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Analysis of Multi-Stakeholder Behavioral Strategies in the Construction and Demolition Waste Recycling Industry through an Evolutionary Game Theory

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Abstract: Construction and demolition waste (C&DW) recycling products have drawn worldwide attention over the past few decades. There is a general agreement among researchers that C&DW recycling is an important means for curbing the deterioration of the environment. Previous papers mainly focused on the decision-making behavior of dual stakeholders or tripartite stakeholders, as well as the lack of cooperation among multiple stakeholders. This study explored a dynamic evolutionary game model with three different parameter conditions to research the decision-making behaviors and stable strategies of the multi-stakeholders involved in the C&DW recycling product industry, including government departments and some enterprises. This research also investigated how the government's supervision costs, penalties applied to enterprises, and resource taxes affect the dynamic evolution process of C&DW recycling. This research conducted numerical simulations using Python to analyze stakeholders' behavioral evolutionarily stable strategy (ESS) and the sensitivity to main factors in each stage of the C&DW recycling process to accelerate the development of construction waste resource utilization. Based on the results of the evolutionary game, this paper proposed that the roles of multi-stakeholders are different at different stages of industry development, and that supervision costs, penalties, and resource tax have their own impacts on the C&DW recycling product industry. The paper suggests a range of discussions and simulation studies to highlight the significance of the government's refined and moderate adjustments to the regulatory incentive system and the level of government regulation and involvement at different stages of the process. These adjustments are aimed at promoting the sustainable recycling and utilization of construction and demolition waste (C&DW) products within some countries' construction industry.

Keywords: construction and demolition waste; recycling products; stakeholder; evolutionary game theory

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1. Introduction

The rapid growth of construction and building waste is a by-product of rapid urbanization. This waste constitutes a considerable quantity of the total urban waste [1]. Its random disposal or burial without proper treatment causes severe environmental issues, such as groundwater contamination and land resource occupation [2,3]. The recycling of construction and demolition waste (C&DW) varies from country to country and region to region. For instance, in 2018, the US generated 600 million tons of C&DW, of which 145 million tons went to landfill and 455 million tons were reused [4]. Countries like Japan, the UK, and the Netherlands recycle about 80% of their C&DW, but some other countries like India and Italy recycle far less C&DW and have far lower recycling rates [5]. Nowadays, China generates approximately 2.3 billion tons of C&DW annually [6] and China's urbanization rate has surpassed 60%, which will cause a significant loss of resources if this waste continues to accumulate.

Recent advancements in C&DW recycling technology have led to a significant increase in the availability of high-quality C&DW recycling products [7]. However, the utilization of these products is still below the desired level [8]. The disposal of C&DW recycling products involves various stakeholders, each with their own interests, which together form the industrial chain for recycling products from the sourcing of C&DW. Within this chain, the conflicting interests of different stakeholders have hindered the promotion and use of recycling C&DW products.

To address this issue, it has been recognized that accelerating the promotion of waste recycling is crucial. The goal is to reduce the total amount of C&DW at its source and to move forward with the process of construction waste resourcefulness. Therefore, developing recycling technologies for C&DW represents a promising approach to managing waste effectively. By using C&DW as raw materials and processing them into new construction material products, resources can be conserved, and the environment can be protected more effectively.

Addressing this challenge requires not only reducing the generation of C&DW, but also recycling C&DW resources through cooperation among multiple parties [9]. While most previous papers have focused on 2–3 stakeholders, such as the government, contractors, building material companies, and the public, by using a two-party or three-party evolutionary game, this paper takes a different approach. Here, the different intelligent departments of the government and various companies are considered as two main categories of game subjects. The study examines the spatial composition of different strategic subjects and explores the decision-making of stakeholders in the progress of C&DW recycling products across various scenarios.

The paper analyzes the decision-making behaviors and strategy alternatives of multi-stakeholders under different scenarios, including two types of players: government agencies and related enterprises. This study provides a comprehensive explanation to address the following questions: What are the stable equilibrium states and associated conditions for the growth of the C&DW recycling product industry? How do stakeholders' strategy alternatives and interconnected elements affect the evolution of equilibrium states? To achieve these targets, we propose a multi-stakeholder evolutionary game model to calculate the expected payoffs and ESSs of each stakeholder using calculating replicator dynamic equations. We drive the corresponding stability conditions based on Lyapunov stability theory and Jacobi matrix [10], check ESSs by numerical simulations, and then perform numerical simulations of regulatory costs, resource taxes, and penalties based on the shortcomings of the simulation analysis in previous papers. Finally, some suggestions for promoting sustainable development of the C&DW recycling product industry are proposed.

2. Literature Review

This section provides a brief overview of some scholars' research in the domain of C&DW resourcing, specifically addressing the identification of stakeholders. It also summarizes the existing body of work and identifies research gaps in the application of game theory within this domain. The paper then proceeds to present its innovations.

The management of C&DW resources involves intricate systems incorporating multi-stakeholders and links [11]. Government departments play significant roles and serve as the central regulators and supervisors of waste management [12]. Shen et al. [13] concluded that the government has acknowledged the health and environmental hazards posed by enterprises' illegal dumping. However, due to the limited budget and personnel available, the government cannot adequately control the behaviors of enterprises that violate the rules. Addressing this issue requires the collaborative efforts of various government departments like health authorities, urban law enforcement, building material departments, housing and construction, and environmental protection to formulate policies [14–16]. Too many studies concentrate on individual stakeholders, while few consider the synergistic influences among these groups. One of the innovations of this paper is to divide the government into multiple authorities and consider how these departments influence each other. This segmentation groups related enterprises into broader categories, thereby impacting the decision-making of the government as a whole.

The action mechanism between the critical stakeholders in the C&DW recycling products market is summarized in Figure 1. It illustrates the role and responsibilities of the government (manager) in the process of recycling and reusing construction waste. The chart is divided into two main parts: supply management and demand management. In terms of supply management, the government is responsible for regulating and market-controlling construction companies, dismantling and transportation companies, waste recycling plants, and resource enterprises. These measures are aimed at promoting the prosperity of the C&DW recycling products market. For demand management, the government implements these policies through contractors. The ultimate goal is to achieve environmental, economic, and social benefits.

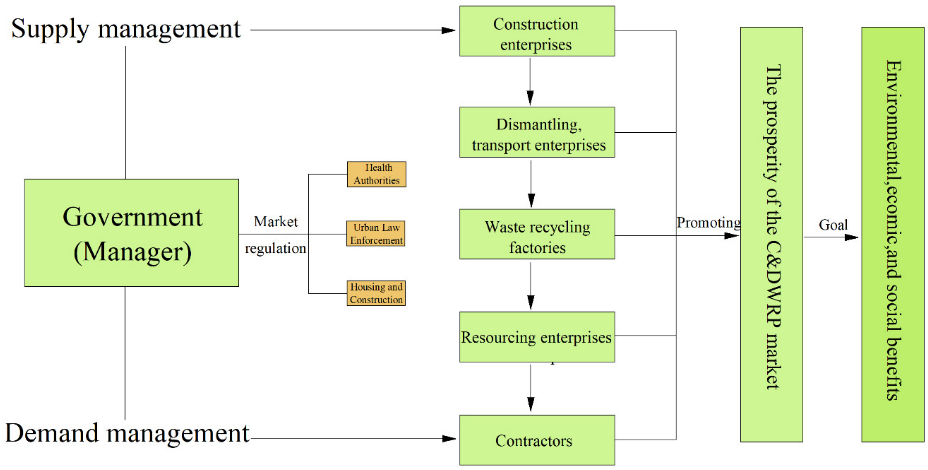

Figure 1. The action mechanism between the critical stakeholders in the C&DW recycling product market.

To foster the enthusiasm across all stakeholders in the C&DW recycling chain, experts have evaluated the financial benefits of C&DW management from various angles. Liu et al. [17] concluded that the amount of government compensation for enterprise disposal costs exceeds the disposal cost; this provides incentives for enterprises to engage in recycling and reusing C&DW. This, in turn, stimulates their participation in C&DW management efforts. Wang et al. [18] and Wang et al. [19] proposed an approach to optimize the collection of C&DW management fees. They based this method on the environmental effect throughout the complete lifespan of C&DW and the social desire to improve C&DW management. Their approach considers the broader environmental implications and societal will associated with improving C&DW management practices. Liu et al. [20] analyzed the influence of resource tax and subsidy on the recycling sector. Their findings suggested that a fusion of tax and subsidy can effectively reduce public sector expenditures. It can also decrease landfill volumes and reduce the consumption of natural materials. These measures can thereby benefit the overall C&DW recycling ecosystem. Du et al. [21] investigated the impact of governmental penalties and incentives on the decision-making processes of contractors and the public. Their research revealed that these measures can effectively curtail the illegal disposal of C&DW and enhance stakeholders' enthusiasm for participating in responsible waste management practices.

These previous papers have laid a robust basis for the economic aspects of C&DW recycling. It is essential to recognize that relevant government departments possess the authority to penalize enterprises involved in C&DW mismanagement, and such penalties can be economically significant. However, few studies analyze both parameters resource tax and penalty to enterprises together, and there is relatively little research on the supervision cost. In addition to more common forms of taxation and penalties, this text considers the costs of regulatory compliance. In an ideal scenario, where both government and corporate strategies are inclined towards active participation, it is possible to achieve a cost-optimal state. This can generate positive externalities. However, in practice, the strategies of governments and enterprises often diverge. Governments face a choice: to implement a strict regulatory strategy, which may entail high costs and administrative burdens, and could even lead to corporate backlash; or to adopt a lenient regulatory strategy, relying on market conditions and corporate negotiations. This approach may lower costs in the short term, but could lead to negative externalities in the long run due to constraints such as information asymmetry and transaction costs, for instance, market failure and the influence of enterprises on regulatory capture. A sensitivity analysis was conducted to explore the impacts of three key factors: penalties applied to enterprises, government supervision costs, and resource tax to extend the understanding of their influence on the C&DW recycling product industry.

In practice, the relationships among multi-stakeholders in the C&DW recycling product industry can be quite complex. This complexity often makes it challenging for the government to gain timely insights into the industry's dynamics and implement effective strategic actions. Game theory is commonly employed to address challenges in dynamic systems involving multi-stakeholders. Based on previous research findings, some researchers have applied game theory to gain a more profound understanding of the collaborative evolution of stakeholders within the industry chain [22,23]. Additionally, Shen et al. [24] merged prospect theory with evolutionary game theory to explore the decision-making behaviors of C&DW management stakeholders subjected to different environmental regulations. Currently, many researchers are concentrating on the stakeholders involved in the efficient utilization of C&DW. Khanzadi et al. [25] examined the decision-making behaviors of contractors facing delays using game-theoretic methodology. Some studies have explored two-party [26], three-party [27,28], and multi-party scenarios [29]. Dong and Song [30] studied the strategic decisions of individual suppliers in reverse supply chains and pointed out that macro-level controls, such as government sanctions, can encourage suppliers to cooperate. Ji et al. [31] focused on the cooperative relationships between suppliers (recycling firms) and manufacturers (firms that reuse recycled materials in production) and analyzed their behavioral trends by developing an evolutionary game model. The results of their study show that the capacity of recycling companies has a significant impact on the efficiency of the green supply chain. Chen et al. [32] examined the strategies chosen by contractors and management and analyzed the impact of management sanctions on contractor decision-making. Tian et al. [33] introduced evolutionary game theory to analyze green supply chain management. Their results showed that supporting the producer is more effective than supporting the consumer. Wang et al. [34] examined the leading role of government in the e-waste recycling process, presenting a three-pronged evolutionary game model consisting of government, recyclers, and consumers. Each subject in these studies generally maintains an approximately equal spatial composition within the broader stakeholder landscape. There is no clear differentiation in terms of the extent of stakeholder involvement. This paper aims to address this issue by categorizing the various related subjects participating in the C&DW recycling product industry chain. By classifying the subjects in this way, the paper aims to clarify the patterns of interests among them within the C&DW utilization industry chain. Additionally, it utilizes a strategic evolutionary game model to investigate the spatial composition and strategic decisions of these subjects.

3. Evolutionary Game Modeling

This study developed an evolutionary game model engaging multiple stakeholders including health authorities, urban management and law enforcement departments, housing and construction departments, dismantling and transport enterprises, waste recycling factories, resourcing enterprises, and contractors. Then, a multiple evolutionary game model was established and its equilibrium solution calculated. This paper analyzed the stability strategies based on the Lyapunov and Jacobi matrix stability theory. The technical flowchart of this paper is displayed in Figure 2.

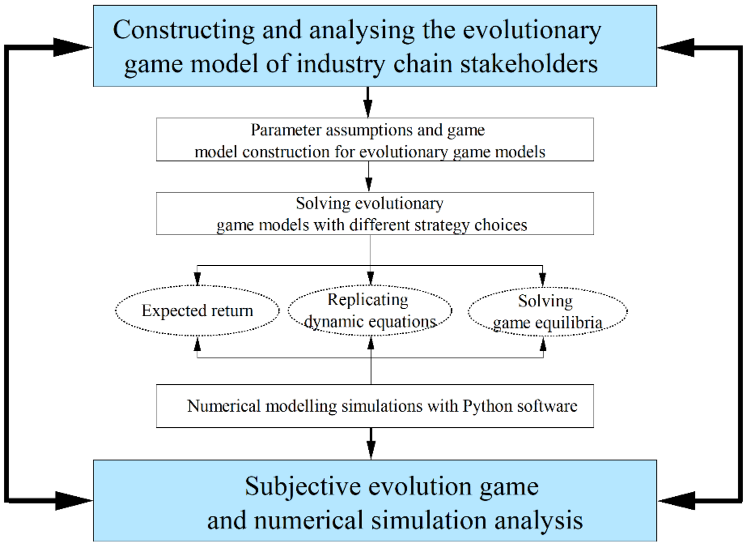

Figure 2. Technology flowchart.

3.1. Model Assumptions

The following assumptions were developed taking into account the features of stakeholders related to C&DW recycling products [35].

Assumption 1

The evolutionary game model incorporates two primary players within the game process of C&DW recycling. Each player possesses bounded rationality, is capable of autonomous decision-making, and is motivated by the maximization of self-interest. These players can also adjust their strategies to environmental shifts.

The first players in this scenario include demolition and transport companies, recycling plants, construction firms, resource companies, and contractors. Each player has two strategic options: strategy "*G*" or strategy "*H*". Choosing "*G*" indicates proactive participation in the C&DW resource industry, while "*H*" signifies a lack of commitment to the industry's development. Enterprises are responsible for managing building materials to satisfy construction needs. For simplification, this model equates the purchase of materials to their utilization. The production of new building materials depletes natural resources and contributes to environmental degradation. High recycled material utilization rates, however, can conserve resources and enhance environmental credentials. As noted, few provincial governments have implemented policies that can subsidize recycling plants and grant reputational benefits to contractors. Dismantling and transport firms choosing the "*G*" strategy collaborate with recycling plants under government oversight, as opposed to opting for landfill. Choosing the "*H*" strategy equates to a disengagement from the C&DW resource utilization industry. Furthermore, contractors face a binary choice: to purchase C&DW recycling products, influenced by sustainability recognition and government incentives, or to opt for typically cheaper conventional building materials.

Assumption 2

The second player in this scenario is the government, encompassing health authorities, urban management, law enforcement, and housing and construction departments. It is assumed that these entities have two primary strategies: to provide incentives or not. The "with incentives" approach, labeled as "*M*", implies that the government enacts proactive strategies to bolster C&DW recycled product development. This could involve funding, the application of innovative technologies, and offering land concessions, tax breaks, financial subsidies, and even consumer incentives, not to mention ramping up policy advocacy for C&DW recycled products. Conversely, the "without incentives" strategy, labeled as "*N*", suggests a more passive role due to budgetary constraints, where the government might only offer basic advocacy and encouragement.

Assumption 3

The effects in this game are reciprocal, with the first class of game participants designated as type I, accounting for $(1-\omega)$ proportion of the total participants. This class has a strategy set of $P = \{G, H\}$, where "G" represents investment and "H" represents a refusal to invest. At any t within the set T, if a participant chooses strategy "G", they will contribute effort d from the set $D \geq 0$ to the recycling product pool that benefits all participants. Conversely, choosing strategy "H" indicates a refusal to participate in the C&DW recycling industry chain.

The second class of participants is labeled as type II, representing a weight of ω in the total participant population. Their strategies are denoted as $Q = \{M, N\}$. Choosing strategy "M" means that they will create regulations and supervise, contributing effort d to the shared recycling products. If they choose strategy "N", there is a probability p that they will ignore the shared recycling effort, or, alternatively, with probability $(1-p)$, they may participate in the C&DW recycling chain or accept bribes from type I participants who choose strategy "H".

In each round, "n" individuals are randomly chosen from the group to join the game, with n set at 8 for this analysis. Once the participants have executed their strategies, the total investment in the C&DW recycling products is multiplied by a factor k $(1 < k < n)$. The resulting amount is then distributed equally among the n participants. The strategy choices are public, meaning all participants can observe the strategies of others.

In this context, when type II participants using strategy "M" observe any type I participants employing strategy "H", they will impose a penalty $\alpha(\alpha \geq \beta \geq 0)$ at a cost of β per type I participant using strategy "H". Conversely, type II participants with strategy "N" will, with probability p, disregard the recycling product, or with probability $(1-p)$, contribute to the public pool. In the latter case, they will charge beta value γ $(0 \leq \gamma \leq \alpha)$ to each type I participant who chose strategy "H".

From the given context, it is evident that the second type of game subject has additional rights. These rights include the abilities to punish and collect bribes, unlike the first type. Thus, the second type effectively exerts additional external incentives on the first type, influencing their strategic choices. Notably, when the first type of subject chooses strategy "N", indicating disinterest in the development of the C&DW recycling product industry, the second type of subject using strategy "M" will not punish those with strategy "N". The game model assumptions are illustrated in Figure 3. Throughout the C&DW recycling product development, both types of stakeholders have unique strategic choices and interests. Their decisions are interconnected, and the choices made by any one subject affect both stakeholder types. These varied strategic choices dynamically impact the advancement of C&DW recycling products.

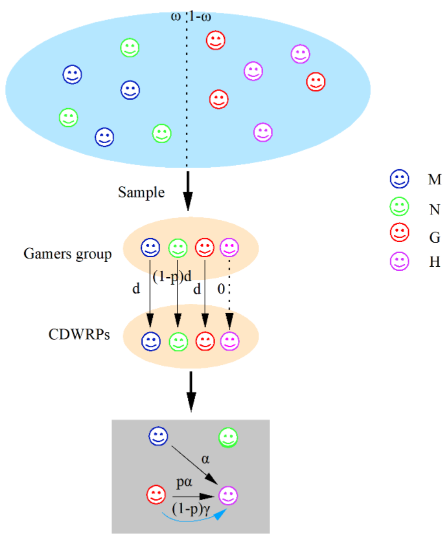

Figure 3. Schematic diagram of the game model.

3.2. Model Establishment and Equilibrium Solution

At any given $t \geq 0$, let $y(t)$ and $x(t)$ represent the proportions of game subjects in the first and second categories adopting strategies "G" and "M", respectively. Consequently, $(1-y(t))$ and $(1-x(t))$ signify the proportions of game subjects in the first and second categories selecting strategies "H" and "N", respectively. It is also assumed that the individual game subject roles within the group are constant, meaning their category does not change over time. Therefore, the strategy evolution dynamics for each subgroup can be separately depicted using the replication dynamics in Equation (1).

$$\begin{cases} \dot{x} = x\left(f_M - \dot{\tilde{\tilde{f}}}_U\right), \\ \dot{y} = y\left(f_G - \dot{\tilde{\tilde{f}}}_V\right), \end{cases} \tag{1}$$

The dynamics of the C&DW recycling product game can be expressed as follows:

$$\begin{cases} \dot{x} = x(1-x)f(x,y), \\ \dot{y} = y(1-y)g(x,y), \end{cases} \tag{2}$$

where $\dot{x} = \frac{dx(t)}{dt}$, $\dot{y} = \frac{dx(t)}{dt}$, f_M, and f_N represent the expected payoffs for subjects with strategies "M" and "N", respectively, and f_G and f_H represent the expected payoffs for subjects with strategies "G" and "H", respectively.

The expected payoffs for subjects with strategy "G" and strategy "H" are

$$f_G = -\sigma + \frac{kd}{n}(n-1)[\omega x + (1-\omega)y + (1-p)\omega(1-x)] \tag{3}$$

$$f_H = \frac{kd}{n}(n-1)[\omega x + (1-\omega)y + (1-p)\omega(1-x)] - p(n-1)\omega x\alpha - (1-p)(n-1)\omega(1-x)\gamma \tag{4}$$

For subjects with strategy "M" and strategy "N", the expected payoffs are

$$f_M = -\sigma + \frac{kd}{n}(n-1)[\omega x + (1-\omega)y + (1-p)\omega(1-x)] - p(n-1)(1-\omega)(1-y)\beta \tag{5}$$

$$f_N = -(1-p)\sigma + \frac{kd}{n}(n-1)[\omega x + (1-\omega)y + (1-p)\omega(1-x)] + (1-p)(n-1)(1-\omega)(1-y)\gamma \tag{6}$$

We obtain Equation (7) by substituting expressions (3)–(6) into the evolutionary dynamics in Equation (2); thus, we can calculate the equilibrium points of the game. The possible equilibrium points are $(0,0)$, $(0,1)$, $(1,0)$, $(1,1)$, $(0,y_0)$ (if $l_0 = 0$) and $(1,y_0)$ (if $l + l_0 = 0$), where y_0 is in the range [0, 1].

$$\begin{cases} \dot{x} = x(1-x)(by - b_0), \\ \dot{y} = y(1-y)(lx + l_0), \end{cases} \tag{7}$$

in which

$$\begin{cases} b = (n-1)(1-\omega)[p\beta + (1-p)\gamma], \\ b_0 = (n-1)(1-\omega)[p\beta + (1-p)\gamma] + p\sigma, \\ l = (n-1)\omega(p\alpha - \gamma + p\gamma), \\ l_0 = (n-1)(1-p)\omega\gamma - \sigma, \end{cases} \tag{8}$$

3.3. Analysis of Evolutionarily Stable Strategy (ESS)

There is uncertainty regarding whether the equilibrium points identified in the previous subsection are ESSs. The equilibrium point does not necessarily represent the ESS. The stability analysis of the government sector in C&DW can be verified. This analysis can be based on the determinant and trace of the Jacobian matrix and the Lyapunov methods.

To determine the ESS, we let the right-hand term of Equation (7) be 0, resulting in $\dot{x} = 0$ and $\dot{y} = 0$. By solving this system of equations and noting that $f(x, y) < 0$ is always true, we obtain six possible equilibrium points: $(0, 0)$, $(0, 1)$, $(1, 0)$, $(1, 1)$, $(0, y_0)$ (if $l_0 = 0$) and $(1, y_0)$ (if $l + l_0 = 0$), where y_0 is in the range [0, 1], as follows:

$$J|_{(x,y)} = \begin{pmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{pmatrix} = \begin{pmatrix} (1-2x)f(x,y) + x(1-x)\frac{\partial f(x,y)}{\partial x} & x(1-x)\frac{\partial f(x,y)}{\partial y} \\ y(1-y)\frac{\partial g(x,y)}{\partial x} & (1-2y)g(x,y) + y(1-y)\frac{\partial g(x,y)}{\partial y} \end{pmatrix} \tag{9}$$

$$Tr(J) = J_{11} + J_{22} = (1-2x)f(x,y) + x(1-x)\frac{\partial f(x,y)}{\partial x} + (1-2y)g(x,y) + y(1-y)\frac{\partial g(x,y)}{\partial y} \tag{10}$$

Substituting each of the six equilibria mentioned above into matrix (9) and using Equation (7) leads us to the following inference:

$$\begin{cases} f(x,y) = (by - b_0), \\ g(x,y) = (lx + l_0), \end{cases} \tag{11}$$

To confirm the asymptotic stability of the equilibrium points, we can examine the eigenvalues of the Jacobian matrix of the system. In accordance with the Lyapunov stability theory, specific criteria can be utilized to determine whether a Nash equilibrium point constitutes an ESS [9,22].

Based on Figure 1, we can obtain the values of the six local equilibrium points for the determinant of the Jacobian matrix, denoted as $J|_{(x,y)}$, by substituting each of the points into the expressions. Similarly, we can calculate the trace of the matrix, $Tr(J)$, using the same method. The local stability analysis of the government sector and other principal evolving systems of C&DW recycling products can be verified. This verification can be based on the values and traces of the Jacobian matrix determinant and the Lyapunov methodology presented in Table 1.

Table 1. Stability analysis of equilibrium points.

Equilibrium Points	$J\|_{(x,y)}$	$Tr(J)$	l_0	+/−($J\|_{(x,y)}$)	+/−(Tr(J))	Stability
$(0,0)$	$(-b_0) \times l_0$	$-b_0 + l_0$	Positive number	−	+/−	unstable
			0	0 (repeated)	−	stable
			Negative number	+	−	stable
$(0,1)$	$(b - b_0) \times (-l_0)$	$(b - b_0) + (-l_0)$	Positive number	+	−	stable
			0	0 (repeated)	−	stable
			Negative number	-	+/−	unstable
$(1,0)$	$(l + l_0)b_0$	$b_0 + (l + l_0)$	+/−		+/unknown	unstable
$(1,1)$	$(l + l_0)(b - b_0)$	$(b_0 - b) - (l + l_0)$	−/+		−/unknown	unstable
$(0, y_0)$	0	$(by_0 - b_0)$	0		unknown	unstable
$(1, y_0)$	0	$-(by_0 - b_0)$	0		unknown	unstable

When $x = 0$, in Equation (7), the sign is only affected by $(lx + l_0)$, so it can be divided into three cases: $l_0 < 0$, $l_0 > 0$, and $l_0 = 0$. This is equivalent to $\sigma > (n-1)(1-p)\omega\gamma$, $\sigma < (n-1)(1-p)\omega\gamma$ and $\sigma = (n-1)(1-p)\omega\gamma$.

For point $(0,0)$, when $\sigma > (n-1)(1-p)\omega\gamma$, the determinant of the Jacobi matrix $Det(J) > 0$ and the trace $Tr(J) < 0$; when $\sigma = (n-1)(1-p)\omega\gamma$, one eigenvalue of the $Det(J) < 0$ and the other eigenvalue is 0, and the reweight is 1: in this case, $(0,0)$ is stable; when $\sigma < (n-1)(1-p)\omega\gamma$, $Det(J) < 0$, making $(0,0)$ unstable. Similarly, for the equilibrium point (0, 1), when $\sigma \leq (n-1)(1-p)\omega\gamma$, (0, 1) is stable; when $\sigma > (n-1)(1-p)\omega\gamma$, $(0,1)$ is unstable.

For the equilibrium point $(1,0)$, when $(l+l_0) > 0$, $Det(J) > 0$ and $Tr(J) > 0$. When $(l+l_0) < 0$, $Det(J) < 0$ and $Tr(J)$ is uncertain. When $(l+l_0) = 0$, it corresponds to the point $(0, y_0)$. For this equilibrium point $(0, y_0)$, since $g(x,y) = (lx+l_0) \leq 0$ holds for $l < 0$, where the equalization holds if and only if $x = 0$, $\dot{y} = y(1-y)(lx+l_0) < 0$ always holds in the feasible domain of Equation (7). Therefore, if a small perturbation is applied at the equilibrium point $(0, y_0)$, the variable $y(t)$ will eventually evolve to $y = 0$ over time.

For the equilibrium point $(1,1)$, when $(l+l_0) > 0$, $Det(J) < 0$ and $Tr(J) < 0$. When $(l+l_0) < 0$, $Det(J) > 0$ and the $Tr(J)$ is uncertain. When $(l+l_0) = 0$, it corresponds to the point $(1, y_0)$, for the equilibrium point $(1, y_0)$, since $g(x,y) = (lx+l_0) \geq 0$ holds for $l < 0$, where the equality sign holds if and only if $x = 1$, $\dot{y} = y(1-y)(lx+l_0) > 0$ always holds in the feasible domain of Equation (7). Since the sign of the trace of their corresponding Jacobian matrix is unknown and there is always a 0 eigenvalue, neither method can be used to identify the stability. Therefore, if a small perturbation [36,37] is applied at the equilibrium point $(1, y_0)$, the variable $y(t)$ will eventually evolve to $y = 1$ over time. Therefore $(1, y_0)$ is unstable. According to the above analysis, the following conclusions can be drawn:

(a) if $l_0 \leq 0$, then $(0,0)$ is stable; otherwise, it is unstable.
(b) if $l_0 \geq 0$ then $(0,1)$ is stable; otherwise, it is unstable.
(c) $(1,1)$, $(1,0)$, $(0, y_0)$, and $(1, y_0)$ are all unstable equilibrium points.

4. Numerical Modeling

To validate the theoretical results from the previous chapter, this chapter conducts numerical simulation studies using Python 2023.1.3 with specific model parameters.

4.1. Multi-Stage Dynamic Evolution Results

In Section 3.3, it can be seen that the stability analysis of the equilibrium points in the strategy evolution dynamics equation of the building waste recycling product game mainly depends on the positive or negative value of the parameter $l_0 = (n-1)(1-p)\omega\gamma - \sigma$. Figure 4a illustrates the vector field streamline diagram of the strategy evolution for three parameter conditions: $l_0 < 0$, $l_0 > 0$, and $l_0 = 0$. The arrows indicate the direction of the strategy evolution, and the darkness of the color gradient bar represents the magnitude of the vector field modes of Equation (7), which reflects the strength of the strategy evolution. The parameter values p and ω in Figure 4 are $(p,\omega) = (0.5, 0.4)$, $(p,\omega) = (0.01, 0.6)$, and $(p,\omega) = (0.25, 0.6)$, respectively, with l_0 approximated to 0 since the case of $l_0 = 0$ is special. The remaining parameter settings for the numerical simulation of evolutionary dynamics are shown in Table 2.

Table 2. Parameter assignments for strategy evolution under three different parameter conditions.

Parameter	Value	Parameter	Value
n	8	σ	0.625
β	0.3	k	3
γ	0.2	d	1
α	0.8		

As observed in Figure 4, the theoretical results from Section 3.3 agree perfectly with the numerical simulation results. In this figure, x represents the proportion of individuals choosing the active strategy "M" in the relevant government departments; additionally, y represents the proportion of individuals choosing the active strategy "G" in the relevant enterprises and society.

When $l_0 < 0$ $((n-1)(1-p)\omega\gamma - \sigma < 0)$, the equilibrium point $(0,0)$ is stable in Figure 4a. At this point, the proportion of game subjects with strategy "G" in the first type of game subjects evolves from 1 to 0, while the proportion of game subjects with strategy "M" in the second type of game subjects evolves from 1 to 0. This means that when promoting C&DW recycling products, relevant government departments will dedicate efforts to recycling products shared by all game subjects. These efforts will be achieved primarily through rulemaking and regulation. Other entities should invest in C&DW recycling products and actively participate in their promotion. This situation is balanced by the self-regulating market for recycling products once the C&DW recycling product industry is well established. At different stages of the C&DW recycling product industry, stakeholders continuously adjust their behavioral strategies. These adjustments are based on their responsibilities and interests. This process helps to understand a balanced spatial structure and the relationship between stakeholder decisions and C&DW recycling product development.

When $l_0 = 0$ $((n-1)(1-p)\omega\gamma - \sigma = 0)$, all points on the line x = 0 are equilibrium points for Equation (7) in Figure 4b. However, all equilibrium points except (0, 0) will eventually evolve to the equilibrium point $(0,0)$ when subjected to small perturbations. Therefore, $(0,0)$ is the only evolutionarily stable equilibrium point in Figure 4b. This situation is comparable to when $l_0 < 0$.

When $l_0 > 0$ $((n-1)(1-p)\omega\gamma - \sigma > 0)$, $(0,1)$ is the only stable equilibrium point in Figure 4c. At this point, the proportion of game subjects with strategy "G" in the first type of game subjects evolves from 1 to 0, while the proportion of game subjects with strategy "M" in the second type of game subjects remains at 1. This implies that when promoting C&DW recycling products, the relevant government departments will make an effort. This effort is directed towards recycling products that are shared by all game subjects. The methods employed include rule formulation and supervision. Other entities should actively participate in C&DW recycling product promotion. The simulation results indicate that the government plays a leading part in the initial stage of the C&DW recycling product market. As the industry matures, the government gradually reduces its intervention in the market and eventually withdraws from it. As the C&DW recycling product industry develops, the market for recycling products can be self-regulated. Relevant government departments will be involved in rule formulation and supervision, and this situation can also be stabilized during the promotion of C&DW recycling products.

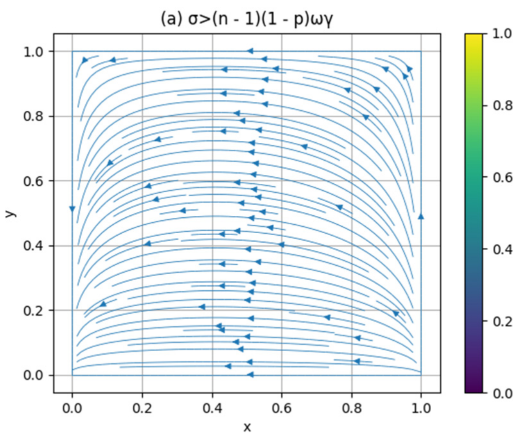

Figure 4. *Cont.*

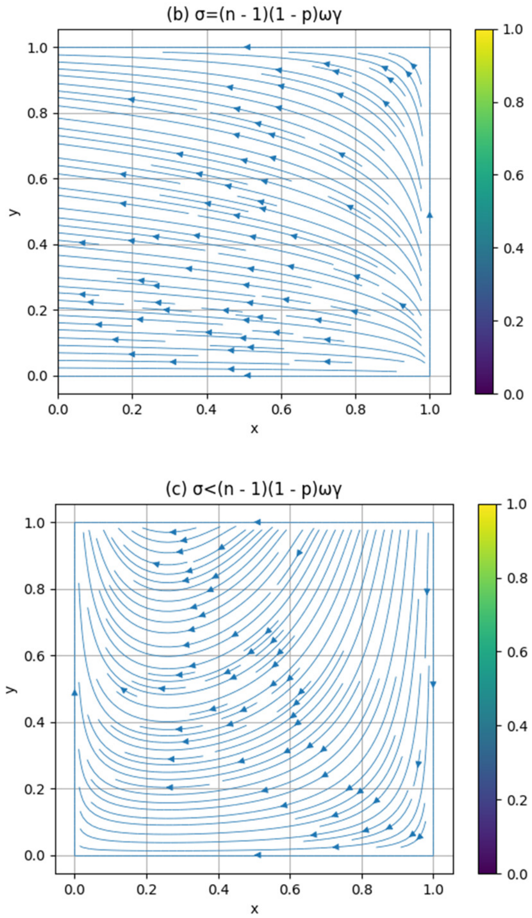

Figure 4. Phase diagram of strategy evolution corresponding to three different parameter conditions ($l_0 < 0$; $l_0 = 0$; $l_0 > 0$).

4.2. Sensitivity Analysis Using Different Parameters in Initial Stage

As is known, the government can impose a penalty $\alpha(\alpha \geq \beta \geq 0)$ at a cost β on enterprises adopting strategy "H". To analyze the influence of government-related parameters on the initial stage of multi-stakeholders' strategic evolution, we conducted numerical simulations with α, β, and γ set as 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9, respectively. Each of these three parameters was chosen from vectors ranging between 0.1 and 0.25. The results are illustrated in Figures 5–7.

When keeping other parameters constant, we varied α from 0.1 to 0.9. From Figure 5, we can observe that the proportion of other stakeholders susceptible to penalties from relevant government departments decreases as α increases. This suggests that lower penalties mitigate the enthusiasm of related enterprises for selecting C&DW recycling products. When $\alpha = 0.1$, the proportion of enterprises choosing C&DW recycling products gradually decreases, indicating that a lower penalty weakens their willingness. When $\alpha = 0.5$, the chosen strategy "H" has minimal impact on related enterprises, regardless of the measures taken by the government. When $\alpha = 0.9$, the proportion of enterprises choosing C&DW recycling products increases, indicating that a higher penalty enhances their willingness. Furthermore, since penalties generate revenue for the government, the proportion of related enterprises adopting C&DW recycling products remains stable in all three cases. In conclusion, related enterprises are relatively resilient to low penalties. As the penalty increases, the strategic behavior of multi-stakeholders gradually evolves towards the optimal stable point.

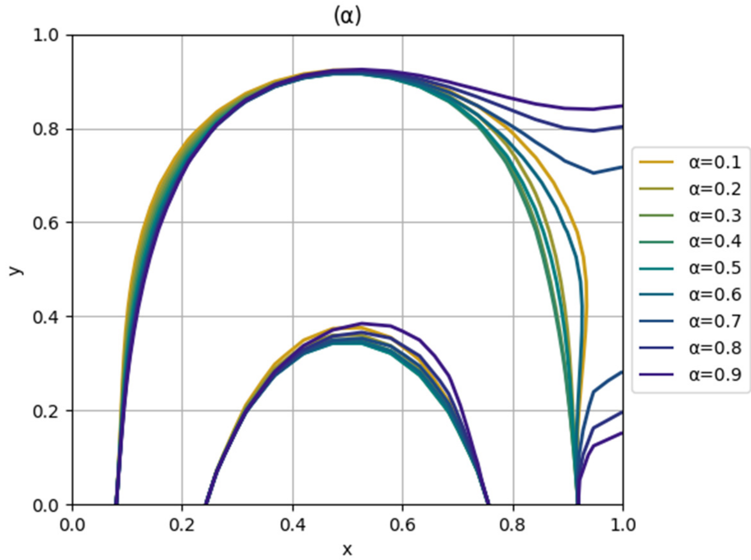

Figure 5. The effect of the penalty on the behavior evolution of multi-stakeholders.

Holding other parameters constant, β is varied from 0.1 to 0.9. From Figure 6, we can observe the effect of the supervision cost on the behavior evolution of multi-stakeholders. According to the graphical representation of the change in β, it appears that the magnitude of the cost of penalizing relevant firms and purchasers for adopting a non-participation strategy has a negligible effect on the spatial composition of various subjects. In short, the sensitivity of related enterprises to the supervision cost is not significant. Regardless of the supervision cost, the behavioral strategies of multi-stakeholders gradually evolve towards the optimal stable point.

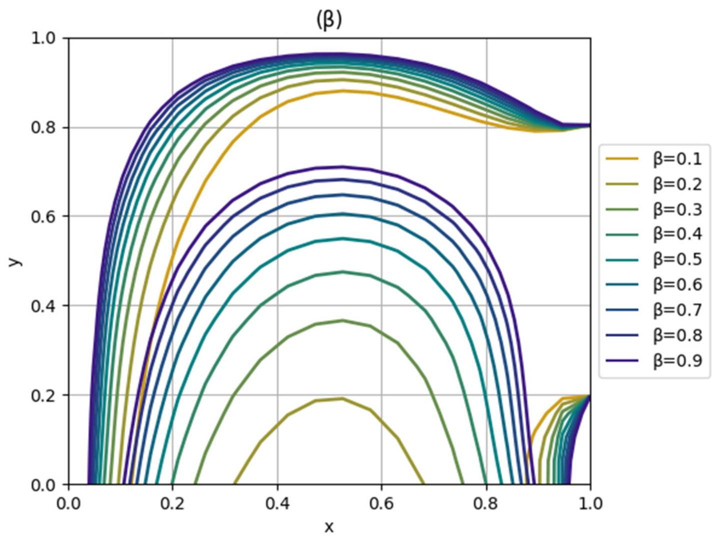

Figure 6. The effect of the supervision cost on the behavior evolution of multi-stakeholders.

When keeping other parameters constant, γ is set from 0.1 to 0.9. In cases where relevant enterprises adopt a no-attention strategy for C&DW recycling products, the relevant government department has a probability of $(1-p)$ to pay attention to the industry's development. Furthermore, the department can collect revenue from the firms that neglect industry development. As shown in Figure 7, as the collected resource taxes gradually increase, the simulation results indicate a more drastic trend towards the equilibrium point. The higher the collected revenue, the greater the proportion of relevant enterprises and purchasers choosing to actively participate in industry development strategies. Conversely, when the revenue collected is lower, relevant enterprises and purchasers pay less attention to industry development. The watershed between these two cases is at γ taking 0.4. In conclusion, the sensitivity of related enterprises to low supervision costs is substantial.

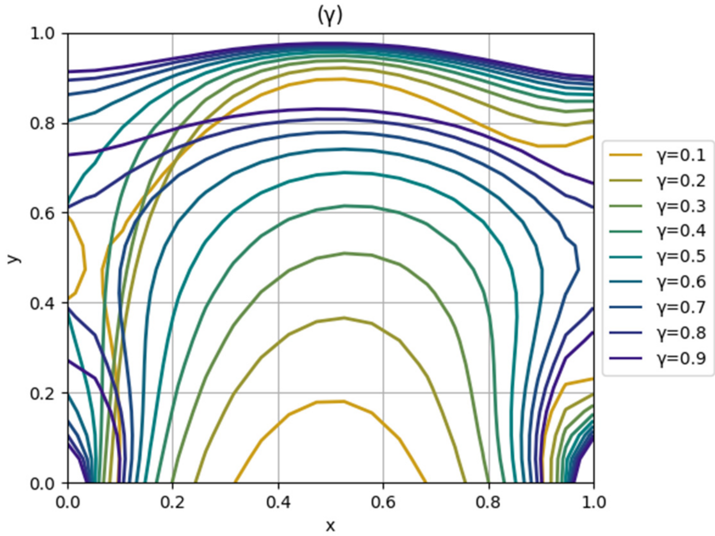

Figure 7. The effect of the resource taxes on the behavior evolution of multi-stakeholders.

5. Results and Discussion

Based on the above analysis and simulations, this section presents a spatial composition of multi-stakeholders in the C&DW recycling product industry under different development scenarios. It also suggests several policy implications that could be derived from these findings.

5.1. Research Findings

This research initially developed a multi-stakeholder evolutionary game model for theoretical examination, demonstrating that this dynamic system has two ESSs: (1) if $l_0 \leq 0$, then $(0, 0)$ is stable; (2) if $l_0 \geq 0$ then $(0, 1)$ is stable. When l_0 is under the relevant qualification, the simulation demonstrates that regardless of the initial strategies of the number of parties involved, they can ultimately converge to an ESS. Moreover, the numerical simulation investigates the impact of three crucial parameters on the evolution of multiple participants in the industry. Based on this simulation, the following key findings are discussed.

Many countries' industrial chain promoting C&DW recycling products is in the early stages of development. It confronts several challenges, including poor coordination among multi-stakeholders. Additionally, there is a chaotic array of management models, an incomplete industrial chain, and an imperfect management system. These factors make it difficult to achieve synergistic development relying solely on market orientation. Therefore, it is prominent to depend on the "invisible hand" of the government's macro-control. The government's "invisible hand" carries out macro-regulation and controls the synergistic development of the C&DW resourcing industry. To ensure the fulfillment of each stakeholder's self-interest within the chain, a shared value chain for promoting recycled products is established. This allows stakeholders to collaborate with one another, exchange information, and grow harmoniously, thereby achieving concurrent development across the C&DW management recycling industry chain. This is in line with the results of Wu et al. [38].

"Uncertainty in the market environment", "Mistrust among stakeholders" and "Lack of government support" are the three most significant barriers influencing the promotion of C&DW recycling. It is also noted that the second type of gaming subject, i.e., government departments, may choose strategy "N", which has a probability p to ignore the regeneration product; conversely, it has a probability of $(1 - p)$ to participate in the industry. Then, it charges the payoff value $\gamma(0 \leq \gamma \leq \alpha)$ for each first type of game subject with strategy "H", which means no effort. This could lead to them neglecting the progress of the C&DW recycling industry. Among the subjects of the second type of game, the government department that chooses a positive strategy does not penalize the government department that chooses a negative strategy. This indicates that different government departments lack oversight over one another. Consequently, each department determines independently whether to participate in the promotion of recycling construction waste based on its own operational requirements. According to stability analysis and simulation evolution studies, it has been proposed that if a government department opting for a positive strategy excludes a government department choosing a negative strategy, the former could incur a fixed cost. This exclusion would be in the form of foregone dividends from the recycling products. As a result, the outcomes for both departments would differ. At the outset of promoting C&DW recycling, if all stakeholders actively participate in the promotion and collaborate together, they will all benefit from the recycling process. However, if any stakeholder decides not to cooperate, the party that chooses to collaborate bears all of the consequences. This situation could lead to fear of loss among some stakeholders, resulting in their reluctance to cooperate. Therefore, relevant government departments should take a leading role and act as the guiding force for the efficient use of C&DW. They need to formulate policies and measures according to local conditions [39–41]. Furthermore, they must regulate the behavior of the main players and implement corresponding rewards or penalties for other key participants. This enables the relevant government departments to impose additional external incentives on related enterprises. This encourages them to actively participate in the resource utilization of C&DW. Stakeholders like construction companies, waste recycling plants, contractors, resource utilization companies, and the general public all need to make trade-offs between the benefits and costs of cooperation, as the gaming process involves continuous adjustments and adaptations. The decision of relevant government departments to supervise depends on the relationship between the values of the policy parameters. This relationship is influenced by the probability of participation by various enterprises and the public [42]. The utilization of resources by construction enterprises and public supervision primarily depends on the numerical relationship of the parameters. Realizing the recycling of C&DW and achieving positive social and environmental benefits is the ultimate goal.

Additionally, the sensitivity analysis of the three parameters indicates that two specific parameters, concerning government penalties for non-participation and the collection of proceeds, have a corresponding impact on the evolution of the strategy [43]. The higher the penalties or the resource tax, the fewer companies and purchasers opt out of the C&DW recycling product industry. Take the resource tax, for example: an increase in resource tax directly raises the production costs for enterprises involved in recycling construction waste. This because these companies are required to pay more in taxes. This could lead to a reduction in profits, which, in turn, affects their financial position and investment choices. The establishment of resource tax rates impacts the incentives for enterprises to produce and utilize recycled construction products. If the tax is set at a high enough level, it may encourage a shift towards using recycled materials to decrease tax expenses. Moreover, the level of resource tax can influence the competitiveness of the construction waste recycling industry. A lower tax rate might entice more companies to enter the market. Conversely, a higher rate could result in some enterprises exiting, thereby altering the industry's competitive dynamics. The high sensitivity of resource tax to change indicates that the government needs to adjust tax policies with caution. The aim is to prevent any detrimental effects on the supply chain for recycled construction products. At the same time, the government aims to foster efficient resource use and environmental conservation. Additionally, this sensitivity may drive enterprises to invest in technological advancements and process optimizations. These efforts are aimed at improving resource efficiency and lessening the tax burden, which, in turn, can enhance their competitive edge. In conclusion, the strong sensitivity of resource tax within the supply chain of recycled construction products signifies the tax policy. As such, it serves as a critical tool for fostering industry development and sustainable management. It is essential for both the government and enterprises to vigilantly monitor changes in tax policy. They should respond with appropriate measures. Therefore, the government's developed strategy significantly contributes to the development of the recycling industry for C&DW [44].

5.2. Policy Implications

C&DW recycling products are vital for advancing the sustainability of the construction industry, and the strategies of its stakeholders significantly impact this process. We propose some policy implications. Penalties and rewards are the crucial paraments effecting the decision-making behaviors of the prominent stakeholders of C&DW recycling products.

The government should set up a dynamic penalty and reward system to aid relevant enterprises the implementation of C&DW recycling products [45]. A heavier punishment can efficiently inspire these companies to alter their actions, while a minimal penalty might not be enough to encourage developers to adopt C&DW recycling products. Moreover, offering appropriate subsidies can prevent enterprises from becoming overly reliant on them and alleviate the government's financial pressure, as outlined in Section 4.2. This may perhaps be because when substantial financial incentives are provided by the government, enterprises may merely apply prefabrication practices to pursue private interests in developing C&DW recycling products. This study suggests formulating a penalty and reward system that can promote the gradual evolution of behavioral strategies among all stakeholders. The government should impose higher penalties and suitable incentives during the early stages of the C&DW recycling product industry to prompt developers to implement these products. In the mature stage, the social, economic, and environmental benefits of C&DW recycling projects foster a pure circle in related domains. Consequently, the government can slowly withdraw incentive strategies and determine an appropriate time to terminate the incentive policies for C&DW recycling schemes.

C&DW recycling is an important pathway to sustainable development. From Section 4.2, it can be concluded that the resource tax is sensitive and should be properly used by the government to manage the development of the construction waste resource industry. The imposition of a resource tax by the government plays an important role in this process. By imposing a resource tax, the economic attractiveness of C&DW recycling can be increased. This encourages businesses to reduce resource consumption at source and increases enthusiasm for recycling and resource utilization. The resource tax can provide the government with additional tax revenues. These revenues can be used to invest in environmental protection and circular economy projects, thereby further encouraging improvements in the level of construction waste management. Resource taxation improves the cost of resource use, reinforces the role of the market in the rational allocation of resources, and motivates companies to find alternative resources and use recycled materials. The recycling and reuse of construction waste contributes to reducing pollution caused by landfill and incineration. It can also reduce greenhouse gas emissions and achieve environmental protection objectives. However, the imposition of a resource tax on companies involved in the recycling and reuse of construction waste may increase their operating costs. Especially if the tax burden is high, this could reduce companies' profits. Furthermore, such a tax could discourage investment in recycling. If the method of resource tax collection is not appropriate, it could hit the fledgling construction waste recycling and reuse industry and stifle its healthy development. The imposition of the resource tax could lead to greater competitive inequality between companies with high resource efficiency and good cost control. Setting resource tax and collection standards for construction waste is quite complex and requires precise quantitative analysis and effective regulatory mechanisms. Otherwise, it may lead to increased enforcement difficulties and the reduced efficiency of resource tax collection.

In addition to more common forms of taxation and penalties, this text considers the costs of regulatory compliance. In an ideal scenario, where both government and corporate strategies are inclined towards active participation, it is possible to achieve a cost-optimal state, thereby generating positive externalities. However, in practice, the strategies of governments and businesses often diverge. Governments face a choice: to implement a strict regulatory strategy. This strategy may entail high costs and administrative burdens, and could even lead to corporate backlash [22]. Alternatively, they can adopt a lenient regulatory strategy. This approach relies on market conditions and corporate negotiations, which might reduce costs in the short term. However, in the long run, it could lead to negative externalities. These include constraints such as information asymmetry and transaction costs, potentially resulting in market failure and regulatory capture by businesses. Strict regulation may encourage businesses to improve transparency and compliance, but may also face resistance from firms regarding the costs involved. Conversely, lenient regulation may reduce immediate administrative costs, but it could result in long-term insufficient market regulation and potential market inefficiency. Therefore, the ideal state should be a balance between the intensity of regulation and cost-effectiveness, taking into account market reactions and potential long-term effects [46]. This approach avoids the unnecessary costs that could arise from strict regulation and the oversight of necessary market supervision that might occur from lenient regulation. Consequently, it leads to a mixed regulatory approach to foster healthy and orderly market development.

These findings highlight the significance of affordability in government penalties, resource tax, and regulatory compliance. Since the sensitivity of relevant enterprises to low supervision costs is not strong enough, it remains unknown whether the supervision costs can contribute to increasing government oversight and decreasing information asymmetry among stakeholders. Although active government supervision raises public awareness of C&DW recycling products and enhances reputation, supervision costs do not play a crucial role in equilibrium evolution. Therefore, the government should avoid excessive expenditure on supervision costs. To make penalties more affordable, the government can manage the cost within a reasonable limit and set up a behavior evaluation system. It can motivate enterprises to achieve self-discipline, leading to sustainable supervision. Enterprises' endorsement serves as a motivating factor for encouraging both the government and relevant enterprises to adopt C&DW recycling products. The government should intensify public education to stimulate market demand. In turn, negative public perceptions can be alleviated, and public confidence in C&DW recycling products can be gradually enhanced. Moreover, unless there are ample incentives, a defensive shared perception of C&DW recycling products persists. The government should allocate special funds to C&DW recycling product technology and public information services and increase financial subsidies for contractors opting for C&DW recycling products.

6. Conclusions and Limitations

The behavioral decisions of multi-stakeholders will impact the development of C&DW recycling products, but there is a scarcity of quantitative research exploring the behavioral strategies of stakeholders involved in C&DW recycling products. This study establishes a multiple evolutionary game model that engages different government regulators and various related enterprises, which are divided into two groups. The model is designed to examine their long-term behaviors and strategy adjustment mechanisms. The analysis demonstrates how the government assumes various roles at distinct phases of the C&DW recycling product industry's lifecycle. To foster the systematic and sustainable growth of the sector, the government should adopt targeted measures based on the unique traits of the C&DW recycling market.

Additionally, government-related parameters like penalty, resource tax, and supervision costs significantly influence multi-stakeholders' decision-making. The penalties from the government and resource taxes from others can determine the behavior strategies of related enterprises, increasing the ratio of those who choose C&DW recycling products as a stable state. But supervision costs did not contribute to the advancement of the optimal solution for multi-stakeholder issues. Escalating penalties and imposing resource taxes on others could boost the government's regulatory enthusiasm, thus increasing the enthusiasm of related enterprises in opting for C&DW recycling products.

The aim of this research is to offer direction to the multi-stakeholders involved in the C&DW recycling product industry. It places a particular focus on the government. Throughout the industry's different phases, stakeholders are affected by their obligations and interests. They continuously adapt their behavioral strategies. This study helps to clarify the connection between stakeholders' decision-making behaviors and the development of C&DW recycling products. As a result, this paper contributes to enhancing the government's promotion mechanism. It provides a theoretical foundation for regulating related enterprises' behavioral strategies and aiding multi-stakeholders in making long-term decisions.

The recycling of construction waste can create economic opportunities by generating revenue from waste disposal fees, and by creating jobs in the recycling and waste management sectors. This can lead to cost savings for construction companies and increase economic activity, with ripple effects on the broader economy. As the global community becomes more aware of the importance of circular economy principles, governments around the world are implementing policies that encourage or mandate the recycling and reuse of construction waste. The successful implementation of such policies can set precedents for other sectors and countries, promoting a global shift towards more sustainable waste management practices. The global significance of construction waste recycling extends to the social realm, where public awareness campaigns and educational initiatives can encourage more sustainable consumption and waste disposal behaviors. This can lead to a cultural shift towards greater environmental responsibility and stewardship. In summary, the global significance of the evolutionary game of stakeholders in the recycling of construction waste lies in its potential to contribute to environmental sustainability, resource efficiency, economic growth, policy development, technological innovation, and social change on a worldwide scale.

This paper investigated multi-stakeholders' decision-making processes and consistent strategies across various situations in the C&DW recycling product sector. Nevertheless, this assessment only took into account a few key factors influencing stakeholder choices. Additionally, this paper studied deterministic evolutionary game dynamics analysis; such evolutionary game models usually ignore the widespread randomness and uncertainty that exists in the real world. In the future, we will incorporate additional determinants into the game theory model by incorporating case studies, and we will conduct a stochastic evolutionary game dynamics analysis to study a network stochastic game model combined with reinforcement learning theory and robust learning theory.

Author Contributions: Y.W., L.Q. and W.C. conceived and planned the review. Y.W., L.Q. and W.C. performed the search and analyzed the data. Y.W. and L.Q. wrote the paper. Y.W., L.Q. and W.C. critically revised the article. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

Nomenclature

Nomenclature			
G	Enterprises' positive strategy	n	Total number of players
H	Enterprises' negative strategy	σ	Net cost, RMB
M	Government's positive strategy	k	Multiplying factor
N	Government's negative strategy	α	Government penalties for enterprises, RMB
ω	Weighting of enterprises	β	Supervision costs to the government, RMB
$1-\omega$	Weighting of government	γ	Resource tax, RMB
d	The effort involved in choosing the G and M strategy		
Acronyms			
C&DW	Construction and demolition waste	ESS	Evolutionarily stable strategy

References

1. Ding, Z.K.; Zhang, Z.Y.; Chen, W.L.; Duan, L. Counter-stereotype intervention for construction and demolition waste recycling products: A functional near infrared spectroscopy study. *J. Clean Prod.* **2023**, *407*, 9. [CrossRef]
2. Kabirifar, K.; Mojtahedi, M.; Wang, C.X.; Tam, V.W.Y. Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review. *J. Clean Prod.* **2020**, *263*, 16. [CrossRef]
3. Maier, D. The use of wood waste from construction and demolition to produce sustainable bioenergy-a bibliometric review of the literature. *Int. J. Energy Res.* **2022**, *46*, 11640–11658. [CrossRef]
4. EPA. Sustainable Management of Construction and Demolition Materials. Available online: https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials (accessed on 15 October 2023).
5. Duan, H.B.; Miller, T.R.; Liu, G.; Tam, V.W.Y. Construction debris becomes growing concern of growing cities. *Waste Manag.* **2019**, *83*, 1–5. [CrossRef] [PubMed]
6. Envirunion Construction Waste Treatment Industry 2018 Annual Development Report of China. Available online: http://www.envirunion.com/newsinfo-14398.html (accessed on 15 October 2023).
7. Liu, J.K.; Gong, E.Q.; Wang, X.T. Economic benefits of construction waste recycling enterprises under tax incentive policies. *Environ. Sci. Pollut. Res.* **2022**, *29*, 12574–12588. [CrossRef]
8. Ma, L.; Zhang, L. Evolutionary game analysis of construction waste recycling management in China. *Resour. Conserv. Recycl.* **2020**, *161*, 10. [CrossRef]
9. Su, Y.Y.; Si, H.Y.; Chen, J.G.; Wu, G.D. Promoting the sustainable development of the recycling market of construction and demolition waste: A stakeholder game perspective. *J. Clean Prod.* **2020**, *277*, 15. [CrossRef]
10. Khalil, K.H. *Nonlinear Systems*; Prentice-Hall: Upper Saddle River, NJ, USA, 1996.
11. Liu, H.M.; Tang, Y.M.; Iqbal, W.; Raza, H. Assessing the role of energy finance, green policies, and investment towards green economic recovery. *Environ. Sci. Pollut. Res.* **2022**, *29*, 21275–21288. [CrossRef]
12. Guo, F.; Wang, J.W.; Song, Y.H. How to promote sustainable development of construction and demolition waste recycling systems: Production subsidies or consumption subsidies. *Sustain. Prod. Consump.* **2022**, *32*, 407–423. [CrossRef]
13. Shen, L.; Zhang, Z.K.; Tang, L.Y. Research on Determining Resource Utilization Rates of Regional Construction and Demolition Waste from the Perspective of Collaborative Governance. *KSCE J. Civ. Eng.* **2023**, *27*, 27–39. [CrossRef]
14. Xiao, Y.Y.; Zuo, X.R.; Huang, J.Y.; Konak, A.; Xu, Y.C. The continuous pollution routing problem. *Appl. Math. Comput.* **2020**, *387*, 19. [CrossRef]
15. Yuan, J.; Lei, D.L.; Shan, Y.; Tong, H.W.; Fang, X.T.; Zhao, J.T. Direct Shear Creep Characteristics of Sand Treated with Microbial-Induced Calcite Precipitation. *Int. J. Civ. Eng.* **2022**, *20*, 763–777. [CrossRef]
16. Xu, L.F.; Liu, X.; Tong, D.; Liu, Z.X.; Yin, L.R.; Zheng, W.F. Forecasting Urban Land Use Change Based on Cellular Automata and the PLUS Model. *Land* **2022**, *11*, 652. [CrossRef]
17. Liu, J.K.; Teng, Y.; Jiang, Y.H.; Gong, E.Q. A cost compensation model for construction and demolition waste disposal in South China. *Environ. Sci. Pollut. Res.* **2019**, *26*, 13773–13784. [CrossRef] [PubMed]
18. Wang, J.Y.; Wu, H.Y.; Tam, V.W.Y.; Zuo, J. Considering life-cycle environmental impacts and society's willingness for optimizing construction and demolition waste management fee: An empirical study of China. *J. Clean Prod.* **2019**, *206*, 1004–1014. [CrossRef]
19. Wang, Z.L.; Li, H.; Zhang, X.L. Construction waste recycling robot for nails and screws: Computer vision technology and neural network approach. *Autom. Constr.* **2019**, *97*, 220–228. [CrossRef]
20. Liu, J.K.; Li, Y.X.; Wang, Z.S. The potential for carbon reduction in construction waste sorting: A dynamic simulation. *Energy* **2023**, *275*, 14. [CrossRef]
21. Du, L.; Feng, Y.B.; Lu, W.; Kong, L.K.; Yang, Z. Evolutionary game analysis of stakeholders' decision-making behaviours in construction and demolition waste management. *Environ. Impact Assess. Rev.* **2020**, *84*, 11. [CrossRef]
22. Su, Y.B. Multi-agent evolutionary game in the recycling utilization of construction waste. *Sci. Total Environ.* **2020**, *738*, 10. [CrossRef]

23. Sukholthaman, P.; Sharp, A. A system dynamics model to evaluate effects of source separation of municipal solid waste management: A case of Bangkok, Thailand. *Waste Manag.* **2016**, *52*, 50–61. [CrossRef]
24. Shen, H.; Peng, Y.; Guo, C.X. Analysis of the Evolution Game of Construction and Demolition Waste Recycling Behavior Based on Prospect Theory under Environmental Regulation. *Int. J. Environ. Res. Public Health* **2018**, *15*, 1518. [CrossRef]
25. Khanzadi, M.; Eshtehardian, E.; Chalekaee, A. A game theory approach for optimum strategy of the owner and contractor in delayed projects. *J. Civ. Eng. Manag.* **2016**, *22*, 1066–1077. [CrossRef]
26. Fan, R.G.; Dong, L.L.; Yang, W.G.; Sun, J.Q. Study on the optimal supervision strategy of government low-carbon subsidy and the corresponding efficiency and stability in the small-world network context. *J. Clean Prod.* **2017**, *168*, 536–550. [CrossRef]
27. Gao, L.; Zhao, Z.Y. The Evolutionary Game of Stakeholders' Coordination Mechanism of New Energy Power Construction PPP Project: A China Case. *Sustainability* **2020**, *12*, 1045. [CrossRef]
28. Qiao, X.; Lee, H.; Shen, Q.; Li, Y.C. Research on the Tripartite Evolutionary Game of Zero-Waste City Construction in China. *Sustainability* **2023**, *15*, 10507. [CrossRef]
29. Ding, Z.K.; Nie, W.Q.; Wu, H.Y. Investigating the connection between stakeholders' purchase intention and perceived value of construction and demolition waste recycled products. *Environ. Dev. Sustain.* **2022**, *24*, 9285–9303. [CrossRef]
30. Dong, H.Z.; Song, H.L. Research on Duplication Dynamics and Evolutionary Stable of Reverse Supply Chain. *Int. Conf. Appl. Phys. Ind. Eng. (ICAPIE)* **2012**, *24*, 705–709. [CrossRef]
31. Ji, P.; Ma, X.; Li, G. Developing green purchasing relationships for the manufacturing industry: An evolutionary game theory perspective. *Int. J. Prod. Econ.* **2015**, *166*, 155–162. [CrossRef]
32. Chen, J.G.; Hua, C.X.; Liu, C.Y. Considerations for better construction and demolition waste management: Identifying the decision behaviors of contractors and government departments through a game theory decision-making model. *J. Clean Prod.* **2019**, *212*, 190–199. [CrossRef]
33. Tian, Y.H.; Govindan, K.; Zhu, Q.H. A system dynamics model based on evolutionary game theory for green supply chain management diffusion among Chinese manufacturers. *J. Clean Prod.* **2014**, *80*, 96–105. [CrossRef]
34. Wang, Z.; Wang, Q.X.; Chen, B.X.; Wang, Y. Evolutionary game analysis on behavioral strategies of multiple stakeholders in E-waste recycling industry. *Resour. Conserv. Recycl.* **2020**, *155*, 9. [CrossRef]
35. Huang, F. Game System Dynamics and Learning Theory Research. Ph.D. Thesis, Peking University, Beijing, China, 2023.
36. Sasaki, T.; Uchida, S. The evolution of cooperation by social exclusion. *Proc. R. Soc. B-Biol. Sci.* **2013**, *280*, 7. [CrossRef]
37. Sasaki, T.; Brännström, Å.; Dieckmann, U.; Sigmund, K. The take-it-or-leave-it option allows small penalties to overcome social dilemmas. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 1165–1169. [CrossRef]
38. Wu, Z.Z.; Yang, K.J.; Xue, H.; Zuo, J.; Li, S.H. Major barriers to information sharing in reverse logistics of construction and demolition waste. *J. Clean Prod.* **2022**, *350*, 14. [CrossRef]
39. Athari, S.A.; Kirikkaleli, D.; Wada, I.; Adebayo, T.S. Examining the sectoral credit-growth nexus in australia: A time and frequency dynamic analysis. *Econ. Comput. Econ. Cybern. Stud.* **2021**, *55*, 69–84. [CrossRef]
40. Mak, T.M.W.; Yu, I.K.M.; Wang, L.; Hsu, S.C.; Tsang, D.C.W.; Li, C.N.; Yeung, T.L.Y.; Zhang, R.; Poon, C.S. Extended theory of planned behaviour for promoting construction waste recycling in Hong Kong. *Waste Manag.* **2019**, *83*, 161–170. [CrossRef]
41. Yu, A.T.W.; Wong, I.; Wu, Z.Z.; Poon, C.S. Strategies for Effective Waste Reduction and Management of Building Construction Projects in Highly Urbanized Cities-A Case Study of Hong Kong. *Buildings* **2021**, *11*, 214. [CrossRef]
42. Bruce, K.; Costa, H. Enabling environment for PPPs in agricultural extension projects: Policy imperatives for impact. *J. Rural Stud.* **2019**, *70*, 87–95. [CrossRef]
43. Hermans, F.; Geerling-Eiff, F.; Potters, J.; Klerkx, L. Public-private partnerships as systemic agricultural innovation policy instruments—Assessing their contribution to innovation system function dynamics. *NJAS-Wagen. J. Life Sci.* **2019**, *88*, 76–95. [CrossRef]
44. Su, X.N.; Liu, P.F.; Mei, Y.D.; Chen, J.R. The role of rural cooperatives in the development of rural household photovoltaics: An evolutionary game study. *Energy Econ.* **2023**, *126*, 19. [CrossRef]
45. Feng, L.; Wu, Q.M.; Wu, W.J.; Liao, W.J. Decision-Maker-Oriented VS. Collaboration: China's Public Participation in Environmental Decision-Making. *Sustainability* **2020**, *12*, 1334. [CrossRef]
46. Wang, J.; Ye, Q.Y. Evolutionary game analysis of multi-stakeholders in the WEEE recycling industry under propaganda subsidies and environmental damage taxes. *Waste Manag.* **2024**, *175*, 157–169. [CrossRef]