take S; When the local government does not supervise, but the construction enterprise chooses resourcization, the public's support for the local government remains unchanged, and the sense of social efficacy does not change, take S. The rest of the case, take -S.*

Hypothesis 7. *The proportion of local governments adopting supervision is* x*, and the proportion of local governments adopting non-supervision is* $1 - x$*. The proportion of construction enterprises implementing the resource utilization of construction waste is* y*, and the proportion of not implementing the resource utilization of construction waste is* $1 - y$*. The proportion of public supervision is* z*, and the proportion of non-supervision is* $1 - z$*, and* $0 \leq x, y, z \leq 1$*.*

3.2. Parameter Description

The description of model parameters and their meanings are shown in Table 1.

Table 1. Model parameters and their meanings.

Parameter	Express Meaning
B_1	The perceived value of local government incentives to resource-based construction enterprises when choosing supervision
B_2	The perceived value of public rewards for monitoring when local governments choose to regulate
C_1	The perceived value of the human, material, and financial costs paid by local governments in the supervision of the utilization of construction waste resources
C_2	The perceived value of compensation and management costs incurred by local governments for not supervising the recycling of construction waste
C_3	The perceived value of the running cost of construction waste recycling in construction enterprises
C_4	Construction enterprises have not carried out the perceived value of the running cost of the recycling of construction waste
C_5	The perceived value of public supervision costs for the recycling of construction waste
F_1	The perceived value of local government's punishment for non-resource construction enterprises when choosing supervision
F_2	Construction enterprises did not recycle construction waste but put it in open storage or landfill directly, causing public dissatisfaction and the perceived value of reputation loss
S	The perceived value of the influence of the local government's strategy choice on public support and social benefits increased to positive and decreased to negative
R	Construction enterprises carry out the recycling of construction waste to obtain the perceived value of the waste that can be reused after sorting
D	The deluge of construction waste causes serious social and environmental risk costs to the perceived value

According to prospect theory, there is no deviation between the perceived value and the actual expected utility value for the determined costs and benefits, and only when the players perceive the uncertain costs and benefits can they generate psychological perceived utility [21]. The supervision cost of local government for the resource utilization of construction waste is related to the decisions of the local government and belongs to the deterministic expenditure. The operation cost of the construction enterprise taking or not taking resources is related to its development strategy and belongs to deterministic profit and loss. Therefore, there is no perception bias in C_1, C_3, and C_4. Local government's punishment and reward to construction enterprises and reward to the public are jointly determined by the strategy of resource utilization of construction waste of the three parties in the game, which belong to uncertain profit and loss. However, the local government's after-recovery cost, public support, the reputation of construction enterprises, perceived value of waste reuse, and environmental deterioration cost are all uncertain. Therefore, B_1, B_2, C_2, C_5, F_1, F_2, S, R, and D have value perception bias.

Based on assumptions 1–7 and model parameters, the strategy set of the local government, construction enterprises, and the public and the corresponding revenue perception matrix can be obtained, as shown in Table 2.

Table 2. Game revenue perception matrix of local government, construction enterprise, and public.

Serial Number	Set of Policies	Revenue Perception Matrix		
		Local Government	Construction Enterprise	The Public
1	(Regulation, resourcization, supervision)	$-V(B_1)-V(B_2)-C_1+V(S)$	$-C_3+V(R)+V(B_1)$	$-V(C_5)+V(B_2)$
2	(Supervision, not resource, supervision)	$-V(B_2)-C_1+V(F_1)-V(S)$	$-C_4-V(F_2)-V(F_1)$	$-V(C_5)+V(B_2)$
3	(Regulation, resourcing, no supervision)	$-V(B_1)-C_1$	$-C_3+V(R)+V(B_1)$	0
4	(Regulation, no resourcing, no monitoring)	$-C_1+V(F_1)$	$-C_4-V(F_2)-V(F_1)$	0
5	(No regulation, resourcization, supervision)	$-V(C_2)$	$-C_3+V(R)$	$-V(C_5)$
6	(No regulation, no resourcing, supervision)	$-V(C_2)-V(S)$	$-C_4-V(F_2)$	$-V(C_5)$
7	(No regulation, resourcing, no supervision)	$-V(C_2)$	$-C_3+V(R)$	0
8	(No regulation, no resourcing, no monitoring)	$-V(C_2)-V(D)$	$-C_4-V(F_2)$	0

4. Model Construction and Analysis

4.1. Model Construction

The perceived benefits of local government regulation are as follows:

$$\begin{aligned} V_{GY} &= z[y(-V(B_1)-V(B_2)-C_1+V(S))+(1-y)(-V(B_2)-C_1+V(F_1)-V(S))]+(1-z)[y(-V(B_1)-C_1)+(1-y)(-C_1+V(F_1))] \\ &= 2zyV(S)-zV(S)-zV(B_2)-yV(B_1)-C_1+V(F_1)-yV(F_1) \end{aligned} \quad (2)$$

The perceived benefits of local governments choosing not to regulate are as follows:

$$\begin{aligned} V_{GN} &= z[y(-V(C_2))+(1-y)(-V(C_2)-V(S))]+(1-z)[y(-V(C_2))+(1-y)(-V(C_2)-V(D))] \\ &= zyV(S)-zV(S)-V(C_2)-V(D)+zV(D)+yV(D)-zyV(D) \end{aligned} \quad (3)$$

The average perceived benefits of local governments are as follows:

$$\overline{V}_G = xV_{GY}+(1-x)V_{GN} \quad (4)$$

The perceived benefits of the construction enterprise choosing to recycle are as follows:

$$\begin{aligned} V_{EY} &= z[x(-C_3+V(R)+V(B_1))+(1-x)(-C_3+V(R))]+(1-z)[x(-C_3+V(R)+V(B_1))+(1-x)(-C_3+V(R))] \\ &= xV(B_1)+V(R)-C_3 \end{aligned} \quad (5)$$

The perceived benefits of construction enterprises choosing not to recycle are as follows:

$$\begin{aligned} V_{EN} &= z[x(-C_4-V(F_2)-V(F_1))+(1-x)(-C_4-V(F_2))]+(1-z)[x(-C_4-V(F_2)-V(F_1))+(1-x)(-C_4-V(F_2))] \\ &= -xV(F_1)-C_4-V(F_2) \end{aligned} \quad (6)$$

The average perceived income of construction enterprises is as follows:

$$\overline{V}_E = yV_{EY}+(1-y)V_{EN} \quad (7)$$

The perceived benefits of public choice monitoring are as follows:

$$\begin{aligned} V_{PY} &= y[x(-V(C_5)+V(B_2))+(1-x)(-V(C_5))]+(1-y)[x(-V(C_5)+V(B_2))+(1-x)(-V(C_5))] \\ &= xV(B_2)-V(C_5) \end{aligned} \quad (8)$$

The perceived benefits of the public choosing not to monitor are as follows:

$$V_{PN} = 0 \quad (9)$$

The average perceived benefits of the public are as follows:

$$\overline{V}_P = zV_{PY}+(1-z)V_{PN} \quad (10)$$

The dynamic evolution of the players is described by the replication dynamic equation, and the replication dynamic equations of the local government, construction enterprises, and the public to select the resource utilization of construction waste are as follows:

The replication dynamic equation of the local government's strategy of choosing construction waste resource utilization is as follows:

$$\begin{aligned} V(x) &= \frac{dx}{dt} = x(V_{GY} - \overline{V}_G) = x(1-x)(V_{GY} - V_{GN}) \\ &= x(1-x)[z(yV(S) - V(B_2) - (1-y)V(D)) + (1-y)(V(F_1) + V(D)) - yV(B_1) - C_1 + V(C_2)] \end{aligned} \tag{11}$$

The replication dynamic equation of the construction enterprise's strategy of recycling construction waste is as follows:

$$\begin{aligned} V(y) &= \frac{dy}{dt} = x(V_{EY} - \overline{V}_E) = y(1-y)(V_{EY} - V_{EN}) \\ &= y(1-y)(xV(B_1) + xV(F_1) + V(R) - C_3 + C_4 + V(F_2)) \end{aligned} \tag{12}$$

The replication dynamic equation for the public to choose the strategy of recycling construction waste is as follows:

$$\begin{aligned} V(z) &= \frac{dz}{dt} = x(V_{PY} - \overline{V}_P) = z(1-z)(V_{PY} - V_{PN}) \\ &= z(1-z)(xV(B_2) - V(C_5)) \end{aligned} \tag{13}$$

4.2. Model Analysis

4.2.1. Evolution Path Analysis of Local Government Construction Waste Resource Utilization Strategy

Hypothesis $V(x) = \frac{dx}{dt} = 0$, and the solution obtained is the evolutionary equilibrium point [22].

When $z = \frac{(1-y)(V(F_1)+V(D))-yV(B_1)-C_1+V(C_2)}{V(B_2)-yV)(S)+(1-y)V(D)}$, $V(x) \equiv 0$, In this scenario, all levels are in a stable state, and the proportion of the local government's strategy selection does not change with time [23].

When $z \neq \frac{(1-y)(V(F_1)+V(D))-yV(B_1)-C_1+V(C_2)}{V(B_2)-yV(S)+(1-y)V(D)}$, $x = 0$ and $x = 1$ are the two possible stable points for the local government construction waste resource utilization. To further determine the stability point, we have to take a further derivative of $V(x)$ when $\frac{dV(x)}{dx} < 0$. The result obtained is the evolutionary stability strategy (ESS) [24].

$$\frac{dV(x)}{dx} = (1-2x)[z(yV(S) - V(B_2) - (1-y)V(D)) + (1-y)(V(F_1) + V(D)) - yV(B_1) - C_1 + V(C_2)] \tag{14}$$

(1) When $(1-y)(V(F_1) + V(D)) - yV(B_1) - C_1 + V(C_2) > 0$ and $V(B_2) - yV(S) + (1-y)V(D) > 0$, if $z > \frac{(1-y)(V(F_1)+V(D))-yV(B_1)-C_1+V(C_2)}{V(B_2)-yV(S)+(1-y)V(D)}$, then $\frac{dV(x)}{dx}|_{x=0} < 0$, $\frac{dV(x)}{dx}|_{x=1} > 0$. The ESS at this time is $x = 0$. That is, local governments do not choose to supervise the recycling of construction waste; if $z < \frac{(1-y)(V(F_1)+V(D))-yV(B_1)-C_1+V(C_2)}{V(B_2)-yV(S)+(1-y)V(D)}$, then $\frac{dV(x)}{dx}|_{x=0} > 0$, $\frac{dV(x)}{dx}|_{x=1} < 0$. The ESS at this time is $x = 1$. That is, local governments choose to supervise the recycling of construction waste.

(2) When $(1-y)(V(F_1) + V(D)) - yV(B_1) - C_1 + V(C_2) > 0$, $V(B_2) - yV(S) + (1-y)V(D) < 0$, $\frac{dV(x)}{dx}|_{x=0} > 0$, $\frac{dV(x)}{dx}|_{x=1} < 0$. The ESS at this time is $x = 1$. That is, local governments choose to supervise the recycling of construction waste.

(3) When $(1-y)(V(F_1) + V(D)) - yV(B_1) - C_1 + V(C_2) < 0$, $V(B_2) - yV(S) + (1-y)V(D) > 0$, $\frac{dV(x)}{dx}|_{x=0} < 0$, $\frac{dV(x)}{dx}|_{x=1} > 0$. The ESS at this time is $x = 0$. That is, local governments do not choose to supervise the recycling of construction waste.

(4) When $(1-y)(V(F_1) + V(D)) - yV(B_1) - C_1 + V(C_2) < 0$, $V(B_2) - yV(S) + (1-y)V(D) < 0$, if $z > \frac{(1-y)(V(F_1)+V(D))-yV(B_1)-C_1+V(C_2)}{V(B_2)-yV(S)+(1-y)V(D)}$, then, $\frac{dV(x)}{dx}|_{x=0} > 0$, $\frac{dV(x)}{dx}|_{x=1} < 0$. The ESS at this time is $x = 1$. That is, local governments

choose to supervise the recycling of construction waste; if $z < \frac{(1-y)(V(F_1)+V(D))-yV(B_1)-C_1+V(C_2)}{V(B_2)-yV(S)+(1-y)V(D)}$, then, $\frac{dV(x)}{dx}|_{x=0} < 0$, $\frac{dV(x)}{dx}|_{x=1} > 0$. The ESS at this time is $x = 0$. That is, local governments do not choose to supervise the recycling of construction waste.

It can be seen that whether local governments choose to supervise the recycling of construction waste depends on the numerical relationship of parameters and the probability that construction enterprises and the public choose to participate in the recycling of construction waste. The numerical relationship of the parameters mainly depends on the uncertain public support, the cost of environmental degradation, the perceived value of compensation and management costs, subsidies and fines, and the regulatory costs of local governments.

4.2.2. Analysis of Evolution Path of Strategy for Recycling Construction Waste of Construction Enterprises

Hypothesis $V(y) = \frac{dy}{dt} = 0$ is used to solve the evolutionary equilibrium point of the resource utilization of construction waste in construction enterprises.

When $x = \frac{C_3-C_4-V(F_2)-V(R)}{V(B_1)+V(F_1)}$, $V(y) \equiv 0$. In this scenario, all levels are stable, and the proportion of strategy selection of construction enterprises does not change with time.

When $x \neq \frac{C_3-C_4-V(F_2)-V(R)}{V(B_1)+V(F_1)}$, $y = 0$ and $y = 1$ are the two possible stable points of the construction enterprise construction waste resource utilization. Take a further derivative of $V(y)$. When $\frac{dV(y)}{dy} < 0$ the calculated evolutionary stability strategy (ESS) is

$$\frac{dV(y)}{dy} = (1-2y)[x(V(B_1) + V(F_1)) + V(R) - C_3 + C_4 + V(F_2)] \tag{15}$$

(1) When $V(R) - C_3 + C_4 + V(F_2) > 0$, $\frac{dV(y)}{dy}|_{y=1} < 0$, $\frac{dV(y)}{dy}|_{y=0} > 0$. The ESS at this time is $y = 1$. That is, construction enterprises choose to make use of construction waste resources.

(2) When $V(R) - C_3 + C_4 + V(F_2) < 0$, if $x > \frac{C_3-C_4-V(F_2)-V(R)}{V(B_1)+V(F_1)}$, then $\frac{dV(y)}{dy}|_{y=1} < 0$, $\frac{dV(y)}{dy}|_{y=0} > 0$. The ESS at this time is $y = 1$. That is, construction enterprises choose to use construction waste resources; if $x < \frac{C_3-C_4-V(F_2)-V(R)}{V(B_1)+V(F_1)}$, then $\frac{dV(y)}{dy}|_{y=1} > 0$, $\frac{dV(y)}{dy}|_{y=0} < 0$. The ESS at this time is $y = 0$. That is, construction enterprises do not choose to recycle construction waste.

It can be seen that whether construction enterprises choose to recycle construction waste depends on the numerical relationship of parameters; that is, it mainly depends on the value perception of uncertain income from secondary utilization of construction waste, reputation loss, local government subsidies, and fines, and the determined cost of whether construction enterprises choose to recycle construction waste or not.

4.2.3. Evolution Path Analysis of the Public to Make Use of Construction Waste Resources Strategy

Hypothesis $V(z) = \frac{dz}{dt} = 0$ is used to solve the evolutionary equilibrium point of the public to make use of construction waste resources.

When $x = \frac{V(C_5)}{V(B_2)}$, $V(z) \equiv 0$. In this scenario, all levels are stable, and the proportion of the public's choice of strategy does not change with time.

When $x \neq \frac{V(C_5)}{V(B_2)}$, $z = 0$ and $z = 1$ are the two possible, stable points for the public to make use of construction waste resources. Take a further derivative of $V(z)$. When $\frac{dV(z)}{dz} < 0$, the calculated evolutionary stability strategy (ESS) is

$$\frac{dV(z)}{dz} = (1-2z)(xV(B_2) - V(C_5)) \tag{16}$$

(1) When $V(C_5) > xV(B_2)$, $0 < x < \frac{V(C_5)}{V(B_2)}$, then $\frac{dV(z)}{dz}|_{z=0} < 0$, $\frac{dV(z)}{dz}|_{z=1} > 0$. The ESS at this time is $z = 0$. That is, the public does not choose to supervise the recycling of construction waste.

(2) When $V(C_5) < xV(B_2)$, $1 > x > \frac{V(C_5)}{V(B_2)}$, then $\frac{dV(z)}{dz}|_{z=0} > 0$, $\frac{dV(z)}{dz}|_{z=1} < 0$. The ESS at this time is $z = 1$. That is, the public chooses to supervise the recycling of construction waste.

It can be seen that whether or not the public chooses to supervise the resource utilization of construction waste depends on the numerical relationship of parameters, that is, it mainly depends on the perception of the uncertain supervision cost and the value of local government subsidies.

4.2.4. Strategy Stability Analysis of Model Evolution

According to Lyapunov stability theory, the asymptotic stability of the system at the equilibrium point can be judged by analyzing the eigenvalues of the Jacobian matrix of the game system [25], and the Jacobian matrix of the system can be calculated as shown in Equation (17):

$$J = \begin{bmatrix} \frac{dV(x)}{dx} & \frac{dV(x)}{dy} & \frac{dV(x)}{dz} \\ \frac{dV(y)}{dx} & \frac{dV(y)}{dy} & \frac{dV(y)}{dz} \\ \frac{dV(z)}{dx} & \frac{dV(z)}{dy} & \frac{dV(z)}{dz} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{17}$$

And:

$$a_{11} = (1-2x)[z(yV(S) - V(B_2) - (1-y)V(D)) + (1-y)(V(F_1) + V(D)) - yV(B_1) - C_1 + V(C_2)];$$

$$a_{12} = x(1-x)(zV(S) + zV(D) - V(F_1) - V(D) - V(B_1));$$

$$a_{13} = x(1-x)(yV(S) - V(B_2) - (1-y)V(D));$$

$$a_{21} = y(1-y)(V(B_1) + V(F_1));$$

$$a_{22} = (1-2y)(xV(B_1) + xV(F_1) + V(R) - C_3 + C_4 + V(F_2));$$

$$a_{23} = a_{32} = 0;$$

$$a_{31} = z(1-z)V(B_2);$$

$$a_{33} = (1-2z)(xV(B_2) - V(C_5)).$$

Because the asymptotic stability solution of the replication dynamic system of a multi-agent evolutionary game must be a strict Nash equilibrium solution [26], for this dynamic replication system, in addition to (0,0,0), (1,0,0), (0,0,1), (1,1,0), (1,1,1), (0,1,1), (0,1,1), and (1,1,1), the rest are not in a state of gradual stability. The stability points are substituted into the Jacobian matrix to solve the corresponding eigenvalues λ_1, λ_2, and λ_3, as shown in Table 3.

According to the Lyapunov indirect method, if a point is asymptotically stable, the corresponding eigenvalues of the Jacobian matrix must be less than 0. To determine the positive and negative characteristics of characteristic values under different equilibrium points, it is assumed that the public will continue to participate in the resource utilization of construction waste only when they perceive that the local government's reward is higher than their perceived supervision cost, namely $V(B_2) > V(C_5)$. Thus, the positive and negative characteristic values of some equilibrium points and the asymptotic stability of equilibrium points are obtained, as shown in Table 3.

Table 3. Evaluation table of eigenvalues of Jacobian matrix and local stability of equilibrium points.

i	Point of Equilibrium	Value of Characteristic λ_1	Value of Characteristic λ_2	Value of Characteristic λ_3	Asymptotic Stability
1	(0,0,0)	$V(F_1) + V(D) + V(C_2) - C_1$ (*)	$V(R) + V(F_2) + C_4 - C_3$ (*)	$-V(C_5)$ (−)	unknown
2	(1,0,0)	$C_1 - V(C_2) - V(F_1) - V(D)$ (*)	$V(B_1) + V(F_1) + V(R) + V(F_2) + C_4 - C_3$ (*)	$V(B_2) - V(C_5)$ (+)	unstable
3	(0,1,0)	$V(C_2) - C_1 - V(B_1)$ (*)	$C_3 - C_4 - V(R) - V(F_2)$ (*)	$-V(C_5)$ (−)	unknown
4	(0,0,1)	$V(F_1) - V(B_2) - C_1 + V(C_2)$ (*)	$V(R) + V(F_2) + C_4 - C_3$ (*)	$V(C_5)$ (+)	unstable
5	(1,1,0)	$V(B_1) + C_1 - V(C_2)$ (*)	$C_3 - C_4 - V(R) - V(F_2) - V(B_1) - V(F_1)$ (*)	$V(B_2) - V(C_5)$ (+)	unstable
6	(1,0,1)	$V(B_2) - V(F_1) + C_1 - V(C_2)$ (*)	$V(B_1) + V(F_1) + V(R) + V(F_2) + C_4 - C_3$ (*)	$V(C_5) - V(B_2)$ (−)	unknown
7	(0,1,1)	$V(S) - V(B_2) - V(B_1) + V(C_2) - C_1$ (*)	$C_3 - C_4 - V(R) - V(F_2)$ (*)	$V(C_5)$ (+)	unstable
8	(1,1,1)	$V(B_2) + V(B_1) - V(S) + C_1 - V(C_2)$ (*)	$C_3 - C_4 - V(R) - V(F_2) - V(B_1) - V(F_1)$ (*)	$V(C_5) - V(B_2)$ (−)	unknown

Note: The "+" in parentheses after the eigenvalue expression means that the eigenvalue is positive. "−" indicates that the eigenvalue is negative. "*" indicates that the eigenvalue is positive or negative.

As can be seen from Table 3, there are four evolutionary stable states of the system.

(1) When $V(D) + V(C_2) < C_1 - V(F_1)$ and $V(F_2) + C_4 < C_3 - V(R)$, the equilibrium stability point is (0,0,0) and the strategy choice of the game players is (no supervision, no resource utilization, no supervision). At this time, the cost of local government supervision on the recycling of construction waste is higher than the comprehensive cost without supervision, and the net cost of the recycling of construction enterprises is higher than the comprehensive cost without recycling. Therefore, local governments and construction enterprises will not choose to participate in the recycling of construction waste.

(2) When $V(C_2) < C_1 + V(B_1)$, and $C_3 - V(R) < C_4 + V(F_2)$, the equilibrium stability point is (0,1,0) and the strategy choice of the game subject is (no supervision, resource utilization, no supervision). At this time, the comprehensive cost of local government supervision on the recycling of construction waste is higher than that of non-supervision, and the local government will not choose to supervise the recycling of construction waste. When the net cost of recycling construction waste is lower than the comprehensive cost of non-recycling, construction enterprises are willing to choose to participate in recycling construction waste. However, without the government's policy promotion and various economic subsidies, the cost of construction enterprises' recycling of construction waste is hardly lower than that of non-recycling. Therefore, the stability point of this strategy is only theoretical stability.

(3) When $V(B_2) + C_1 - V(F_1) < V(C_2)$ and $V(F_1) + V(F_2) + C_4 < C_3 - V(B_1) - V(R)$, the equilibrium stability point is (1,0,1) and the strategy choice of the game player is (supervision, no resource utilization, supervision). At this time, the cost of local government supervision of the recycling of construction waste is lower than that of non-supervision, and the local government will choose to supervise the recycling of construction waste. Under the continuous supervision of the local government, the proportion of the government's economic incentives and fines in the cost of non-recycling of construction enterprises will be higher. When the cost exceeds the recycling cost, construction enterprises will choose to recycle construction waste. Therefore, the strategic stability point is not the actual evolutionary stability.

(4) When $V(B_2) + V(B_1) + C_1 < V(C_2) + V(S)$ and $C_3 - V(B_1) - V(R) < C_4 + V(F_2) + V(F_1)$, the equilibrium stability point is (1,1,1) and the strategy choice of the game player is (supervision, resource utilization, supervision). At this time, the cost of local governments and construction enterprises choosing to participate in the utilization of construction waste resources is lower than that of not participating, and all three parties in the game choose to participate actively, which is the ideal state of collaborative participation in the utilization of construction waste resources.

5. Conclusions

This paper studied the resource utilization system of construction waste composed of local government, construction enterprises, and the public; introduced prospect theory to construct the benefit perception matrix, which was different from the traditional benefit matrix; and used the replication dynamic equation to analyze the strategy selection and evolution path of the three parties in the game, which provided a certain theoretical basis for realizing the goal of the resource utilization of construction waste. This paper mainly came to the following conclusions:

(1) The strategy selection of local government, construction enterprises, and the public in the game depended on the other party's strategy, and the game process was a process of constant adjustment and adaptation. Whether the local government supervised or not, it depended on the numerical relation of the parameters and the participation probability of the construction enterprises and the public. The resource utilization of construction enterprises and public supervision mainly depended on the numerical relation of the parameters.

(2) The system had four evolutionary stability points, namely (0,0,0), (0,1,0), (1,0,1), and (1,1,1), but only when $V(B_2) + V(B_1) + C_1 < V(C_2) + V(S)$, $C_3 - V(B_1) - V(R) < C_4 + V(F_2) + V(F_1)$, $V(C_5) < V(B_2)$ did the three-party strategy converges to the stable point (1,1,1), which was the ideal state. That is, the local government chooses to supervise, the construction enterprises decide to recycle, and the public chooses to supervise, to realize the recycling of construction waste and obtain good social and environmental benefits.

In order to realize the goal of resource utilization of construction waste, local governments should pay attention to the negative effects brought by construction waste; strengthen the supervision of enterprises through policy support, economic support, and appropriate reward and punishment measures; enhance the public's perception of the value of construction waste through increasing publicity; and give certain economic or spiritual incentives. Construction enterprises should enhance the consciousness of resource recycling and actively introduce advanced technology and management means of resource utilization of construction waste. The public should enhance their sense of social responsibility and actively participate.

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