Evolutionary Game Model Study of Construction Green Supply Chain Management under the Government Intervention

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Abstract. The paper first has defined the concepts of green supply chain management and evolution game theory, and pointed out the characteristics of green supply chain management in construction. The main participants and key links of the construction green supply chain management are determined by constructing the organization framework. This paper established the evolutionary game model between construction enterprises and recycling enterprises for the green supply chain closed-loop structure. The waste recycling evolutionary stability equilibrium solution is obtained to explore the principle and effective scope of government policy intervention. This paper put forward the relevant countermeasures to the green supply chain management in construction recycling stage from the government point of view. The conclusion has reference value and guidance to the final product construction enterprises, recycling enterprises and the government during green supply chain.

1. Introduction

Not only do the construction industries consume a lot of energy and resources, but it also cause serious pollution to the environment. Green supply chain management has become an inevitable trend in the development of the construction industry due to its characteristics of low energy consumption, health and environmental protection. Relevant charges for waste generated by reverse logistics have described among the environmental laws that have been enacted in many industrial countries in Europe. For example, IBM transnational enterprise has taken a series of measures to the supply chain system. Nowadays, Chinese construction industries lack of effective energy-saving environmental protection system. GSCM can make an organic combination of all participants in the supply chain to realize the environmental impact management of the whole life cycle of construction industry. The related research is still at the initial stage. Most current researches focused on the optimization and simulation of the supply model, but lack the evolutionary game analysis of the closed-loop operation structure for the green supply chain. The organizational structure model of construction green supply chain management was established to analyse the enterprise's strategic behaviour of the closed-loop structure in supply chain. It can provide the government with a theoretical basis for policy formulation and make the construction-related enterprises to carry out policy guidance. It is of great significance for the construction industry energy-saving emission reduction and economic sustainable development.

2. Literature review

From the domestic and foreign research literature, the issues about green supply chain management and construction have also made some progress. Geoffrey Hagelaar and J-vander Vorst [1] pointed out that the best way to analyse green supply chain is life cycle analysis (LCA). Purba Rao [2] investigated the practice of green supply chain in Southeast Asia, and proposed that business, society and the public should create a good environment for the implementation of green supply chain. Qinghua Zhu and Joseph Sarkis[3] surveyed 186 Chinese manufacturing enterprises and concluded that the implementation of GSCM could help improve environmental and economic benefits. Handfield R, Sroufe R and Walton S [4] developed a green supply chain strategy decision frame model from the survey in US, UK, Japan and Korea, and provided a reference for the development of green supply chain. Vachon et al. [5] concluded that the partnership for green projects in the supply chain operations was related to five performance indicators, based on the survey data from the packaging and printing industries in Canada and the United States. Hsu CW et al.[6] applied the concept of hazardous substance management to the supplier selection process in the green supply chain to build a multi-objective decision model. Pishvaee MS et al.[7] proposed a two-way target mixed integer programming model based on green supply chain closed-loop business processes and environmental factors. Hui-Ming Weea[8] and Andrei Kostin [9] detailed the green supply chain management approach and the popularity of renewable energy. George Ofori [10] pointed out that Singapore's construction industry is moving in the direction of green supply chain management. Marcus Wagner and Stefan Schaltegger[11] provided a method for selecting and evaluating members of the green building supply chain using the DEA approach. Hong IH et al.[12] explored the problem of recycling costs and government subsidy decision-making in the reverse supply chain of electronic products, and constructed the Stackelberg game between the government and manufacturers. Sheu JB[13] used the asymmetric Nash bargaining game method of uncertainty to study the negotiation and cooperation between the recyclers and the producers in the green supply chain under the government financial intervention. At present, the research on the reverse logistics of the construction industry is still relatively small. According the evolutionary game model between construction enterprises and waste recycling enterprises, this paper focused on the characteristics of the green supply chain management in the closed-loop structure of the construction industry supply chain.

3. Related concepts

3.1 Green Supply Chain Management

The concept of Green Supply Chain Management (GSCM) was first proposed by Michigan State University's Manufacturing Research Association in 1996 during an "Environmental Responsibility Manufacturing (ERM)" study. GSCM is a modern comprehensive management model that takes the environmental impacts, resources and efficiency into account in the entire supply chain. GSCM shows consideration for the owner’s or customer’s demand based on green construction theory and supply chain management technology. It involves designers, contractors, suppliers and other entities. The purpose is to make the building products from the design, material acquisition and construction, use to scrap processing during the entire supply chain process, the negative impact on the environment the smallest, the highest efficiency of resources.

3.2 Evolutionary Game Theory

Evolutionary Game Theory supposed that the participants of the game are bounded rational and reflected in three aspects: Participants do not always discover changes in the environment, and then choose the right optimal strategy. Participants only consider short-term gains when adjusting strategy. Due to the influence of random factors, there are "irrational" variation strategies in the game. Replicator dynamics refer to a strategy in which the result is better than the average level in the group composed of bounded rational game players, which will gradually be adopted by more players, so the proportion of the game parties in the group will change. Replicator dynamics model assumed that it is

in an infinite and mixed homogeneous population. There are n strategies, x_i is the frequency of the strategy i in the population, $F_i(x)$ represents the adaptability of strategy i when the system state is x, $\overline{F}(x)$ represents the average adaptability of the population under system state x. The replicator dynamics equation of the evolution of the population strategy is

$$x_i = x_i\left(F_i(x) - \overline{F}(x)\right) \tag{1}$$

Evolutionary Stabilization Strategy (ESS) means that if the majority of members of the population choose a certain strategy, there is no strategy with a mutated feature to produce higher adaptability.

4. Construction Green Supply Chain Management Model

4.1 Characteristics of Construction Green Supply Chain Management

The construction waste into recycled materials through recycling, screening, re-processing, and then into the supply chain again, forming a closed-loop structure, so that all kinds of materials circulated in the supply chain can achieve the full life cycle management of building products to maximize the use of resources. It can reduce resource inputs, lower inventory costs, and make additional value. Green supply chain is consistent with environmental policies and regulations can improve customer satisfaction, establish a corporate image and increase the intangible assets of enterprises. The environmental impact management control carried out from the beginning of the supply chain. The environmental protection focuses on the source control rather than the End-of-Pipe control. It is conducive to the full use of resources through the sharing of information between the upstream and downstream enterprises in the supply chain. GSCM focused on information communication and resources sharing in upstream and downstream enterprise.

4.2 The main participants in the Construction Green Supply Chain Management

Construction unit: the sponsor of the construction project who put forward sustainable requirements on the construction design, production, waste recycling and other processes, guides the design unit and the construction unit for green design and green production. *Design unit:* design construction projects according to the requirements of the owners, and have a decisive role for the performance of building products. *Construction enterprises:* directly involved in the production of building products, construction materials equipment procurement, construction process, construction waste recycling process, including general contractors and subcontractors. *Construction waste recycling enterprises:* including construction waste recycling and reprocessing centre. Recycling enterprises make the construction waste be re-entered the construction productive process by recycling, thereby reducing the environmental impact and improving resource utilization.

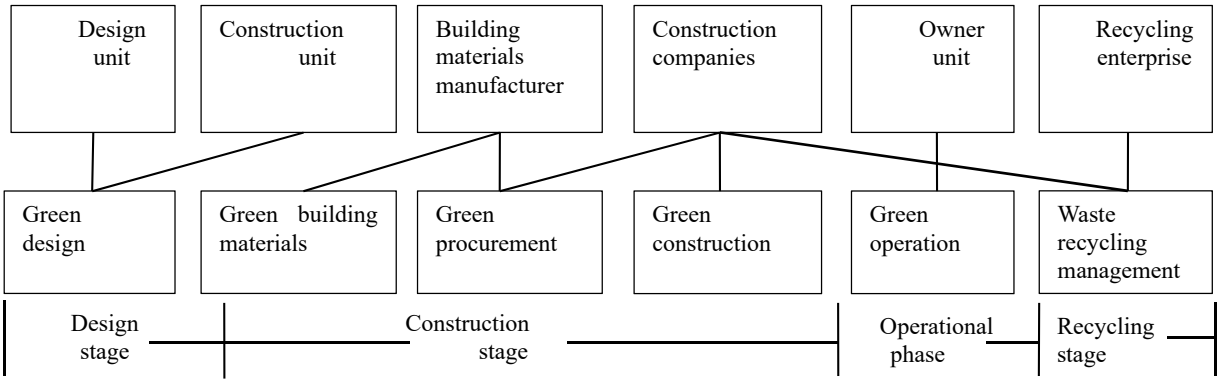

Figure 1. Construction green supply chain management operation process chart.

4.3 Organizational Framework of Construction Green Supply Chain Management

4.3.1.Operation Process of Construction Green Supply Chain Management. From the perspective of the whole life cycle of building products, the operation process of Green Supply Chain Management in construction industry is shown in Figure 1, including green design, green building materials, green procurement, green construction, green operation and waste recycling management. The main participants in all aspects are not single, only if the all parties coordinate, cooperation and mutual game can it achieve green supply chain management.

4.3.2.Organizational Structure of Construction Green Supply Chain Management. The organizational structure of Construction Green Supply Chain Management shown in Figure 2, in the figure the solid line arrow indicates logistics direction; dotted line arrow indicates information communication. There are eight major members in the construction green supply chain management organizational structure, including the building materials manufacturers, equipment suppliers, construction enterprises, construction units, design units, supervision units, recycling units and the government. There are no logistics through the government. The role of government is to monitor other participants. When the system lack of motivation, the government will use policies encourage the construction industry to implement green supply chain management. The construction unit as the project sponsor and the investor, the construction project information was originally issued from the construction unit. In the procurement process, decision-making of construction companies can affect building materials manufacturers and equipment suppliers, and the behaviour of building materials manufacturers and equipment suppliers can limit the decision-making of building enterprises as well. The supply chain eventually forms a closed-loop supply chain structure through forward logistics and reverse logistics.

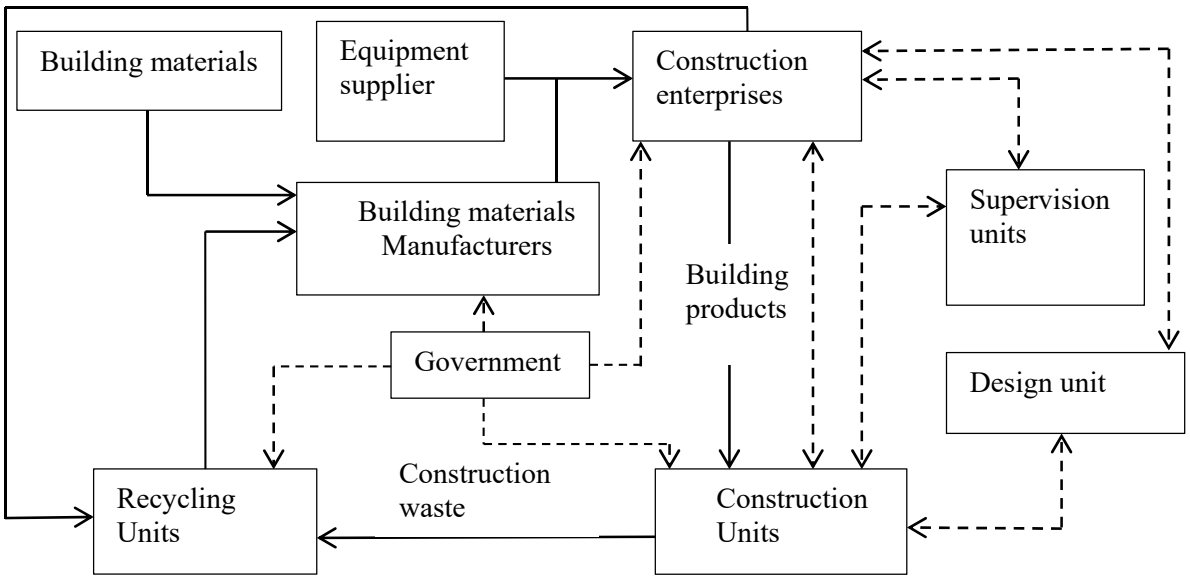

Figure 2. Construction green supply chain management organizational structure chart.

5. Evolutionary Game Analysis between Construction Enterprises and Recycling Enterprises in the supply chain closed-loop structure

The construction waste recycling is the key to the closed-loop structure of the construction green supply chain. It is the starting point of the reverse logistics and the necessary link of the construction industry resource recycling and the environmental pollution reduction. The main participants in the recycling phase are construction enterprises and recycling enterprises. In the operation of the construction project, construction enterprises sell construction waste to recycling enterprises. Recycling enterprises make the construction waste screening and regeneration treatment, so that it can in the form of recycled materials to re-enter forward logistics for the construction production process.

5.1Evolutionary Game Model under government intervention

It is supposed that the high price recycling waste's cost is c_1 , and its income is s_1 ; suppose the low price recycling waste's cost is c_2 , and its income is s_2 . If the construction enterprises choose to recycle, will pay the recovery cost c_r . When the waste is high price recycled by the recycling enterprise, the construction enterprise will receive the profit R_1 ; while the waste is low price recycled by the recycling enterprise, the construction enterprise will receive the profit R_2 ; if the construction enterprises choose recycle none, need to pay the landfill cost c_b . The government supervises the recycling of construction waste. Assuming that the construction industries will receive government subsidies z_g when choose recycle the waste; and the construction industries will pay a fine f_g to the government while choose no recycle the waste. By model assumptions, evolutionary game income matrix of recycling enterprises and construction enterprises under the government intervention can be obtained. As shown in Table 1.

Table 1. Income matrix between recycling enterprise and construction enterprise under governmental intervention.

		construction enterprise recycle	Non recycle
Recycling enterprise	High-price	（s_1- c_1 , R_1–c_r+z_g）	（0,－c_b－f_g）
	low-price	（s_2-c_2 , R_2-c_r+z_g）	（0,－c_b－f_g）

It is supposed that the probability is x when the waste was high price recycled by the recycling enterprise, and the probability is $1-x$ while the waste is low price recycled by the recycling enterprise. If the probability is y when the construction enterprise choose to recycle, and the probability is $1-y$ while the construction enterprise choose to recycle none.

It is supposed that the expected earning is u_{r1} when the waste was high price recycled by the recycling enterprise, and the expected earning is u_{r2} while the waste is low price recycled by the recycling enterprise; the average expected earning is $\overline{u_r}$.

$$u_{r1} = y(s_1 - c_1) \tag{2}$$

$$u_{r2} = y(s_2 - c_2) \tag{3}$$

$$\overline{u_r} = xy(s_1 - c_1) + y(1-x)(s_2 - c_2) \tag{4}$$

It is supposed that the expected earning is u_{cr} when the construction enterprise chooses to recycle, and the expected earning is u_{cb} while the construction enterprise chooses not to recycle, the average expected earning is $\overline{u_c}$.

$$u_{cr} = x(R_1 - c_r + z_g) + (1-x)(R_2 - c_r + z_g) \tag{5}$$

$$u_{cb} = -c_b - f_g \tag{6}$$

$$\overline{u_c} = y[x(R_1 - c_r + z_g) + (1-x)(R_2 - c_r + z_g)] - (1-y)(c_b + f_g) \tag{7}$$

5.2 Dynamic evolutionary game stability strategy analysis

（1）when recycling enterprises choose high-priced recycle, the replicator dynamics equation as shown below

$$\begin{aligned} F_{(x)} &= \frac{dx}{dt} \\ &= x(u_{r1} - \overline{u_r}) \\ &= x[y(s_1 - c_1) - xy(s_1 - c_1) - y(1-x)(s_2 - c_2)] \\ &= xy(1-x)(s_1 - c_1 - s_2 + c_2) \end{aligned} \tag{8}$$

When $y = 0$ or $s_1 - c_1 - s_2 + c_2 = 0$, $F_{(x)} \equiv 0$ can be obtained, at this point the game is stable state regardless of x take any value.

When $y \neq 0$ or $s_1 - c_1 - s_2 + c_2 \neq 0$, Suppose $F_{(x)} = 0$, got $x_1 = 0$, $x_2 = 1$ are two possible stabilization points of x.

As long as there is no mutant who can change the opposite strategy, the strategy of recycling enterprise will be stable at low price recycle or high price recycle.

Derivation of $F_{(x)}$,

$$F'_{(x)} = \frac{dF_{(x)}}{dx} = (1-2x)y(s_1 - c_1 - s_2 + c_2) \tag{9}$$

Evolutionary Stability Strategy（ESS） requires $F'_{(x)} < 0$ .Since $y > 0$, $s_1 - c_1 - s_2 + c_2$ is discussed.

When $s_1 - c_1 - s_2 + c_2 > 0$, got $F'_{(x)} \,/_{x=0} > 0$, $F'_{(x)} \,/_{x=1} < 0$.

So $x = 1$ is the stability point. Recycling companies will eventually tend to recycle the waste at high prices.

When $s_1 - c_1 - s_2 + c_2 < 0$, got $F'_{(x)} \,/_{x=1} > 0$, $F'_{(x)} \,/_{x=0} < 0$.

So $x = 0$ is the stability point.Recycling enterprise will eventually tend to recycle the waste at low price.

（2）when construction enterprises choose to recycle the waste, the replicator dynamics equation as shown below

$$\begin{aligned} F_{(y)} &= \frac{dy}{dt} \\ &= y(u_{r1} - \overline{u_r}) \\ &= y(1-y)\left[x(R_1 - R_2) + R_2 - c_r + c_b + f_g + z_g\right] \end{aligned} \tag{10}$$

When $x = \frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2}$, $F_{(y)} \equiv 0$ can be obtained, at this point the game is stable state regardless of *x* take any value.

When $x \neq \frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2}$, Suppose $F_{(y)} = 0$, got $y_1 = 0$, $y_2 = 1$ are two possible stabilization points of x.

As long as there is no mutant which can change the opposite strategy, the strategy of construction enterprise will be stable at recycle or recycle none.

Derivation of $F_{(y)}$,

$$F'_{(y)} = \frac{dF_{(y)}}{dy} = (1-2y)\left[x(R_1 - R_2) + R_2 - c_r + c_b + f_g + z_g\right] \tag{11}$$

Evolutionary Stability Strategy（ESS） requires $F'_{(y)} < 0$.

When $x > \frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2}$,got $F'_{(y)} \,/_{y=0} > 0$, $F'_{(y)} \,/_{y=1} < 0$.

So $y = 1$ is the stability point. Construction companies will eventually tend to recycle the waste.

When $x < \frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2}$, got $F'_{(y)} \,/_{y=1} > 0$, $F'_{(y)} \,/_{y=0} < 0$.

So $y = 0$ is the stability point. Construction companies will eventually tend to recycle none.

5.3 Evolutionary equilibrium stability analysis

Five equalization points are obtained from $F_{(x)} = 0, F_{(y)} = 0$. (0, 0), (0, 1), (1, 0) and (1, 1) formed the boundary of evolutionary game, the internal equilibrium point (x^*, y^*) meets the equations as below

$$\begin{aligned} xy(1-x)(s_1 - c_1 - s_2 + c_2) = 0 \\ y(1-y)\left[x(R_1 - R_2) + R_2 - c_r + c_b + f_g + z_g\right] = 0 \end{aligned} \tag{12}$$

Got $$x^* = \frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2}, y^* = 0 \tag{13}$$

According to the relationship of the cost and benefit in different strategies, there are two cases about the evolution of the strategy between the recycling enterprise and the construction enterprise.

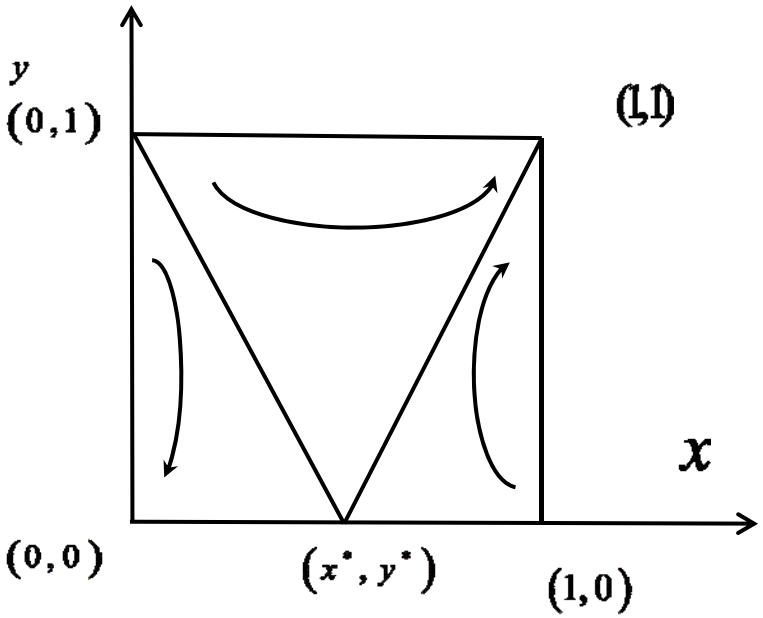

Figure 3. Combination strategy evolution diagram of recycling enterprises and construction enterprises under governmental intervention（I）

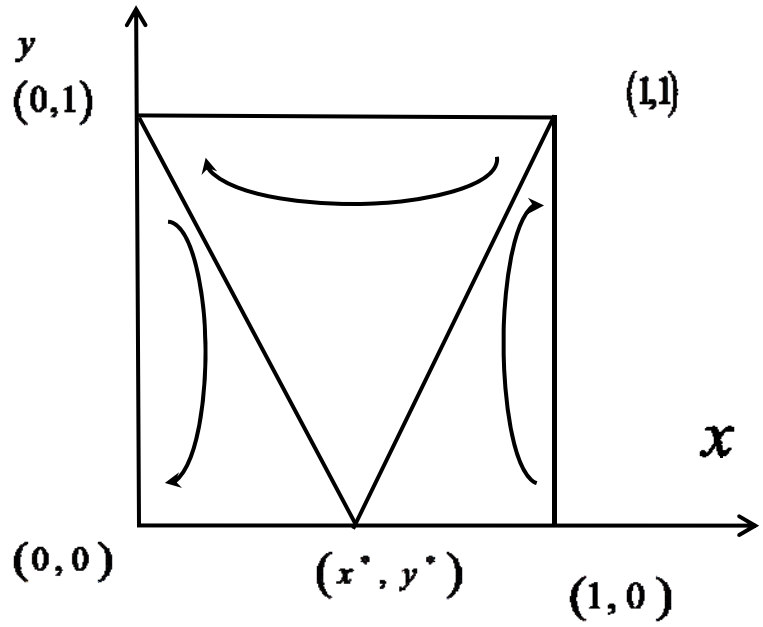

Figure 4. Combination strategy evolution diagram of recycling enterprises and construction enterprises under governmental intervention（II）

When $s_1 - c_1 - s_2 + c_2 > 0$, the evolution analysis of portfolio strategy of recycling enterprises and construction enterprises under the government intervention is shown in Figure 3.

When $s_1 - c_1 - s_2 + c_2 < 0$, the evolution analysis of portfolio strategy of recycling enterprises and construction enterprises under the government intervention is shown in Figure 4.

The analysis results show that the cost and benefit of the enterprise are the main influencing factors of the evolutionary game decision of the recycling enterprise and the construction enterprise in the case of government intervention. The decision of the recycling enterprise is not affected by the proportion of waste recycling in the construction business.

（1）When $s_1 - c_1 - s_2 + c_2 > 0$, recycling companies choose to carry out high-price recycling. At this situation, the profits of high-price recycle are higher than the low-cost recycle.

When $c_r - R_2 - c_b - z_g - f_g < 0$, has been able to get $x > \frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2}$, construction companies finally tend to choose recycle.

When $R_1 = c_r - c_b - z_g - f_g$, $\frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2} = 1$, got $x < \frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2}$, construction companies tend to never recycle.

（2）When $s_1 - c_1 - s_2 + c_2 < 0$, recycling companies choose to carry out low-cost recycling. At this situation, the profits of high-priced recycle are lower than the low-cost recycle.

When $c_r - R_2 - c_b - z_g - f_g < 0$, got $x > \frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2}$, construction enterprises finally tend to choose to recycle.

When $R_1 = c_r - c_b - z_g - f_g$, $\frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2} = 1$, $x < \frac{c_r - R_2 - c_b - z_g - f_g}{R_1 - R_2}$ can be obtained, construction enterprise finally tends to choose not recycle.

6. Government countermeasures in construction green supply chain management

6.1 Focus on cultivating professionals

From a technical perspective, the government provides technical personnel training for enterprises to help promote the popularization of green building materials production and green operation technology. It can promote enterprise technological innovation, reduce the production and operation cost of enterprises and improve the core competitiveness of enterprises. GSCM needs enterprises to establish a sound management system to coordinate the operation of both parties inside and outside the enterprise. Perfect management system can reduce the cost, enhance corporate culture and create more value. The government should pay attention to the university education and make the university students as the focus of personnel training. The construction green supply chain management research investment be increased to attract overseas talent.

6.2 Improve the relevant laws and regulations

Participant's responsibility are clearly defined can restrain and control the participants, so as to avoid the management confusion. To facilitate the effective implementation of green supply chain management, the government and relevant departments need to establish and improve the standards of the green building materials and other products. A good institutional environment should be created to promote the development of related products market. For the different links of construction green supply chain, it recommended the introduction of specific laws and regulations and related specifications to constrain the behaviour of participants. To meet the sustainable development requirements, the construction project should gradually guide and standardize the construction industry's energy-saving emission reduction measures.

6.3 Formulate scientific policy incentives

According to the different market environment, the government can formulate scientific policies, effectively encourage enterprises and improve the viability of environment-friendly enterprises. Increase the market share of enterprise which implemented the green supply chain management method, can create a better market environment to promote the development of energy-saving emission reduction in the construction industry. As the game between the government and enterprises may have cyclical changes, it is necessary to grasp the characteristics of cyclical changes while maintain a smooth policy, and recommended the introduction of targeted measures to be guided. At the same time, in the process of policy formulation, enterprise should make flexible use of policy tools.

7. Conclusion

This paper defined the key links and key participants in the construction green supply chain management. An evolutionary game model was established for the construction enterprises and the recycling enterprises. The evolutionary stability equilibrium solution of the waste recycle in the case of different government financial intervention was discussed. According to the analysis of the game model, it is found that the decision of the recycling enterprise is not affected by the proportion of the waste recycling in the construction enterprise. There are still some problems that have not been discussed in the evolutionary game analysis of green supply chain management in construction industry. For example, the waste recycling game only considered the role of direct recycling. Recycling enterprise's recycling costs are not only affected by the waste recycling price, but also the nature of the waste itself. Other possible analyse techniques that might be employed for future research includes dynamic network equilibrium.

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