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Evolutionary Game Study of Waste Separation Policy in the Context of the "Double Carbon" Target

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Abstract: Research on waste separation promotion policies is of great theoretical and practical significance for the universal implementation of the domestic waste separation system. This paper constructs a non-cooperative tripartite evolutionary game model that includes central command, local deployment, and enterprise performance. An evolutionary game approach was used to analyze the strategic choices of the central government, local government, and separation enterprises in waste separation promotion, and this study investigated the factors influencing the evolution of these choices using numerical simulations. The findings indicated the following: central government, local governments, and separation enterprises are affected differently by their respective willingness to participate; the behavior of separation enterprises is less influenced by the central government's and local governments' willingness to participate and is primarily influenced by market factors, whereas local government is more influenced by the central government's willingness to participate; and local government and classification enterprises are affected differently by their respective willingness to participate. While separation firms are more susceptible to the cost-sharing, income, and revenue distribution coefficient, local governments are more responsive to policy support. The promotion of waste separation in China requires strengthened centralized waste management to avoid the failure of local waste separation, broadening of the scope of central funding incentives and establishing local separation compensation mechanisms, clarifying local waste separation performance responsibilities and new waste tax collection standards, supporting separation enterprises' technological innovation and guiding public participation in waste separation, creating an environment for waste separation, and deepening the study of waste separation accordingly.

Keywords: waste separation; central government; local government; separation enterprises; promotion policy; tripartite evolutionary game

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1. Introduction

Along with the rapid development of industrialization and urbanization, the issue of low-carbon development has become an increasing concern in countries worldwide. The traditional waste treatment methods are landfill (Sauve and Van Acker, 2020 [1]), incineration (Yao et al., 2019 [2]), and biochemical treatment (Lu et al., 2020 [3]). These traditional waste treatment methods (Laurence, 2008 [4]; Adrados et al., 2013 [5]; Ohnishi et al., 2018 [6]) and the concept of low-carbon development are clearly in conflict (Sawangphol and Pharino, 2011 [7]; Chomaitong and Perera, 2014 [8]; Phu et al., 2022a [9]). In order to achieve the national goals of green industrial transformation, sustained economic growth, and synergistic social development (Lyu et al., 2019 [10]), in 2021, the Chinese Ministry of Housing and Urban–Rural Development and 15 other departments issued Opinions on Strengthening Green and Low-Carbon Construction in County Cities, a document that places emphasis on improving the carrying capacity and public services of county cities, enhancing the total service capacity of county cities, and promoting the formation of green production and lifestyles, including strengthening the county's domestic waste separation.

Based on the global trend of low-carbon development, in 2020, China proposed, for the first time, the strategic direction of "striving to achieve peak carbon by 2030 and carbon neutrality by 2060". Effectively addressing waste separation is directly related to the achievement of peak carbon and carbon neutrality (in the future referred to as "double carbon") (Wang et al., 2022 [11]). In 2021, the State Council of China issued the Opinions of the Central Committee of the Communist Party of China on the Complete and Accurate Implementation of the New Development Concept and the Action Plan for Carbon Neutrality by 2030, both of which mention improving the resource recycling system, promoting the resource utilization of construction waste, and vigorously promoting waste separation. The "Action Plan for Carbon Peak by 2030" mentions improving the resource recycling system, promoting the resource utilization of construction waste, vigorously promoting waste separation and incineration of domestic waste, reducing the proportion of landfill, and exploring the resource utilization technology suitable for China's food waste characteristics. Countries around the world have also introduced policies addressing these issues (Wong et al., 2007 [12]; Slagstad and Brattebo, 2013 [13]; Fujii et al., 2016 [14]) and clarifying the requirements for waste separation to ensure the achievement of the "double carbon" goal (Matsuda et al., 2012 [15]; Wallace et al., 2015 [16]; Fernández-Braña et al., 2020 [17]).

The central government is the leader in the current approach to waste separation in China; local governments at all levels provide information and support for waste separation and actively encourage social organizations, public participation, and supervision (Zhang et al., 2010) [18]. The report of the 20th Five-Year Plan proposes to build an environmental governance system with the government as the leader, enterprises as the main body, and social organizations and the public as participants. However, if this collaboration between the government, enterprises, social organizations, and the public to shift waste separation from an activity of "non-cooperation" to "cooperation" is not successful, it will be difficult for China to implement a national system of domestic waste separation.

From the perspective of waste separation promotion, there is a competitive mechanism for local governments to implement waste separation policies as formulated by the central government. Waste separation is often used as a gaming tool among local governments to compete for environmental resources (Zhang, 2016) [19]. From the perspective of source classification, local governments and separation enterprises often collaborate. Waste separation enterprises bear additional separation costs that are funded by local finance or tax sources; this results in enterprises having a formal responsibility to ensure waste separation. From the viewpoint of interest coordination, the central government's incentive fund subsidy can play a role in sharing the cost of local waste classification. The state exerts macro control, establishing a compensation mechanism for waste classification and promoting the cooperation of local governments and classification enterprises in waste classification activities through the reasonable allocation of incentive funds. Therefore, China's commitment to eco-friendly development is built on the construction of government-led enterprise as the main body, and social organizations and public participation as supports, in the promotion of a waste separation system of "central command + local deployment + enterprise performance".

The evolutionary game approach is used to study waste separation promotion policies due to the properties of public goods, pollution from waste, and the non-competitive and non-exclusive nature of waste, as well as the "public tragedy" and "prisoner's dilemma" arising from the waste separation process (Nowak and Sigmund, 1993 [20]; Ott and Aoki, 2002 [21]). At the same time, the assumption of limited rationality in evolutionary game theory is consistent with the behavior of individual residents in the source separation of waste. In the waste separation process, the game of participants is a stochastic and shared-learning repetitive game process, so the adjustment process of individual strategies can be modeled using the replication dynamics mechanism. Therefore, evolutionary game analysis can reflect the evolutionary path and stable strategies of participants' behaviors. At the same time, since realizing "double carbon" is a future goal, the objective conditions for

empirical verification are unavailable at this stage, and the evolutionary game simulation can make specific predictions and forecasts. This is important for achieving effective waste separation and the double carbon goal.

2. Literature Review

2.1. Waste Separation Policy

2.1.1. Waste Separation and Recycling Policy

The waste separation and recycling policy is a government policy that requires separation of waste and recycling it according to different categories and channels. In areas with low environmental awareness, local governments generally adopt the idea of "end-of-pipe intervention" in waste disposal channels to develop local waste separation policies (Mbiba, 2014 [22]). In recent years, local governments have been influenced by the globally recognized policies of comprehensive waste reduction and recycling, and have gradually realized the importance of addressing waste separation at the source. Local authorities have developed waste separation and recycling policies that are compatible with the development of the emerging low-carbon economy. Waste segregation and recycling policies are seen as an upstream social marketing intervention in the environmental management supply chain (Matsumoto, 2011 [23]; Issock et al., 2020 [24]), but policy implementation has not had a moderating effect on household waste segregation intentions.

2.1.2. Waste Segregation Management Policy

Waste segregation management policy development, implementation, effectiveness, and feedback are subject to various factors. First, a well-functioning waste management system is needed (Zanjani et al. (2012) [25]; Knickmeyer, 2020 [26]); this can improve recycling performance in order to recover quality materials, save resources, and keep waste out of landfills. Policymakers can design future strategies and interventions based on the operational reality of waste management systems. National policies (Moh, 2017 [27]; Fukuda et al., 2018 [28]; Razali and Wai, 2019 [29]) have led to significant improvements in waste separation at the source and recycling by establishing a dual-track waste separation management policy of federalization and privatization, which effectively integrates multiple participants such as the government, private organizations, the public, and social elites.

2.1.3. Waste Separation Policy Moderation

Enforced and moral norms are often considered to directly and significantly affect residents' behavioral intentions to sort waste. Waste separation policy implementation and sociodemographic variables moderate the effect of these normative forces on behavioral intentions to sort waste (Issock et al., 2020 [23]). However, policy implementation should focus on a combination of "awareness" (shaping values), "user convenience", "household routines network", "household order perception", and "user trust in the waste system" (Pedersen et al., 2020 [30]); these are the five critical points for successful waste separation. Policy credibility and perceived policy effectiveness (Nguyen et al., 2015 [31]; Negash et al., 2021 [32]) are also indispensable factors in increasing the behavioral intention of waste separation.

2.2. The Game of Waste Separation

Game theory is a mathematical model for studying strategic interactions between rational decision makers (Myerson, 1991) [33]. Previous studies have mainly used differential and evolutionary game theory to study the relationship between subjects in waste separation.

2.2.1. Differential Games

The differential game refers to a continuous game played by two participants in a time-continuous system, striving to optimize their independent and conflicting goals and ultimately achieving equilibrium based on the relationship of participation (Friedman,

1972) [34]; Dockner, 2000 [35]; Friedman, 2013 [36]). If the two participants are independent, Nash equilibrium is achieved; if both parties have a subordinate relationship, Stackelberg equilibrium is achieved. However, the differential game is more suitable when applied between the uppermost and lowermost levels of subjects in the supply chain (Cohen and Halfon et al., 2021 [37]). This is mainly because, firstly, the relationship of interest between the two levels of subjects occurs directly, and secondly, the two levels of subjects apply to the characteristics of the differential game between the two. Scholars usually apply environmental supply chain management ideas to analyze the relationship between the subjects of waste separation (Naini and Aliahmadi, 2011 [38]; Noufal and Maalla, 2021 [39]) and provide managerial insight by pointing out the influence of critical influencing factors such as remanufacturing rates, market elasticity, and government subsidies on the choice of appropriate strategies by each participating subject.

2.2.2. Evolutionary Games

The evolutionary game theory differs from traditional game theory. The traditional game theory usually assumes that the participants are perfectly rational (Taylor and Jonker, 1978 [40]; Kaniovski and Young, 1995 [41]; Young, 1999 [42]; Schmidt, 2004 [43]), but this is challenging to achieve in reality. The evolutionary game theory argues that the participating subjects are finite and rational. The main reasons for this are, first, the perceived cognitive capacity of human beings is limited. This includes the impossibility for individuals to be accurate in acquiring, storing, tracking, and using information; secondly, there are limitations of human language expression ability. This is because individuals can only express their knowledge or feelings by using words, numbers, or diagrams that are fully understood by others. Meanwhile, participants are believed to reach the overall equilibrium of the game usually through trial and error (Lewontin, 1961 [44]; Poethke and Kaiser, 1985 [45]; Friedman, 1998 [46]). Due to the large number of subjects involved in waste separation, different subjects have limited rationality, and their decision-making behavior changes over time. The advantage of evolutionary game theory is that it can dynamically study the process of multi-subject behavior change and observe the influence of different factors on the behavior change of different participating subjects (Estalaki et al., 2015 [47]; Pedersen and Manhice, 2020 [30]; Korsunova et al., 2021 [48]).

Due to the vast area of China, the difference in topography and altitude between east and west, and the difference in climate between north and south, waste separation and disposal is heterogeneous among the cities in different regions. Therefore, the central government needs to provide comprehensive and orderly guidance on waste separation from a global perspective, establish a general guiding framework, and introduce taxation and other policies that are beneficial to waste separation enterprises. Local governments need to develop their waste separation management methods according to the actual situation in their regions, determined through active inspection of waste separation enterprises. Local governments should work with enterprises by coordinating loans, facilitating land acquisition, and collaborating on environmental protection. In addition to operating their businesses, waste separation enterprises actively seek financial subsidies from local and higher-level governments. This shows a game between the central government, local governments, and waste separation enterprises in promoting waste separation. Due to the participants' information asymmetry and cognitive differences, it is difficult to determine the optimal strategy in one game, and it is necessary to adjust the strategy in several games. Therefore, it is appropriate to apply evolutionary game theory to analyze the behavior of each participant and the influencing factors in the promotion of waste separation.

The above studies represent important information and guidance for waste separation policy research. However, there remain several issues with the current literature. Firstly, the existing literature generally considers only two-game subjects, namely, residents and government, and only a few papers use the assumption of "neutral government" to build a tripartite game model of government, enterprises, and residents. In fact, only the central government meets the assumption of a generalized "neutral government" (Yao, 2018) [49],

while the local government is a rational "political economist" (Chu et al., 2019) [50]. Without central government system regulation, it is difficult to effectively integrate the local government and separation enterprises into the waste separation promotion process. Secondly, by ignoring the competing strategic motives involved in waste separation under Chinese-style decentralization, errors are introduced in the principal–agent relationship between the central government and local government with regard to waste separation promotion. The presupposed cooperative game cannot accommodate the expected reality that waste separation is not fully implemented. Thirdly, the benefits the central government brings to local governments and separation enterprises as the game subject are not considered. Only the role of the central government's financial subsidies is often considered, ignoring the reduced promotion costs brought by the central government's policy support as the game subject. Fourthly, the influence of the willingness to participate on the choice of strategy is not considered among the game subjects in waste separation promotion.

Therefore, this paper considers splitting the government into central and local governments. The central government is considered in terms of the overall situation. In contrast, the local government represents the local situation. The different positions of the two sides must be considered in terms of the impact of policy support on the promotion of waste separation, through the construction of a non-cooperative game model involving the central government, local government, and separation enterprises; this new mechanism of waste separation promotion is based on central command, local deployment and enterprise performance. The stabilization strategies under different situations are analyzed, and the influence of relevant parameters on the promotion strategies of the three parties is assessed through numerical analysis of cases. The solution of the idealized cooperation game between the central government and the separation enterprises is proposed to provide a theoretical basis and policy suggestions for formulating waste separation promotion policies and accelerating the achievement of China's "double carbon" goal.

3. Method

This study analyzes the roles of the central government, local government, and separation enterprises in the promotion of waste separation. The relationship between these three stakeholder groups in this area is continually evolving (see Figure 1), which can be well revealed by the evolutionary game research method. Finally, the process of jointly promoting the goal of waste separation is achieved.

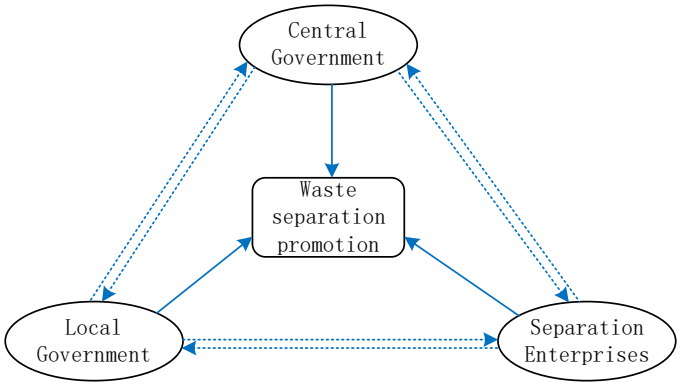

Figure 1. Evolution of waste separation promotion.

3.1. Modeling

3.1.1. Modelling Basic Assumptions

In China, waste separation promotion is essential to achieving strong urban management and services, and creating a healthy living environment. In addition to the separation enterprises directly involved in waste separation and treatment, the central and local governments play a significant role in promoting waste separation. As the party that implements regulations and issues incentives, the central government also receives

indirect dividends from optimizing the environment, made possible by waste separation in terms of reduction, resourcefulness, and harmlessness, which can be quantified in the national budget for environmental management costs. In the initial stage of promoting waste separation, local governments and enterprises can agree on their responsibilities and obligations by introducing management measures. In promoting waste separation, the central government can regularly assess the implementation performance of each local government and provide incentives to separation enterprises in the form of subsidies and tax rebates. Based on this, the following hypotheses are presented.

(1) Promotion subjects. In the process of waste separation promotion, there are three types of subjects: the central government (CG), local governments (LGs), and separation enterprises (SEs). The central government promotes waste separation through different incentive mechanisms for local governments and residents, including regulation and management; local governments are mainly responsible for providing resources to promote waste separation and "end" treatment after waste separation; separation enterprises are mainly responsible for the technical implementation of waste separation treatment. Moreover, the three parties are finitely rational in the game process and find the optimal strategy through multiple games.

(2) Promotion strategy. In the process of the waste separation promotion game, the central government can choose to provide preferential policies for local governments and separation enterprises and supervise the waste separation promotion process of these two entities, or it can choose not to provide preferential policies and supervise the waste separation promotion process of local governments and separation enterprises; thus, the strategy set is (regulation, non-regulation). Local governments and separation enterprises can choose to participate in waste separation promotion according to their own needs or choose not to participate in waste separation promotion; thus, their strategy set is (participation, non-participation).

(3) Promotion cost. Although the central government will not directly participate in the waste separation promotion process, it will provide preferential policies for local governments and separation enterprises, and supervise the participation of these entities in the waste separation promotion process, resulting in a regulatory cost of C_{CG}. Local governments and separation enterprises, as the prominent participants in waste separation promotion, will undoubtedly invest specific financial, material, and human resources, resulting in a standard total cost of C_{GE}. When the central government chooses to regulate waste separation promotion, the preferential policies provided by the central government will lead to the local government and the separation enterprises investing the total cost reduction coefficient of d in the process of waste separation promotion; the reduced cost is expressed by dC_{GE}. The cost-sharing coefficient of local governments and separation enterprises is m ($0 \leq m \leq 1$). The cost shared by the local government is mC_{GE} or mdC_{GE}. The cost shared by separation enterprise is $(1 - m)C_{GE}$ or $(1 - m)dC_{GE}$.

(4) Promotion gains. U_6 denotes the gain from the central government's strategy of "regulation", U_7 denotes the gain from the central government's "non-regulation", and U_2 and U_3 denote the initial gain of local governments and separation enterprises before they are involved in waste separation. When local governments and separation enterprises participate in waste separation promotion, they will generate additional revenue, K_1. The distribution coefficient of this additional revenue is n, i.e., local governments earn additional revenue nK_1, and residents earn additional revenue $(1 - n)K_1$. In addition, the central government gives incentive funds S_1 to residents who actively participate in waste separation promotion, and the coefficient of distribution of incentive funds is f. The local governments' share is fS_1. The government's share is denoted by fS_1, and the separation enterprise's share is denoted by $(1 - f)S_1$.

3.1.2. Build Payment Matrix

In the model, the central government, local governments, and separation enterprises make strategy choices according to their wishes. Assuming that the probability that

the central government chooses to regulate waste separation promotion is x, then the probability that the central government chooses not to regulate waste separation promotion is (1 − x). Assuming that the probability that the local government chooses to participate in waste separation promotion is y, then the probability that the local government chooses not to participate in waste separation promotion is (1 − y). Assuming that the probability of separation enterprises choosing to participate in waste separation promotion is z, then the probability of choosing not to participate in waste separation promotion is (1 − z). Thus, x, y, z ∈ [0, 1]. Furthermore, according to the above five assumptions, the evolutionary game payment matrix of waste separation promotion is obtained, as shown in Tables 1 and 2. The incentive constraint in the table is reflected in the additional benefit allocation coefficient n, and the incentive constraint is reflected in the additional benefit allocation coefficient 1 − n.

Table 1. Game payment matrix for waste separation promotion under central government (CG) regulation (x).

		Separation Enterprises (SEs)	
		Participation (z)	**Non-Participation (1 − z)**
Local governments (LGs)	Participation (y)	$U_6 - C_{CG} - S_1$	$U_6 - C_{CG} - fS_1$
		$U_2 + nK_1 - mdC_{CG} + fS_1$	$U_2 - mdC_{CG} + fS_1$
		$U_3 + (1 - n)K_1 - (1 - m)dC_{CG} + (1 - f)S_1$	U_3
	Non-participation (1 − y)	$U_6 - C_{CG} - (1 - f)S_1$	$U_6 - C_{CG}$
		U_2	U_2
		$U_3 - (1 - m)dC_{CG} + (1 - f)S_1$	U_3

Table 2. Game payment matrix for waste separation promotion under central government (CG) non-regulation (1 − x).

		Separation Enterprises (SEs)	
		Participation (z)	**Non-Participation (1 − z)**
Local governments (LGs)	Participation (y)	U_7	U_7
		$U_2 + nK_1 - mC_{CG}$	$U_2 - mC_{CG}$
		$U_3 + (1 - n)K_1 - (1 - m)C_{CG}$	U_3
	Non-participation (1 − y)	U_7	U_7
		U_2	U_2
		$U_3 - (1 - n)C_{CG}$	U_3

3.2. Model Discussion

3.2.1. Earning Expectation Function Construction

According to Tables 1 and 2, the expected return of the central government in the game is ECG_1 for the "regulation" strategy, ECG_2 for the "non-regulation" strategy, and ECG_3 for the average expected return.

$$\begin{aligned} ECG_1 = {} & yz(U_6 - C_{CG} - S_1) + y(1-y)(U_6 - C_{CG} - fS_1) + (1-y)z(U_6 - C_{CG} - (1-f)S_1) \\ & + (1-y)(1-z)(U_6 - C_{CG}) = -z(1-f)S_1 - yfS_1 + U_6 - C_{CG} \\ ECG_2 = {} & yzU_7 + y(1-z)U_7 + (1-y)zU_7 + (1-y)(1-z)U_7 = U_7 \\ ECG_3 = {} & xECG_1 + (1-x)ECG_2 \end{aligned}$$

The expected returns for local governments in the game are ELG_1 when they choose the "participation" strategy, ELG_2 when they choose the "non-participation" strategy, and ELG_3 on average.

$$\begin{aligned} ELG_1 = \;& zx(U_2 + nK_1 - mdC_{GE} + fS_1) + (1-z)x(U_2 - mdC_{GE} + fS_1) + z(1-x)(U_2 + nK_1 - mC_{GE}) \\ & + (1-z)(1-x)(U_2 - mC_{GE}) = x(mC_{EG} - mdC_{EG} + fS_1) + znK_1 + U_2 - mC_{EG} \\ ELG_2 = \;& zxU_2 + (1-z)xU_2 + z(1-x)U_2 + (1-z)(1-x)U_2 = U_2 \\ ELG_3 = \;& xELG_1 + (1-x)ELG_2 \end{aligned}$$

The expected returns of the categorized firms in the game are ESE_1 when they choose the "participation" strategy, ESE_2 when they choose the "no participation" strategy, and ESE_3 on average.

$$\begin{aligned} ESE_1 = \;& xy(U_3 + (1-n)K_1 - (1-m)dC_{GE} + (1-f)S_1) + x(1-y)(U_3 - (1-m)dC_{GE} + (1-f)S_1) \\ & + (1-x)y(U_3 + (1-n)K_1 - (1-m)C_{GE}) + (1-x)(1-y)(U_3 - (1-m)C_{GE}) \\ & = x(-(1-m)dC_{GE} + (1-f)S_1 + (1-m)C_{GE}) + y((1-n)K_1 + (1-m)C_{GE}) + U_3 - (1-m)C_{GE} \\ ESE_2 = \;& xyU_3 + x(1-y)U_3 + (1-x)yU_3 + (1-x)(1-y)U_3 = U_3 \\ ESE_3 = \;& zESE_1 + (1-z)ESE_2 \end{aligned}$$

3.2.2. Stable Evolutionary Strategy

From the above analysis, the dynamic replication equation of the central government is obtained as follows:

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x(ECG_1 - ECG_3) = xECG_1 - x^2ECG_1 - x(1-x)ECG_2 = xECG_1(1-x) - x(1-x)ECG_2 \\ &= x(1-x)(ECG_1 - ECG_2) = x(1-x)(-yfS_1 - z(1-f)S_1 + U_6 - U_7 - C_{CG}) \end{aligned} \quad (1)$$

The dynamic replication equation for local governments is:

$$F(y) = \frac{dy}{dt} = y(ELG_1 - ELG_2) = y(1-y)(ELG_1 - ELG_2) = y(1-y)(x(mC_{GE} - mdC_{GE} + fS_1) + znK_1 - mC_{GE}) \quad (2)$$

The dynamic replication equation for the separation enterprises is:

$$\begin{aligned} F(z) = \frac{dz}{dt} &= z(ESE_1 - ESE_3) = z(1-z)(ESE_1 - ESE_2) \\ &= z(1-z)(x(-(1-m)dC_{GE} + (1-f)S_1 + (1-m)C_{GE}) + y((1-n)K_1 + (1-m)C_{GE}) - (1-m)C_{GE}) \end{aligned} \quad (3)$$

According to the Malthusian equation, the three-dimensional dynamical system of the central government, local government, and separation enterprises is obtained by associating Equations (1)–(3), as follows:

$$\begin{cases} F(x) = x(1-x)(-yfS_1 - z(1-f)S_1 + U_6 - U_7 - C_{CG}) \\ F(y) = y(1-y)(x(mC_{GE} - mdC_{GE} + fS_1) + znK_1 - mC_{GE}) \\ F(z) = z(1-z)(x(-(1-m)dC_{GE} + (1-f)S_1 + (1-m)C_{GE}) + y((1-n)K_1 + (1-m)C_{GE}) - (1-m)C_{GE}) \end{cases} \quad (4)$$

According to the method proposed by Friedman (1991) [51], the evolutionary stability strategy (ESS) of the system of differential equations is obtained from the local stability analysis of the Jacobian matrix of this system, which is obtained from Equation (4) as follows:

$$J = \begin{bmatrix} (1-2x)(-fS_1y - (1-f)S_1z + U_6 - U_7 - C_{GE} & x(1-x)(-fS_1) & -x(1-x)(1-f)S_1 \\ y(1-y)((1-d)mC_{GE} + fS_1) & (1-2y)(x((1-d)mC_{GE} + fS_1) + znK_1 - mC_{GE} & y(1-y)nK_1 \\ z(1-z)((1-d)(1-m)C_{GE} + (1-f)S_1 & z(1-z)((1-n)K_1 + (1-m)C_{GE}) & (1-2z)(x((1-d)(1-m)C_{GE} + (1-f)S_1) + y((1-n)K_1 + (1-m)C_{GE}) - (1-m)C_{GE} \end{bmatrix} \quad (5)$$

In the three-dimensional dynamical system (Equation (4)), let F(x) = F(y) = F(z) = 0. The local equilibrium points can be obtained as E_1 (0, 0, 0), E_2 (0, 0, 1), E_3 (0, 1, 0), E_4 (0, 1, 1), E_5 (1, 0, 0), E_6 (1, 0, 1), E_7 (1, 1, 0), and E_8 (1, 1, 1). According to evolutionary game theory, the equilibrium point that satisfies the Jacobian matrix when all eigenvalues are non-positive is the system's evolutionarily stable strategy point (ESS).

3.2.3. Equilibrium Point Stability Analysis

The equilibrium point E_1 (0, 0, 0) is first analyzed below when the Jacobian matrix is as follows:

$$J_1 = \begin{bmatrix} U_6 - U_7 - C_{CG} & 0 & 0 \\ 0 & -mC_{GE} & 0 \\ 0 & 0 & -(1-m)C_{GE} \end{bmatrix}$$

It can be seen that the eigenvalues of the Jacobian matrix are $\lambda_1 = U_6 - U_7 - C_{CG}$; $\lambda_2 = -mC_{GE}$; $\lambda_3 = -(1 - m)C_{GE}$ at this time. The eigenvalues of the Jacobian matrix corresponding to the equilibrium points can be obtained by substituting the eight equilibrium points from E_1 to E_8 into Equation (5), as shown in Table 3.

Table 3. Eigenvalues of the Jacobian matrix.

Equilibrium Point	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3
E_1 (0, 0, 0)	$U_6 - U_7 - C_{CG}$	$-mC_{GE}$	$-(1 - m)C_{GE}$
E_2 (0, 0, 1)	$-(1 - f)S_1 + U_6$-$U_7 - C_{CG}$	$nK_1 - mC_{GE}$	$(1 - m)C_{GE}$
E_3 (0, 1, 0)	$-fS_1 + U_6 - U_7 - C_{CG}$	mC_{GE}	$(1 - n)K_1$
E_4 (0, 1, 1)	$-S_1 + U_6 - U_7 - C_{CG}$	$-(nK_1 - mC_{GE})$	$-(1 - n)K_1$
E_5 (1, 0, 0)	$-(U_6 - U_7 - C_{CG})$	$(1 - d)mC_{GE} + fS_1 - mC_{GE}$	$(1 - d)(1 - m)C_{GE} + (1 - f)S_1 - (1 - m)C_{GE}$
E_6 (1, 0, 1)	$-(-(1 - f)S_1 + U_6 - U_7 - C_{CG})$	$(1 - d)mC_{GE} + fS_1 + nK_1 - mC_{GE}$	$-((1 - d)(1 - m)C_{GE} + (1 - f)S_1 - (1 - m)C_{GE})$
E_7 (1, 1, 0)	$-(-(1 - f)S_1 + U_6 - U_7 - C_{CG})$	$-((1 - d)mC_{GE} + fS_1 - mC_{GE})$	$(1 - d)(1 - m)C_{GE} + (1 - f)S_1 + (1 - n)K_1$
E_8 (1, 1, 1)	$-(-S_1 + U_6 - U_7 - C_{CG})$	$-((1 - d)mC_{GE} + fS_1 + nK_1 - mC_{GE})$	$-((1 - d)(1 - m)C_{GE} + (1 - f)S_1 + (1 - n)K_1)$

According to the eigenvalues of the Jacobian matrix listed in Table 3, the judgment condition that the equilibrium point is an evolutionarily stable strategy point (ESS) is that for all eigenvalues, $\lambda < 0$; the judgment condition that the equilibrium point is an unstable point is that for all eigenvalues, $\lambda > 0$; the judgment condition that the equilibrium point is a saddle point is that both $\lambda > 0$ and $\lambda < 0$ for the eigenvalues (Selten, 1980) [52].

To analyze the signs of different eigenvalues and to allow generalization, this paper makes the following assumptions: $-S_1 + U_6 - U_7 - C_{CG} > 0$; $(1 - d)mC_{GE} + fS_1 + nK_1 - mC_{GE} > 0$; i.e., as per the central government's policy support, local governments bear the cost of participating in the promotion of garbage classification, share the central government incentive funds, and receive additional benefits from participating in "non-regulation" activities. The benefits obtained by the central government's choice of a "regulation" strategy are greater than the sum of the incentive funds paid by the central government, the benefits obtained by "non-regulation" activities, and the regulatory costs. Due to the complexity of the parameters in the model, the following three scenarios are used to analyze the evolutionary game stabilization strategy.

Scenario 1: $(1 - d)mC_{GE} + fS_1 - mC_{GE} < 0$ and $(1 - d)(1 - m)C_{GE} + (1 - f)S_1 - (1 - m)C_{GE} < 0$, i.e., the sum of the cost borne by local governments participating in the promotion of garbage classification under the support of central government policies and the incentive funds received by the central government is smaller than the cost borne by local governments participating in the promotion of garbage classification without the support of central government policies. Furthermore, participating in waste separation and the share of central government incentive funds for separation enterprises supported by central government policy is smaller than the cost of participating in waste separation for separation enterprises without central government policy support. We can see from Table 4 that the two equilibrium points, E5 and E8, are non-positive. The system has two stabilization points: (1, 0, 0) and (1, 1, 1). The corresponding stabilization strategies are (regulation, non-participation, non-participation) and (regulation, participation, participation).

Table 4. Local stability of equilibrium points.

Equilibrium Point	Scenario 1				Scenario 2				Scenario 3				Scenario 4			
	λ_1	λ_2	λ_3	Stability	λ_1	λ_2	λ_3	Stability	λ_1	λ_2	λ_3	Stability	λ_1	λ_2	λ_3	Stability
E_1 (0, 0, 0)	+	−	−	Unstable point	+	−	−	Unstable point	+	−	−	Unstable point	+	−	−	Unstable point
E_2 (0, 0, 1)	+	+/−	+	Saddle Point	+	+/−	+	Saddle Point	+	+/−	+	Saddle Point	+	+/−	+	Saddle Point
E_3 (0, 1, 0)	+	+	+	Saddle Point	+	+	+	Saddle Point	+	+	+	Saddle Point	+	+	+	Saddle Point
E_4 (0, 1, 1)	+	−/+	−	Unstable point	+	−/+	−	Unstable point	+	−/+	−	Unstable point	+	−/+	−	Unstable point
E_5 (1, 0, 0)	−	−	−	ESS	−	+	+	Unstable point	−	−	+	Unstable point	−	+	−	Unstable point
E_6 (1, 0, 1)	−	+/−	+	Unstable point	−	+	−	Unstable point	−	+/−	−	Unstable point	−	+	+	Unstable point
E_7 (1, 1, 0)	−	+	+	Unstable point	−	−	+	Unstable point	−	+	+	Unstable point	−	−	+	Unstable point
E_8 (1, 1, 1)	−	−	−	ESS	−	−	−	ESS	−	−	−	ESS	−	−	−	ESS

Scenario 2: $(1 - d)mC_{GE} + fS_1 - mC_{GE} > 0$ and $(1 - d)(1 - m)C_{GE} + (1 - f)S_1 - (1 - m)C_{GE} > 0$, i.e., the sum of the cost of participating in waste separation promotion and the share of central government incentive funds under the central government policy support is greater than the cost of participating in waste separation promotion under the local government without central government policy support, and the sum of the cost of participating in waste separation promotion and the share of central government incentive funds under the central government policy support is greater than the cost of participating in waste separation promotion under the local government without central government policy support. Furthermore, the sum of participating in waste separation and the share of central government incentive funds is greater than the cost of participating in waste separation without central government policy support. We can see from Table 4 that the equilibrium point E8 is non-positive. In this case, the system has a stable point (1, 1, 1), and its corresponding stable strategy set is (regulation, participation, participation).

Scenario 3: $(1 - d)mC_{GE} + fS_1 - mC_{GE} < 0$ and $(1 - d)(1 - m)C_{GE} + (1 - f)S_1 - (1 - m)C_{GE} > 0$, i.e., the sum of the cost of participating in waste separation promotion and the share of central government incentive funds under the central government policy support is smaller than the cost of participating in waste separation promotion under the local government without central government policy support, and the sum of the cost of participating in waste separation promotion and the share of central government incentive funds under the central government policy support is larger than the cost of participating in waste separation promotion under the local government without central government policy support. Furthermore, participating in waste separation and the share of central government incentive funds borne by separation enterprises under the central government policy support is greater than the cost of participating in waste separation borne by separation enterprises without the central government policy support. We can see from Table 4 that the equilibrium point E8 is non-positive. In this case, the system has a stable point (1, 1, 1), and its corresponding stable strategy set is (regulation, participation, participation).

Scenario 4: $(1 - d)mC_{GE} + fS_1 - mC_{GE} > 0$ and $(1 - d)(1 - m)C_{GE} + (1 - f)S_1 - (1 - m)C_{GE} < 0$, i.e., the sum of the cost of participating in waste separation promotion and the share of central government incentive funds under the central government policy support is greater than the cost of participating in waste separation promotion under the local government without the central government policy support, and the sum of the cost of participating in waste separation promotion and the share of central government incentive funds under the central government policy support is less than the cost of participating in waste separation promotion under the central government policy support. Moreover,

participating in waste separation and the share of central government incentive funds borne by the separation enterprises under the central government policy support is smaller than the cost of participating in waste separation borne by the separation enterprises without the central government policy support. We can see from Table 4 that the equilibrium point E8 is non-positive. In this case, the system has a stable point (1, 1, 1), and its corresponding stable strategy set is (regulation, participation, participation).

4. Results

4.1. Date and Parameter Values

In China, there are two common ways for the central government, local governments, and separation enterprises to participate in waste separation jointly: the government purchase of waste separation services and the waste separation PPP model.

4.1.1. Government Purchase of Waste Separation Services

According to the statistical data of the China Environment Federation Research Institute, the transaction amount for waste separation services is small, being primarily allocated to street- or district-level services under pilot projects. The transaction parties are small local service enterprises. With the expansion of the pilots, the purchase of waste separation service projects will gradually increase. The total number of waste separation service projects is approximately 40 projects, of which Jiangsu Province has the most projects, a total of 14, in Nanjing, Nantong, Jiangyin, and other locations; these are closely related to the implementation of the "263" action plan in Jiangsu Province, which vigorously promotes waste separation. According to statistics, on 27 March 2017, Suqian City issued a tender announcement for the preparation of the "Suqian City Urban and Rural Waste Separation and Management Planning Project"; within seven months, a total of 27 cities in Jiangsu Province issued similar tender announcements. Beijing has eight waste separation service projects, followed by three in Jiangsu, four in Guangdong, four in Zhejiang, three in Shanghai, and the remaining projects in Chengdu and Jiangxi. The garbage separation service projects are mostly supplied by local companies, as seen from the winning bidders. For example, the projects in Jiangsu Province are divided between China Tianying and Nanjing Zhida Environmental Protection.

4.1.2. Waste Separation PPP Model

Unlike the government purchase services concentrated in Beijing, Shanghai, Jiangsu, and other developed regions, the waste separation PPP model is more widely distributed, across Jiangsu, Sichuan, Hunan, Hubei, and especially in the Xinjiang region, which has as many as five PPP projects. These PPP projects involve large, more experienced enterprises; this is related to the operating characteristics of PPP projects, which have an extended cooperation period, entail more complicated operational methods, and require great financial support. Waste separation as a front-end service project of waste treatment is often included in the integrated sanitation system and is less often tendered separately. To date, there have been 10 "sanitation super-single" projects with a contract value of over RMB 2.5 billion, which were picked up by five enterprises—Beihuan, Qiaoyin, Longma, Yuhetian, and Xugong, with Beihuan having six seats.

In this paper, we combine two methods of joint participation in waste separation promotion in China and present assumptions regarding the initial values of parameters in the payment matrix, as shown in Table 5.

Table 5. Parameter assignment.

Parameters	Parameter Meaning	Assignment
U_6	Gains from the central government's choice of a "regulatory" strategy	20
U_7	Gains from the central government's choice of a "non-regulation" strategy	1
K_1	Local governments and separation enterprises choose to participate in waste separation promotion to bring additional benefits	100
n	Allocation factor for additional benefits	0.5
C_{CG}	Central government regulatory costs	6
C_{GE}	Standard costs incurred by local governments and separation enterprises involved in waste separation promotion	90
d	Cost reduction factor for local governments and separation enterprises after central government regulation	0.5
m	Cost-sharing factors for local governments and separation enterprises	0.5
S_1	Central government incentive costs	10
f	Central government incentive cost funding allocation factor	0.5

Note: Let the initial willingness of the central government, local government, and separation enterprises be x = y = z = 0.5.

4.2. The Evolutionary Impact of the Willingness of Three Parties to Promote Participation in Waste Separation

Figure 2a shows the simulation of the effect of the change of initial willingness of the central government, local government, and separation enterprises to participate in waste separation promotion on the waste separation promotion strategy, with other parameters unchanged. Assuming that the initial willingness of the central government, local government, and separation enterprises is the same, i.e., x = y = z, it can be seen in Figure 2a that there is a threshold value of 0.4–0.5 for the initial willingness of the three parties; when the initial willingness x, y, and z is less than this threshold value, x converges to 1, y and z converge to 0, and the final equilibrium point tends to the point (1, 0, 0), which is influenced by policy factors. When the initial willingness x, y, and z is greater than the threshold value, x, y, and z converge to 1, and the final equilibrium point tends to the point (1, 1, 1); however, when the willingness of the three parties is at a medium level, the willingness of the central government increases steadily, the willingness of the local government increases slowly, and the willingness of the separation enterprises first shows a decline and then a rapid rise. Finally, all three parties choose to participate. When the willingness of all three parties is high, the willingness of the central government, local government, and separation enterprises will increase, with the local government and separation enterprises increasing faster than the central government. The simulation results show that as the initial willingness increases for all three entities, the convergence speed of x slows down, and the convergence speed of y and z accelerates. Eventually, all three parties tend to participate in waste separation promotion; this is because when the willingness of local governments and separation enterprises to participate is not high, the central government will play a leading role in promoting participation.

Figure 2b shows the simulation of the change of the central government's willingness (x) on the participation of local governments and separation enterprises in promoting waste separation, with other parameters constant. As shown in Figure 1b, the willingness of local governments and separation enterprises is moderate, and the central government's willingness (x) has a threshold value between 0.3 and 0.4. When x exceeds this threshold value, x converges to 1, and y and z converge to 0. The equilibrium point converges to the point (1, 0, 0), at which the increase in x makes the convergence of x slow down, the convergence of y and z speed up, with the convergence of z slower than y. When x is more significant than this threshold, x, y, and z all converge to 1. The equilibrium point converges to the point (1, 1, 1). At this time, the increase in x accelerates the convergence speed of y

and z. The simulation results show that as the central government's willingness is enhanced, the willingness of both local governments and separation enterprises is enhanced. The local governments are more obviously affected due to the vertical management of the central government of local governments. In contrast, separation enterprises are affected by market factors. The separation enterprises' willingness decreases when the central and local governments' willingness is not strong.

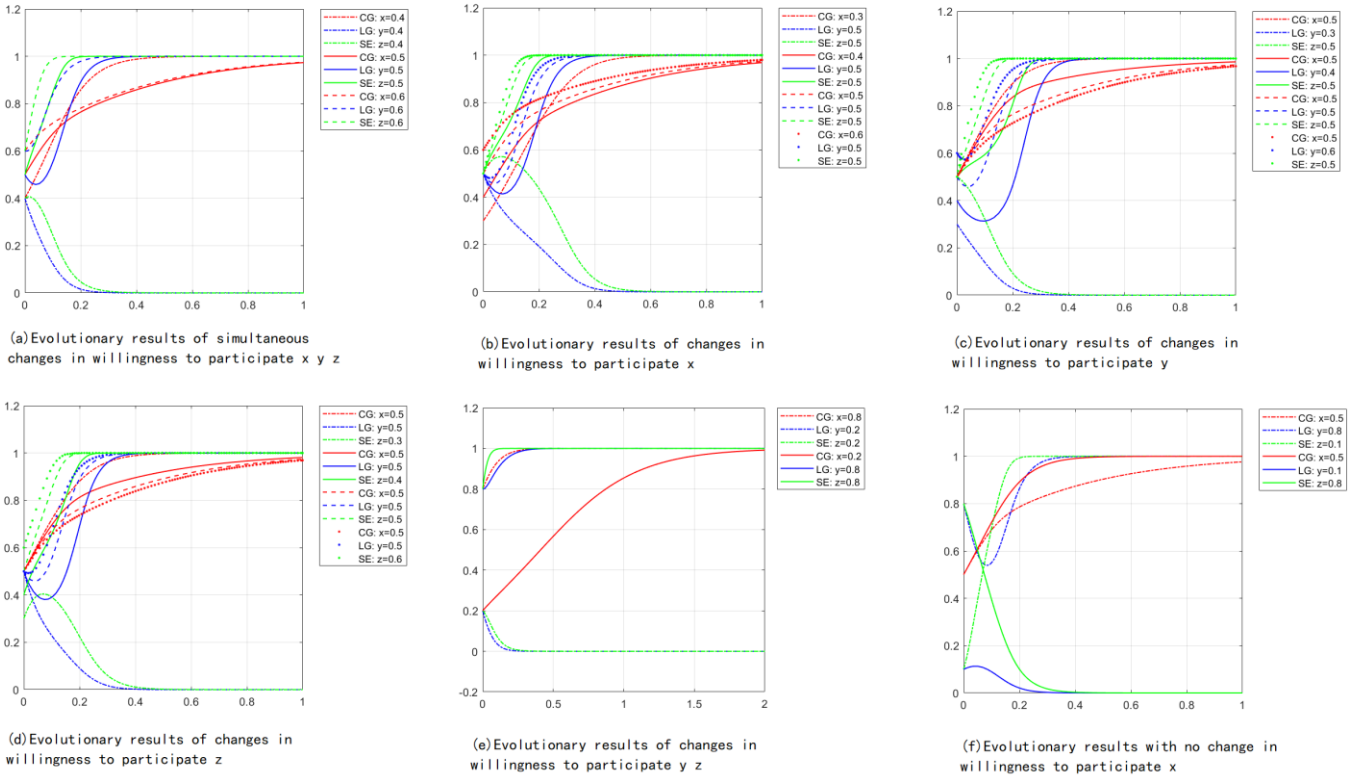

Figure 2. Evolutionary results of simultaneous changes in willingness to participate.

Figure 2c shows the simulation of the effect of the change of the initial willingness of the local government on the participation of the central government and the separation enterprises in the waste separation promotion strategy, with other parameters held constant. As shown in Figure 2c, the initial willingness of the central government and separation enterprises is in a moderate state. The initial willingness of the local government (y) has a threshold value between 0.3 and 0.4. When y exceeds this threshold value, x converges to 1, and y and z converge to 0. The final equilibrium point tends to the point (1, 0, 0), at which the increase in y makes the convergence of z faster, but slower than y. When y is more significant than this threshold value, x, y, and z converge to 1. The final equilibrium point converges to the point (1, 1, 1). At this time, the increase in y makes the convergence of z faster, and faster than y.

Figure 2d shows the simulation of the effect of the change of initial willingness (z) of separation enterprises on the strategy of the central government and local government to participate in waste separation promotion, with other parameters unchanged. Figure 2d shows that the central government and local government's willingness (x, y) is in a moderate state. The initial willingness (z) of separation enterprises has a threshold value between 0.3 and 0.4. When z is less than this threshold value, x converges to 1, y and z converge to 0, and the equilibrium point tends to the point (1, 0, 0). At this time, the increase in z accelerates the convergence speed of y. The convergence speed of z is faster than y; when z is more significant than this threshold value, x, y, and z converge to 1. The equilibrium point tends to be (1, 1, 1). At this time, the increase in z accelerates the convergence of y. The convergence of x slows down. When z = 0.4, z presents the condition of first decreasing

and then increasing, indicating that as the willingness of separation enterprises increases, the local government's willingness also increases.

In contrast, the willingness of the central government slows down. The simulation results in Figure 2c,d show that as the willingness of the local government or separation enterprises increases, the willingness of separation enterprises or the local government will also gradually increase. Eventually, they will choose to participate in waste separation promotion.

In contrast, the central government's willingness will slow down, and the local government and separation enterprises will be more influenced. This is because the waste separation process needs to be tailored to local conditions and based on the actual local situation. The local government guarantees the necessary implementation conditions for promoting waste separation.

Figure 2e shows that with other parameters unchanged, the initial willingness (y, z) of both local government and separation enterprises is high, even when the initial willingness of the central government is low, i.e., x, y, z will converge to 1, with all three parties participating in waste separation promotion; when the initial willingness (y, z) of both the local government and separation enterprises is low, even when the initial willingness (x) of the central government is high, x will converge to 1, while y and z will converge to 0. The simulation results show that when the central government's participation in waste separation promotion is weak, the central government's participation or non-participation has little influence on the local government and separation enterprises' participation in waste separation promotion. Market factors affect the willingness of separation enterprises, and the willingness of local governments is more influenced by the central government. At the local level, when the central government's support is not sufficient, but the local government's willingness to participate in the waste separation promotion is good, the enterprises will choose to participate in the waste separation promotion. When the local government's willingness is not strong enough to obtain the expected benefits, the enterprises' willingness to participate will decrease, and they will not participate in the waste separation promotion.

Figure 2f shows that with other parameters unchanged and with the central government's willingness (x) unchanged, when the separation enterprises' willingness to participate (z) is high, even if the local government's willingness is not high, x will converge to 1, and y and z will converge to 0. At this time, y will slightly rise and fall, but z will fall faster than y. When the willingness of local government decreases to a certain level, the willingness of separation enterprises also decreases, resulting in both local government and separation enterprises not choosing to participate in waste separation promotion; when the willingness of local government is high and the willingness of separation enterprises to participate is low, the equilibrium point converges to the point (1, 1, 1), at which the willingness of local government will first decrease and then rapidly increase, making all three parties choose to participate in waste separation promotion. The simulation results show that when the central government's willingness is constant and moderate, local governments and separation enterprises will jointly decide to participate in waste separation promotion because local governments are the guarantors of necessary implementation conditions for waste separation promotion and separation enterprises are the essential entities for achieving source waste separation. Therefore, only when both parties' willingness to participate reaches a certain level can the waste separation promotion work be carried out effectively.

4.3. The Evolutionary Impact of Central Government Support on Promoting Participation in Waste Separation

The central government's willingness to participate generally manifests itself in two ways: (1) policy support, which will lead to a decrease in the total cost of waste separation promotion; and (2) financial incentives. Considering source separation, the central government can give the incentive funds directly to separation enterprises, instead of

local governments, through tax breaks. Figure 3a shows the simulation of the impact of the change of the cost reduction coefficient d on the participation of local governments and separation enterprises in the waste separation promotion strategy after the central government's preferential policy support, with other parameters unchanged. Figure 3a shows a threshold value of cost reduction coefficient d between 0.6 and 0.7. When d is more significant than this threshold value, x converges to 1, x and y converge to 0, and the equilibrium point tends to the point (1, 0, 0). At this time, the increase in d makes y and z converge slower, and y converges faster than z. When d is less than this threshold value, x, y, and z converge to 1, and the equilibrium point tends to be (1, 1, 1). At this time, the increase in d makes y and z converge slower, and y converges faster than z. At d = 0.6, the local government (y) will first fall and then rise. Finally, the local government and the central government enterprises choose to participate in promoting waste separation. The simulation results show that the change in the total cost reduction coefficient d affects local governments' selection strategies and significantly impacts local governments more than separation enterprises. This is because the central government will provide preferential policies if it regulates waste separation promotion, lowering the total cost of local governments and separation enterprises. Since local governments are more sensitive to the policies implemented by the central government, the change in the total cost reduction coefficient d has a more significant impact on local governments.

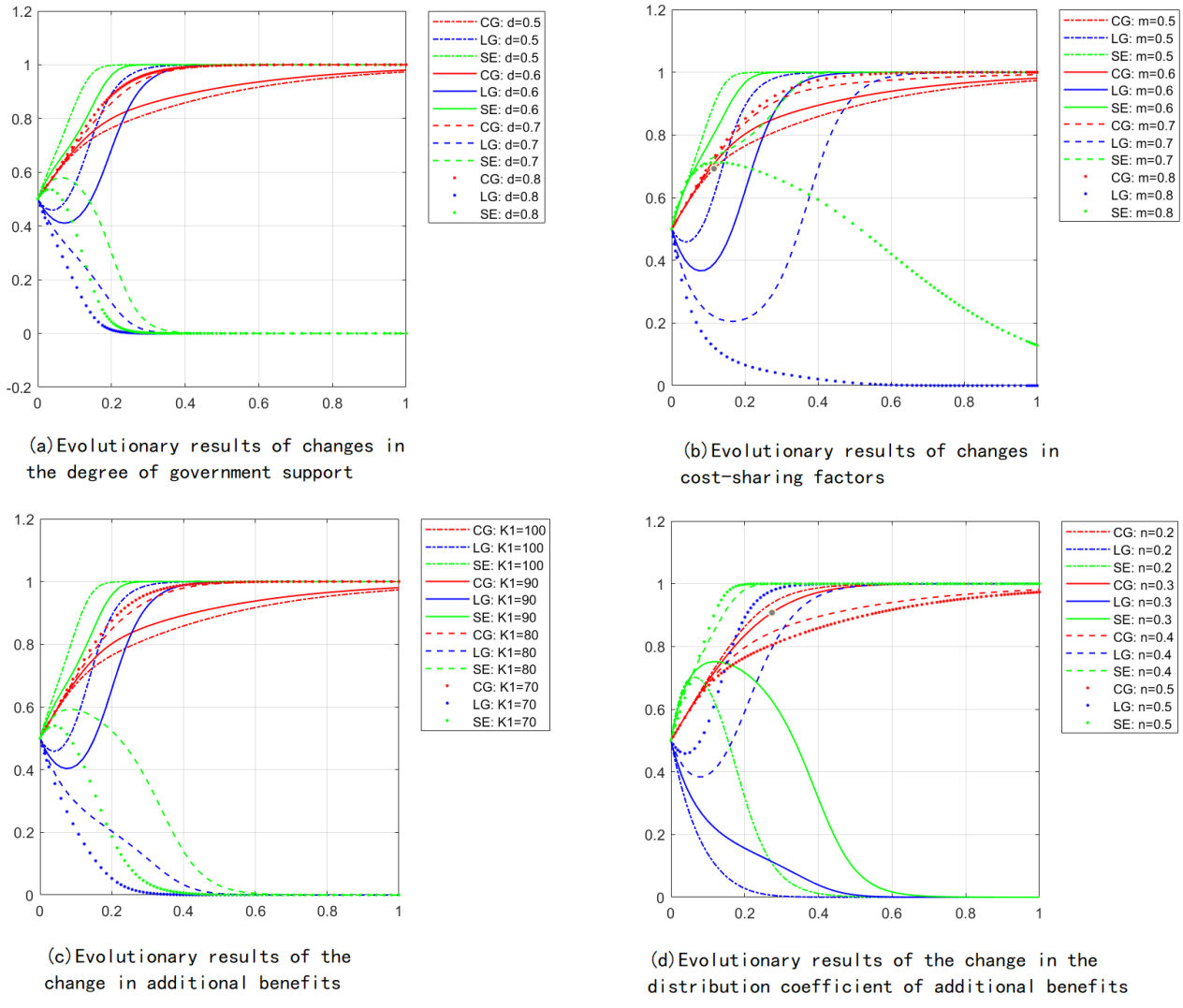

Figure 3. Evolutionary results of changes in central government support.

4.4. The Evolutionary Impact of Cost-Sharing Factors on Promoting Participation in Waste Separation

Figure 3b shows the simulation of the effect of changing cost-sharing coefficients on the participation of local governments and separation enterprises in waste separation promotion strategies, with other parameters held constant. As shown in Figure 3b, the critical value of the cost-sharing coefficient m is between 0.7 and 0.8. When m is more significant than this critical value, x converges to 1, and y and z converge to 0. At this time, b increases, and the x curve has the slowest convergence. The y curve converges faster than z. The z curve first rises rapidly to the highest point, then gradually falls after a period of smoothness, and the equilibrium point converges to the point (1, 0, 0). When m is smaller than the critical value, x, y, and z converge to 1. At this time, b decreases, and the y and z curves converge faster. The x curve converges more slowly. In addition, z converges faster than y. Finally, the equilibrium point converges to (1, 1, 1). The simulation results show a decrease in the cost-sharing coefficient. M affects the strategy choice of local government and separation enterprises; it is more significant for separation enterprises than local government. This is because the profit-seeking property of enterprises makes separation enterprises more sensitive to changes in their costs. Therefore, the cost-sharing coefficient m has a more significant impact on separation enterprises.

4.5. The Evolutionary Impact of Revenue and Its Distribution Coefficient on the Promotion of Participation in Waste Separation

According to the assumption of finite rationality, for local governments and separation enterprises, the feasibility of waste separation is reflected in two points: first, the total amount of additional revenue, i.e., whether the additional revenue generated by waste separation cooperation can meet the psychological expectation of both parties; second, the additional revenue distribution coefficient, i.e., whether the revenue distribution can meet the psychological expectation of both parties at the same time. It is necessary to solve the problem of "widowhood" and the problem of "evenness".

Figure 3c shows the simulation of the effect of the change in the extra benefit K1 of the collaboration between the local government and the separation enterprise on the promotion strategy of participation in waste separation, with other parameters being constant. When K1 is less than this critical value, x converges to 1, y and z converge to 0 with y converging faster than z, and the final equilibrium point tends to the point (1, 0, 0); when K_1 is more significant than this critical value, x, y, and z all converge to 1. At the level of $K_1 = 90$, the y curve first decreases and then rises to 1; when $K_1 = 100$, z converges faster than y, and x converges slower. The final equilibrium point converges to the point (1, 1, 1). The simulation results in Figure 3c show that additional revenue can increase local government and separation enterprises' willingness to participate. The degree of impact on separation enterprises is more significant than local government. The impact on local government is not apparent. This is because the profit-seeking property of enterprises drives separation enterprises to be the most sensitive to benefits, followed by local governments. The central government is the least sensitive to benefits due to its public service provision and policy-oriented factors. There is no significant change in government willingness at the lower level of additional benefits ($K_1 = 70$).

Figure 3d shows the simulation of the impact of the change of the other benefit allocation coefficient n on the participation of local governments and separation enterprises in waste separation promotion, with other parameters being constant. From Figure 3d, the critical value of the additional revenue allocation coefficient n is between 0.3 and 0.4. When the allocation coefficient n is less than this critical value, x converges to 1, y and z converge to 0, and z experiences a significant fluctuation and finally decreases. The y curve decreases smoothly, with the z curve converging slower than y, and the final equilibrium tends to the point (1, 0, 0); when the allocation coefficient n is more significant than this critical value, x, y, and z converge to 1, with the distribution coefficient n being more significant than this critical value. The difference in the convergence speed of the x, y, and z curves is not

apparent. The y curve first decreases and then rises, and the final equilibrium tends to the point (1, 1, 1). According to the simulation results in Figure 3d, as the allocation coefficient n decreases, the willingness of separation enterprises will first rise and then fall. Local governments' willingness will also fall because the allocation coefficient n is too small; thus, the separation of enterprises' shares is too small. Once it falls below the expected return of separation enterprises, the willingness of separation enterprises will immediately decrease.

5. Discussion

According to the practical experience of waste separation in 46 key cities in China, the central government's unified requirement to promote waste separation, reduction, and resource recovery has faced the non-cooperative game of "policy at the top and countermeasures at the bottom"; the lack of full implementation by local governments and separation enterprises seriously affects the joint action of various industries across the country, jeopardizing comprehensive resource efficiency. The existing literature on the incomplete implementation of waste separation by local governments and separation enterprises is insufficient to explain the central government's regulatory mechanism and policy tools in achieving the goals of waste separation, reduction, and resource recovery.

Given this, this paper proposes a fundamental hypothesis of waste separation promotion under the decentralized local government–delegated agency framework from the perspective of waste separation promotion, and uses evolutionary game theory to construct a non-cooperative game of central command, local deployment, and enterprise implementation for waste separation promotion with limited rationality of game parties as a precondition. At the same time, we empirically study the behavior and influencing factors of the central government, local governments, and separation enterprises to achieve an idealized waste separation promotion strategy. The policy tools of the central government to regulate local governments and separate enterprises to achieve the idealized "cooperation" game are studied. The analysis resulted in the following determinations:

(1) The central government, local governments, and separation enterprises have different degrees of influence on each other's willingness to participate. The behavior of separation enterprises is less influenced by the central government's and local government's willingness to participate. Market factors mainly influence these entities, while local governments are more influenced by the central government's willingness to participate. For example, local government participation is much higher than the separation enterprises' participation under the government purchase service model. Local governments and separation enterprises are inconsistent in terms of their mutual influence; separation enterprises are more sensitive to changes in the local government's willingness to participate. For example, in the waste separation PPP model, as the local government's investment in human, material, and financial resources increases, separation enterprises' participation also increases. Therefore, the central government should provide incentive funds to separation enterprises through transfer payments to enhance the participation of separation enterprises, and at the same time, give local governments specific discretionary power to combine waste management regulation, political rewards, and punishment mechanisms to drive separation enterprises to participate in waste separation promotion according to local conditions.

(2) Local governments are more sensitive to central government policy support, and separation enterprises are more sensitive to central government incentive funds. Policy support and incentive funds reflect the central government's guidance for waste separation promotion. Policy support such as tax sharing reduces the participation costs and increases the willingness of local governments to participate in waste separation promotion, while incentive funding policies such as transfer payments reduce the participation costs of separation enterprises while also reducing the risks involved in new technology research and development and improving the service quality of separation enterprises. Therefore, the central government should develop a flexible and diversified policy portfolio in order to establish appropriate policies for local governments and separation enterprises.

(3) Separation enterprises are more sensitive to changes in cost-sharing coefficients. Although the local government's share is lowered, the local government's willingness will rise rapidly in the short term. However, the willingness of the separation enterprises will decrease significantly. The local government's willingness will also decline after a significant decline in the willingness of separation enterprises. Therefore, local governments should take the initiative to bear the corresponding part of the total cost when designing waste separation promotion policies in their respective regions, aim to help separation enterprises reduce their costs, and actively encourage separation enterprises to participate in waste separation promotion.

(4) Separation enterprises are more sensitive to revenue and distribution coefficients than local governments. Enterprises seek to maximize economic benefits, and changes in additional revenue will cause changes in the willingness of separation enterprises to participate. Separation enterprises are an essential critical link in waste separation and are the execution point of waste separation. A low allocation coefficient will rapidly change their willingness to participate when separation enterprises receive less than their target revenue. Therefore, by optimizing the participation scheme for all parties involved in waste separation promotion, the local government strives to increase the total amount of additional revenue and improve the participation of separation enterprises; the revenue distribution is moderately tilted to separation enterprises and efficiently guides separation enterprises to participate in waste separation promotion.

The above findings suggest the use of the Trojan horse principle to achieve the ideal balance of "central command, local deployment, and enterprise performance" for waste separation promotion through a careful policy combination of inspection, transfer payments, and tax sharing of administrative control of waste management, as well as a political reward and punishment mechanism.

6. Conclusions

6.1. Theoretical Implications

Although issues related to waste sorting cooperation have been well studied, the present work still has some novel theoretical implications. First, unlike earlier studies (Yao, 2018 [50]; Chu et al., 2019 [51]), in this study, only the central government is considered as a generalized "neutral government"; the local government is considered to be a rational "political-economic person", which is an essential prerequisite for the effective integration of local deployment and corporate performance under the rubric of central guidance. Second, consideration of the interactive effects of participants' willingness is a unique contribution of this study. Third, unlike many cooperative studies on waste separation, this study considers the central government's strategic competitive motives for waste separation under Chinese-style decentralization, clarifies the principal–agent relationship between the central government and local governments in waste separation promotion, and presupposes that cooperative game theory cannot accommodate the reality of incomplete implementation of waste separation. This study contributes to non-cooperative game research (Pedersen and Manhice, 2020 [31]; Korsunova et al., 2021 [49]).

6.2. Practical Implications

This study provides the following practical contributions. First, the results of this study are directly related to the development of waste separation promotion policies. Considering that the formulation of waste separation policy plays a significant role in the promotion of waste separation, the central government, local governments, and sorting enterprises are all essential players in the promotion of waste separation, and clarifying the changes in the relationship between the three can effectively promote the development of waste separation. Second, this paper considers the benefits brought to local governments and sorting enterprises by the central government as the leading player in the game, and also considers the reduction in promotion costs due to policy support from the central government. This research helps to clarify the main influencing factors of the three parties

in the promotion of waste separation to ensure the development of waste separation more actively and effectively.

6.3. Recommendation

The above findings validate the core theoretical hypotheses of this paper and provide essential insights into the central government's regulatory policy practice and related institutional arrangements. The following recommendations are proposed:

(1) Strengthen centralized waste management to avoid the failure of local waste separation. At this stage, China still needs to implement centralized waste management and further improve the vertical management system of monitoring, regulation, and enforcement of waste management institutions below the provincial level. Due to the lack of central government management constraints, there is room for competition for local government waste separation promotion in law enforcement. Central government management constraints can effectively encourage local governments to promote waste separation. The strength of central government inspection is the institutional guarantee for incentive mechanisms based on "rewarding the good and punishing the bad". According to the model's simulation results, it is recommended that the central government inspectors cover the whole area; in terms of appropriate regulation costs, the intensity of central government inspections should cover at least half of the area per round.

(2) Broaden the scope of central funding incentives and establish a local separation compensation mechanism. According to the fiscal revenue and expenditure report announced by the Ministry of Finance in 2020, the general public budget revenue of the central government accounts for 45% of the total national revenue and 54% of the local revenue; the general budget expenditure of the CPC central government accounts for 14% of the national expenditure and 86% of the local expenditure. This implies that the centralization of fiscal power and decentralization of affairs under the Chinese style of decentralization has led to an imbalance between central and local fiscal and regulatory powers. The central government needs to expand the scope of expenditure on waste management, establish a local compensation mechanism for waste separation that matches the financial and administrative powers of waste separation promotion, and form a parallel system of general transfer payments and special transfer payments, with funds compensating local governments for the rectification and withdrawal of hazardous waste-generating enterprises, the technological innovation of separation enterprises, etc.

(3) Clarify responsibilities under local waste separation and new waste tax collection standards. This paper shows that when the consequences of local governments' ineffective fulfillment of responsibilities for waste separation promotion is changed from administrative interviews to economic penalties, implementing regulation becomes an evolutionary stabilization strategy for local government involvement. The endogenous institutional design plays a more critical role than the exogenous policy tools. The clarification of local responsibility for waste separation comes from innovation in the current performance appraisal system, with environmental protection's "one vote veto" transforming the political performance and development of prominent local leaders. A new waste tax policy could fill localities' cost gap to promote waste separation actively. However, the current system has only a general environmental protection tax, with no targeted waste tax. On the one hand, it is recommended to establish a dynamic waste tax standard, and those who generate hazardous waste pay to realize the double dividend effect of new tax regulation; on the other hand, it is recommended to implement a particular system for waste taxation and make it clear that waste tax revenue is reserved as special funds for local waste separation promotion, to prevent waste tax revenue from becoming part of local general budget revenue for integrated use.

(4) Support technological innovation of separation enterprises and guide public participation in waste separation. The central government must provide financial support for waste separation technology innovation to achieve win–win economic and environmental performance. Thus, it is suggested that the 46 key demonstration cities of waste separation

promotion nationwide should take the lead in including separation enterprises in the technological innovation program of the Ministry of Science and Technology of China, and provide financial support for waste separation innovation through equity financing, debt financing, trust investment, and traditional credit. The public is the fourth party in addition to the central government, local government, and separation enterprises, and it includes residents and social organizations. The active participation of the public in the space between the interests of the government and the separation enterprises can effectively break the "collusion" between local government and separation enterprises. Therefore, it is essential to actively guide the public to participate in waste separation through communication, education, and popularization of waste separation knowledge.

6.4. Limitations and Future Research

Despite the somewhat cautious, simulation-based approach in constructing the non-cooperative tripartite game model of central guidance, local deployment and corporate performance, we acknowledge some limitations. It should be noted that the cases used in the study were collected from a specific country, China. Therefore, care should be taken in extending the study to other countries. Relevant empirical-type studies can be conducted in the future to validate the findings in other countries, thus expanding the application of this study. However, in the specific practice of waste separation promotion, the subjects involved, including residents and social groups, are limited by statistical data sources, time, and other factors. For this reason, this research team intends to conduct a series of empirical studies on the role of residents and social groups in waste separation in the context of digital transformation and big data processing technology in future research work.

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