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Research on Green Express Packaging Pricing Decision Considering the Participation of Recyclers

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Abstract: The green recycling of green express packaging can not only reduce environmental pollution, reduce waste of resources, but also produce economic benefits. Based on the green express packaging pricing decision-making system composed of a single manufacturer, logistics enterprises and recyclers, this paper establishes the Stackelberg game model, studies the effect of the four subsidy strategies of no government subsidies, government subsidy manufacturers, government subsidy logistics enterprises and government subsidy recyclers under the government incentive measures, and then analyzes the profits of the participants through numerical simulation. The impact of the total profit of the system and social welfare. The results show that government subsidies can promote the recycling of green express packaging by recyclers; With the increase in the proportion of recyclers reselling green express packaging to manufacturers for dismantling and remanufacturing, the behavior of government subsidies to logistics enterprises is not conducive to the secondary recycling of green packaging, and government subsidies to recyclers are conducive to promoting the recycling of green express packaging; In the government's subsidy strategy, the profit and social welfare level of the entire decision-making system is highest in the case of subsidizing logistics companies and recyclers.

Keywords: Government subsidies, Green express packaging, Recovery pricing.

1. Introduction

In recent years, with the environmental crisis, people pay more and more attention to the issue of environmental protection, more and more attention to the development of green concepts, the continuous development of new technology makes more and more environmentally friendly materials for green packaging, effectively recycling green express packaging, not only the key issue of green express packaging promotion and use, but also an important link to improve China's express packaging recycling system. In recent years, China's express delivery business has grown rapidly, ranking first in the world for seven consecutive years, but the annual business increment of nearly 10 billion yuan has caused a lot of resource consumption and pollution problems. The secondary use and recycling of green express packaging, while effectively reducing environmental pollution and other problems, can also bring certain economic benefits to the society, realize the rational distribution of social resources, a large number of express waste packaging market has also spawned a number of recyclers, such as Dida recycling, etc., express packaging recycling has formed a huge market. In the recycling process of green express packaging, recyclers need to reasonably price green express packaging, improve consumers' motivation to return green express packaging, encourage consumers to return waste green express packaging at recycling points, and increase the recovery rate of green express packaging. After that, the waste green express packaging is classified and sorted, such as the green packaging with a low degree of damage or no traces of damage for secondary use and directly sold to logistics enterprises, while the seriously damaged green express packaging is directly handed over to the manufacturer for dismantling and remanufacturing, which improves the reuse of waste resources.

In this regard, the state has introduced many relevant policies to support the recycling of green express packaging, and a series of incentive policies of the government can not only effectively promote the development of green express packaging recycling, but also improve the recycling rate of waste resources, but different subsidy strategies produce different effects. Based on the above background, in the face of the government's subsidy strategy, how should recyclers set the recycling price of recycled green express packaging with the participation of recyclers? At what price should manufacturers and logistics companies buy green express packaging from recyclers? How should the government choose a subsidy strategy? What impact will different subsidy strategies have on the decisions of each party in the green express packaging recycling system? This article will discuss the incentive mechanism of green express packaging recycling, provide a decision-making basis for the government to formulate relevant policies, and provide reasonable and feasible solutions for enterprises.

This paper mainly studies the recycling pricing decision of green express packaging and the government's subsidy incentive policy, and many scholars have studied the pricing decision in this field on the issue of green recycling pricing decision-making. Kong Lingcheng and Luo Tangjie [2] used the method of contract theory to study the optimal pricing problem of product recycling at three different quality levels in the "manufacturer-retailer" secondary recycling system, and found the optimal order quantity and recycling price by maximizing profits for retailers, manufacturers and the entire supply chain. Bian Wenliang et al. [3] took into account both recyclers and third-party repair centers, constructed a single and double recycling channel model, and studied the pricing decisions and recycling model choices of the closed-loop supply chain under the two models.

Recyclers are also becoming one of the participants in green pricing decisions. Hong et al. [4] study the impact of centralized and decentralized decision-making on optimal decision-making for local advertising, product collection, and pricing in closed-loop supply chains where third parties are

responsible for recycling. Feng et al. [5] studied the degree of recycling efforts, recycling pricing and other decisions of third-party recyclers under different circumstances, and the impact on members of the entire supply chain. Zhu Xiaodong et al. [6] analyzed the difference in recycling costs between traditional distributors and online recyclers, as well as the impact of factors such as rewrannable rate of recycled products, recycling competition coefficient and consumer recycling price sensitivity coefficient on the optimal recycling pricing and profit of dual-channel closed-loop supply chain under decentralized and centralized decision-making, and designed a revenue-cost sharing contract. In studying the dynamic decision-making problem of closed-loop supply chain, Shu Yadong et al. [7] considered the competition between recyclers and the fairness concern of recyclers, and discussed the equilibrium solution of closed-loop supply chain under the combination of these four strategies.

With the government's attention to green industries such as remanufacturing and the implementation of various subsidy policies, academia has also begun to study the role of government participation in green closed-loop supply chains. Deng et al. [8] examined the impact of government subsidies for recyclers and remanufacturers on closed-loop supply chain equilibrium. Lin Guihua et al. [9] incorporated recyclers into the closed-loop supply chain, established a decision-making model for different entities in recycling, and discussed the impact of government subsidy strategies on the selection strategies of three different subject recycling models. Huang Chunxiang and Li Dengfeng [10] studied how a closed-loop supply chain consisting of one recycler and two competing manufacturers can solve the problem of member strategy optimization and profit distribution at the same time under the government's deposit return system for recyclers.

In terms of government subsidy strategy, Shu et al. [11] considered the two factors of whether the government subsidized and whether the remanufacturer is competitive, and studied the impact of consumer acceptance of remanufactured products on the profits of supply chain members under the four models. Li et al. [12] analyzed the changes in the decision-making of various parties under the three market leadership models before and after government subsidies. Increased environmental awareness among consumers was found to raise the government's best subsidies. Wu Qunli et al. [13] studied the problem of recycling rate thresholds set by recycler governments in closed-loop supply chains under information asymmetry by establishing a government incentive regulation model, so as to improve the recycling rate of waste products and maximize social welfare. Wang Wenbin et al. [14] studied the guiding role of government subsidies on price competition of dual recycling channels and the impact on the recycling volume, recycling price and profit of the two channels. Barman Abhijit et al. [15] compare the optimal pricing strategy for maximizing the overall profit of the supply chain with and without government subsidies. Lin Guihua et al. [16] analyzed the impact of carbon emission reduction technology input, government compulsory recycling amount, and waste product conversion rate on the decision-making participants of the multi-stage green closed-loop supply chain.

Most of these literature studies assume that recyclers resell all recyclables to manufacturers. Based on the existing research, this paper not only considers the recycling process composed of recyclers and manufacturers, but also considers the situation that recyclers can directly sell reusable green packaging to logistics enterprises, and compares and analyzes the impact of different subsidy objects on the decision-making and profits of each participant by constructing the pricing decision model of green express packaging under four government subsidy strategies. The main innovation of this paper is to include the two scenarios of recyclers reselling recyclable packaging and reselling recyclers to manufacturers for dismantling and remanufacturing, and discussing the impact of different government subsidy strategies on green express packaging pricing decisions and the profits of all members.

2. Problem Description and Underlying Assumptions

2.1. Problem Description

This paper constructs a green express packaging pricing decision-making system consisting of a recycler, a manufacturer and a logistics enterprise, as shown in Figure 1, the manufacturer as the Stackelberg game leader, which uses raw materials to produce ordinary express packaging and green express packaging respectively, and is responsible for recycling and remanufacturing the waste green express packaging, logistics enterprises are responsible for selling ordinary express packaging and green express packaging, and recycling green express packaging that can be used twice at low prices. Recyclers are responsible for recycling green express packaging while sorting and transferring it.

In the positive supply chain, manufacturers purchase raw materials to manufacture new packaging, and wholesale ordinary express packaging and green express packaging to logistics enterprises at wholesale prices w_r and w_g, respectively, and $w_r < w_g$, logistics enterprises sell ordinary express packaging and green express packaging at retail prices p_r and p_g, respectively, and $p_r < p_g$; In the reverse supply chain, recyclers recycle green express packaging from consumers at a_r recycling price, part of which is sold to manufacturers for dismantling and remanufacturing at the price a_h, and the remaining part is sold to logistics companies at price a_f for secondary use. The utility of consumers on ordinary express packaging is $U_r = \theta - p_r$, θ obeys the uniform distribution on $[0,T]$, considering the influence of consumers' preference factors on green factors, the utility of green express packaging is $U_g = \alpha\theta - p_g + \lambda g$, $\alpha(0 < \alpha < 1)$ is the consumer's preference coefficient for green express packaging, g is the greenness of green express packaging, λ represents the consumer's sensitivity coefficient to the greenness of express packaging $(\lambda > 0)$, and the conditions that consumers meet to buy ordinary express packaging are $U_r > U_g$, that is, $\theta > \frac{p_r - p_g + \lambda g}{1-\alpha}$, then the demand for ordinary express packaging $q_r = T - \frac{p_r - p_g + \lambda g}{1-\alpha}$. The condition that consumers buy green express packaging is $0 < U_r < U_g$, that is, $p_r < \theta < \frac{p_r - p_g + \lambda g}{1-\alpha}$ is met, then the demand for green express packaging $q_g = \frac{\alpha p_r - p_g + \lambda g}{1-\alpha}$. In order for the model to be established, the recycling volume and market demand of green express packaging need to meet the conditions $G < q_g < q_g + q_r$.

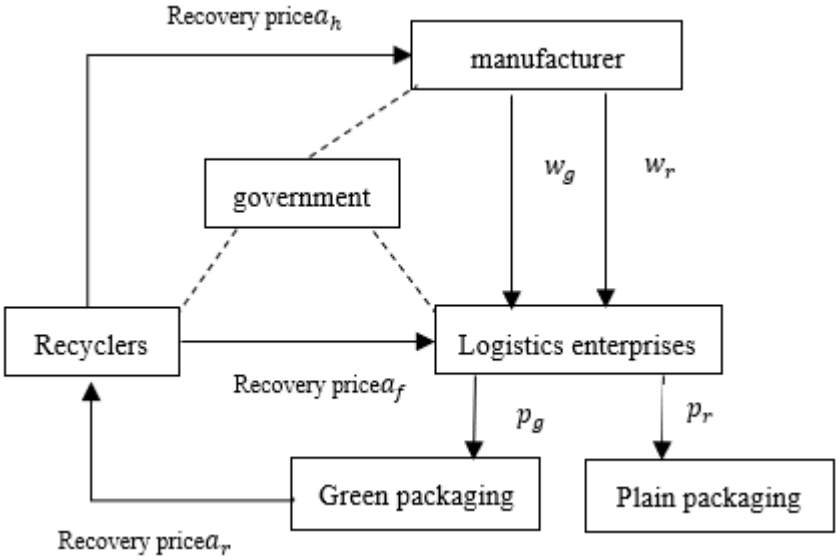

Figure 1. Structure Chart of Green Express Packaging Pricing Decision

2.2. Basic assumptions

Hypothesis 1: The unit cost of manufacturers to produce green express packaging is c_g, and the unit cost of refurbishing and remanufacturing is c_0, and when $c_0 + a_h < c_g$, the cost savings give manufacturers an incentive to recycle green express packaging from recyclers.

Hypothesis 2: The recycling amount of green express packaging is linearly related to the recycling price, referring to the practice of Lin Guihua et al., the function of the recycling amount is expressed as $G = ka_r$, where $k(k > 0)$ is the consumer's sensitivity coefficient to the recycling price, and when the recycling price is zero, the recycling volume of green express packaging is also zero.

Hypothesis 3: The recycled amount of green express packaging of the recycler is all used to transfer to the logistics enterprise or returned to the manufacturer for re-dismantling and manufacturing, of which the recovery amount of green express packaging returned to the manufacturer is ρG, and $\rho(0 < \rho < 1)$ is the proportion of green express packaging returned to the manufacturer.

Hypothesis 4: In order to promote the recycling and reuse of green express packaging, the government will give unit subsidies to manufacturers, logistics enterprises and recyclers for the recycling price v.

Hypothesis 5: This paper assumes that SW social welfare consists of four parts: the total profit π_{SC} of the system, the government subsidy expenditure GS, the surplus CS of consumers, and the economic benefits RS generated by recycling, and social welfare is expressed as $SW = \pi_{SC} + CS + RS - GS$. Among them, the total profit π_{SC} is the sum of the profits of the three members; The GS of government subsidy expenditure will vary according to the target of government subsidies; Consumer surplus: $CS = \int_{\frac{p_r - p_g + \lambda g}{1-\alpha}}^{T} (\theta - p_r)d\theta + \int_{p_r}^{\frac{p_r - p_g + \lambda g}{1-\alpha}} (\alpha\theta - p_g + \lambda g)d\theta = \frac{1}{2}T^2 - p_r T - \frac{1}{2}\alpha {p_r}^2 + \frac{{p_r}^2 + {p_g}^2 + \lambda^2 g^2 - 2p_g\lambda g - 2\alpha p_r(p_g - \lambda g)}{2(1-\alpha)}$;

Recycling Economics RS provides consumers with the revenue generated by selling green express packaging to recyclers $a_r G$.

3. Model Building

According to the above assumptions, the three carry out the Stackelberg game, and the decision-making order is: in the first stage, the manufacturer determines the wholesale price of ordinary express packaging, the w_r wholesale price of green express packaging w_g and the recycling price a_h according to its own interests; In the second stage, logistics enterprises determine the retail price of ordinary express packaging, the p_r sales price of green express packaging p_g and the a_f of recycling payment price according to their own interests. In the third stage, the recycler determines the optimal recycling price a_r. The profit functions of manufacturers, logistics companies and recyclers when there are no government subsidies are:

$$\pi_M = (w_r - c_r)q_r + (w_g - c_g)(q_g - \rho G) + (c_g - a_h)\rho G \quad (1)$$

$$\pi_R = (p_r - w_r)q_r + (p_g - w_g)[q_g - (1-\rho)G] + (w_g - a_f)(1-\rho)G \quad (2)$$

$$\pi_z = (a_f - a_r)(1-\rho)G + (a_h - a_r)\rho G \quad (3)$$

For manufacturers, $(a_h - c_g)\rho G$ is the cost savings for manufacturers by recycling green express packaging; For logistics enterprises, $(a_f - w_g)(1-\rho)G$ is the profit obtained by logistics enterprises by directly purchasing second-hand green express packaging, and $(a_h - a_r)\rho G$ is the profit obtained by recyclers reselling the remaining green express packaging to manufacturers.

3.1. No government subsidies (N)

In the absence of government subsidies, proposition 1 can be obtained according to the profit function equations (1), (2) and (3) of manufacturers, logistics enterprises and recyclers.

Proposition 1: In the absence of government subsidies, the optimal recovery price of manufacturers, the optimal recovery price of logistics enterprises and the optimal recovery price of recyclers are:

$$a_h{}^{N*} = \frac{[4(2\alpha+\alpha^2-1)k+24\alpha\rho+8\alpha^2\rho+(10-42\alpha-16\alpha^2)k\rho-(6-65\alpha-21\alpha^2)k\rho^2-31\alpha k\rho^3-9\alpha^2k\rho^3]T}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{[4(2k+\alpha k+6\rho+\alpha\rho-2\alpha k\rho)-42k\rho+65k\rho^2+21\alpha k\rho^2-31k\rho^3-9\alpha k\rho^3]\lambda g+2(2-5\rho+3\rho^2)kc_r}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{-8(3+\alpha)(-2+5\rho)c_g+(-1+\rho)[28-148\rho+155\rho^2+\alpha(8-42\rho+45\rho^2)]kc_g}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$a_f{}^{N*} = \frac{[-8+16\alpha+8\alpha^2-4(1-2\alpha-\alpha^2)k+4(2-\alpha-\alpha^2)\rho-(6-65\alpha-21\alpha^2)k\rho^2-(31\alpha+9\alpha^2)k\rho^3]T}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(10-42\alpha-16\alpha^2)k\rho T+[4(4+2k+2\alpha+\alpha k-\rho-\alpha\rho-4\alpha k\rho)-42k\rho+(65+21\alpha)k\rho^2]\lambda g}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{2(-4-2k+3k\rho)c_r-(31+9\alpha)k\rho^3\lambda g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{\{56+16\alpha-92\rho-28\alpha\rho+k(-1+\rho)[28-148\rho+155\rho^2+\alpha(8-42\rho+45\rho^2)]\}c_g}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$a_r^{N*} = \frac{(2-4\alpha-2\alpha^2-2\rho+7\alpha\rho+3\alpha^2\rho)T-(4+2\alpha-7\rho-3\alpha\rho)\lambda g-2(1-\rho)c_r-[2+\rho(7+3\alpha)]c_g}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The best wholesale prices for green express packaging and ordinary express packaging are:

$$w_r^{N*} = \frac{-[(48-36k+16\alpha-(4\alpha-12\alpha^2-4\alpha^3)k+(98+8\alpha-38\alpha^2-12\alpha^3)k\rho]T}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(68+3\alpha-30\alpha^2-9\alpha^3)k\rho^2T+16(3+\alpha)c_r-2[14-39\rho+28\rho^2+\alpha(2-7\rho+6\rho^2)]kc_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(8k+(12\alpha+4\alpha^2)k-(26+38\alpha+12\alpha^2)k\rho+(21+30\alpha+9\alpha^2)k\rho^2)\lambda g-}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{(1+\alpha)(-2+3\rho)[2+(7+3\alpha)\rho]kc_g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$w_g^{N*} = \frac{(2k-12\alpha+4\alpha k-4\alpha^2-5k\rho-9\alpha k\rho+3k\rho^2+5\alpha k\rho^2)T+(-2+5\rho-3\rho^2)kc_r}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$
$$+\frac{(-12+4k-4\alpha-9k\rho+5k\rho^2)\lambda g-4(3+\alpha)c_g+[6-26\rho+26\rho^2+\alpha(2-9\rho+9\rho^2)]kc_g}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$

The best retail prices for green express packaging and regular express packaging are:

$$p_r^{N*} = \frac{-80+56k-16\alpha-(154-2\alpha^2)k\rho+(108-\alpha-3\alpha^2)k\rho^2}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{16-16k+48k\rho+2\alpha k\rho+37k\rho^2-3\alpha k\rho^2+2[-8+k(4-11\rho+8\rho^2)]c_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{\{-16+k[8-34\rho+(37+3\alpha)\rho^2]\}c_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$p_g^{N*} = \frac{[-16+12k-64\alpha+40\alpha k-16\alpha^2+4\alpha^2k-(34+106\alpha+12\alpha^2)k\rho+(24+71\alpha+9\alpha^2)k\rho^2]T}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(-64+40k-16\alpha+4\alpha k-106k\rho-12\alpha k\rho+71k\rho^2+9\alpha k\rho^2)\lambda g+16c_r-2(6-17\rho+12\rho^2)kc_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{-16(2+\alpha)+[20-60\rho+53\rho^2+\alpha(8-30\rho+27\rho^2)]kc_g}{4[-8(3+\alpha c_g)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The recycling volume of green express packaging is:

$$G^{N*} = \frac{k\{(2-4\alpha-2\alpha^2-2\rho+7\alpha\rho+3\alpha^2\rho)T-(4+2\alpha-7\rho-3\alpha\rho)\lambda g-2(1-\rho)c_r-[2+\rho(7+3\alpha)]c_g\}}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The total profit of the supply chain is:

$$\pi_{SC}^{N*} = \pi_M^{N*} + \pi_R^{N*} + \pi_Z^{N*}$$

Social benefits are:

$$SW^{N*} = \pi_{SC}^{N*} + CS^{N*} + RS^{N*} - GS^{N*}$$

3.2. The government subsidizes manufacturers (M)

Considering that the government subsidizes the manufacturer's recycling price, the profit functions of logistics enterprises and recyclers are Equation (2) and Equation (3) respectively, then the profit function of the manufacturer is:

$$\pi_M = (w_r - c_r)q_r + \left(w_g - c_g\right)\left(q_g - \rho G\right) + (c_g - a_h + v)\rho G \quad (4)$$

Proposition 2: In the case of government subsidies to manufacturers, the optimal recovery price of manufacturers, the optimal recovery price of logistics enterprises and the optimal recovery price of recyclers are:

$$a_h{}^{M*} = \frac{[(-4+8\alpha+4\alpha^2)k+24\alpha\rho+8\alpha^2\rho+(10-16\alpha^2-42\alpha)k\rho-(6-65\alpha-21\alpha^2)k\rho^2-9\alpha^2k\rho^3]\mathrm{T}}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(4k+4\alpha k+24\rho-42k\rho+8\alpha\rho-16\alpha k\rho+65k\rho^2+21\alpha k\rho^2-31k\rho^3-9\alpha k\rho^3)\lambda g}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(-48\rho+44k\rho-16\alpha\rho+12\alpha k\rho-106k\rho^2-30\alpha k\rho^2+18\alpha k\rho^3)v+2(2-5\rho+3\rho^2)kc_r}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{-8(3+\alpha)(-2+5\rho)c_g+k(-1+\rho)[28-148\rho+155\rho^2+\alpha(8-42\rho+45\rho^2)]c_g}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$a_f{}^{M*} = -\frac{[8+4(1-2\alpha-\alpha^2)k-16\alpha-8\alpha^2-4(2-\alpha-\alpha^2)\rho-2(5-21\alpha-8\alpha^2)k\rho+(6-65\alpha)k\rho^2+]\mathrm{T}}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{[21\alpha^2k\rho^2T+(31\alpha+9\alpha^2)k\rho^3]\mathrm{T}+(16+8k+8\alpha+4\alpha k-4\rho-42k\rho-4\alpha\rho-16\alpha k\rho+65k\rho^2)\lambda g}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(21\alpha k\rho^2-31k\rho^3-9\alpha k\rho^3)\lambda g+2(-1+\rho)(-4-2k+3k\rho)c_r}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(-24\rho+44k\rho-8\alpha\rho+12\alpha k\rho-106k\rho^2-30\alpha k\rho^2+62k\rho^3+18\alpha k\rho^3)v}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{\{56+16\alpha-92\rho-28\alpha\rho+k(-1+\rho)[28-148\rho+155\rho^2+\alpha(8-42\rho+45\rho^2)]\}c_g}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$a_r{}^{M*} = \frac{(2-4\alpha-2\alpha^2-2\rho+7\alpha\rho+3\alpha^2\rho)\mathrm{T}-(4+2\alpha-7\rho-3\alpha\rho)\lambda g-2(1-\rho)c_r}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{c_g[2+\rho(7+3\alpha)]-(6\rho+2\alpha\rho)v}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The best wholesale prices for green express packaging and ordinary express packaging are:

$$w_r^{M*} = -\frac{(48-36k+16\alpha-(4\alpha-12\alpha^2-4\alpha^3)k+(98+8\alpha-38\alpha^2-12\alpha^3)k\rho]\mathrm{T}}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(68+3\alpha-30\alpha^2-9\alpha^3)k\rho^2\mathrm{T}+2[14-39\rho+28\rho^2+\alpha(2-7\rho+6\rho^2)]kc_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{[8k+(12\alpha+4\alpha^2)k-(26+38\alpha+12\alpha^2)k\rho+(21+30\alpha+9\alpha^2)k\rho^2]\lambda g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{16(3+\alpha)c_r-(1+\alpha)(-2+3\rho)[2+(7+3\alpha)\rho]kc_g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}-\frac{[(12+16\alpha+4\alpha^2)k\rho-(18+24\alpha+6\alpha^2)k\rho^2]v}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$w_g^{M*} = \frac{[2k-12\alpha+4\alpha k-4\alpha^2-5k\rho-9\alpha k\rho+3k\rho^2+5\alpha k\rho^2]\mathrm{T}+kc_r(-2+5\rho-3\rho^2)}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$
$$+\frac{(-12+4k-4\alpha-9k\rho+5k\rho^2)\lambda g-4c_g(3+\alpha)+[6-26\rho+26\rho^2+\alpha(2-9\rho+9\rho^2)]kc_g}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$
$$+\frac{(-6k\rho-2\alpha k\rho+9k\rho^2+3\alpha k\rho^2)v}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$

The best retail prices for green express packaging and regular express packaging are:

$$p_r^{M*} = \frac{[-80+56k-16\alpha-(154-2\alpha^2)k\rho+(108-\alpha-3\alpha^2)k\rho^2]\mathrm{T}}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(16-16k+48k\rho+2\alpha k\rho-37k\rho^2-3\alpha k\rho^2)\lambda g-(8k\rho-14k\rho^2-2\alpha k\rho^2)v}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{2[-8+k(4-11\rho+8\rho^2)]c_r+\{-16+k[8-34\rho+(37+3\alpha)\rho^2]\}c_g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$p_g^{M*} = \frac{[-16+12k-64\alpha+40\alpha k-16\alpha^2+4\alpha^2k-(34+106\alpha+12\alpha^2)k\rho+(24+71\alpha+9\alpha^2)k\rho^2]\mathrm{T}}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(-64+40k-16\alpha+4\alpha k-106k\rho-12\alpha k\rho+71k\rho^2+9\alpha k\rho^2)\lambda g+16c_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(-4k\rho-4\alpha k\rho+10k\rho^2+6\alpha k\rho^2)v-2(6-17\rho+12\rho^2)kc_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{16(2+\alpha)c_g-[20-60\rho+53\rho^2+\alpha(8-30\rho+27\rho^2)]kc_g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The recycling volume of green express packaging is:

$$G^{M*} = \frac{k\{(2-4\alpha-2\alpha^2-2\rho+7\alpha\rho+3\alpha^2\rho)\mathrm{T}-(4+2\alpha-7\rho-3\alpha\rho)\lambda g-2(1-\rho)c_r\}}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} - \frac{[2+\rho(7+3\alpha)]kc_g+(6\rho+2\alpha\rho)kv}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The total profit of the supply chain is:

$$\pi_{SC}^{M*} = \pi_M^{M*} + \pi_R^{M*} + \pi_Z^{M*}$$

Social benefits are:

$$SW^{M*} = \pi_{SC}^{M*} + CS^{M*} + RS^{M*} - GS^{M*}$$

The proofs of proposition 2 and subsequent propositions 3 and 4 are similar to proposition 1 and will not be repeated.

From proposition 2 one can be derived from inference 1.

Corollary 1: When the government subsidizes the manufacturer's recycling price, the green express packaging pricing decision changes with the government subsidy as: （1） $\frac{\partial {a_h}^{M*}}{\partial v}>0$，$\frac{\partial {a_f}^{M*}}{\partial v}=0$，$\frac{\partial {a_r}^{M*}}{\partial v}=0$；（2）$\frac{\partial {w_r}^{M*}}{\partial v}>0$，$\frac{\partial {w_g}^{M*}}{\partial v}>0$，$\frac{\partial {p_r}^{M*}}{\partial v}=0$，$\frac{\partial {p_g}^{M*}}{\partial v}=0$；（3）$\frac{\partial {G}^{M*}}{\partial v}=0$，$\frac{\partial {q_r}^{M*}}{\partial v}=0$，$\frac{\partial {q_g}^{M*}}{\partial v}=0$。

Corollary 1 shows that the government's subsidy for manufacturers is not conducive to the recycling of green express packaging, but will affect the profits of logistics enterprises, making manufacturers raise prices for no reason in order to seek profits. When the government subsidizes manufacturers, as the government subsidies increase, the recycling price of manufacturers also increases, while the recycling price of logistics enterprises and the recycling price of recyclers do not change. Since the government subsidy policy allows manufacturers to take advantage of the opportunity to obtain more profits, thereby raising the price of ordinary express packaging and green express packaging, but the recycling price and retail price of logistics enterprises and recyclers are not affected by government subsidies, so the demand for both packaging remains unchanged and the amount of recycling remains unchanged.

3.3. The governments subsidizes logistics enterprises (L)

Considering the government subsidies given to logistics enterprises, the profit functions of manufacturers and recyclers are Equation (1) and Equation (3) respectively, then the profit function of logistics enterprises is:

$$\pi_R = (p_r - w_r)q_r + (p_g - w_g)[q_g - (1-\rho)G] + (w_g - a_f + v)(1-\rho)G \quad (5)$$

Proposition 3: In the case of government subsidies to logistics enterprises, the optimal recovery price of manufacturers, the optimal recovery price of logistics enterprises and the optimal recovery price of recyclers are:

$$a_h{}^{L*} = \frac{[(-4+8\alpha+4\alpha^2)k+24\alpha\rho+8\alpha^2\rho+(10-16\alpha^2-42\alpha)k\rho-(6-65\alpha-21\alpha^2)k\rho^2-31\alpha k\rho^3]\mathrm{T}}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} + \frac{(8k+4\alpha k+24\rho-42k\rho+8\alpha\rho-16\alpha k\rho+65k\rho^2+21\alpha k\rho^2-31k\rho^3-9\alpha k\rho^3)\lambda g-9\alpha^2k\rho^3\mathrm{T}}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} + \frac{-8(3+\alpha)(-2+5\rho)c_g+k(-1+\rho)[28-148\rho+155\rho^2+\alpha(8-42\rho+45\rho^2)]c_g}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} + \frac{(48-20k+16\alpha-4\alpha k-48\rho+90k\rho-16\alpha\rho+22\alpha k\rho-132k\rho^2-36\alpha k\rho^2+62k\rho^3+18\alpha k\rho^3)v}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} + \frac{+2(2-5\rho+3\rho^2)kc_r}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$a_f{}^{L*} = -\frac{[8+4(1-2\alpha-\alpha^2)k-16\alpha-8\alpha^2-4(2-\alpha-\alpha^2)\rho-2(5-21\alpha-8\alpha^2)k\rho+(6-65\alpha)k\rho^2]\mathrm{T}}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} + \frac{[21\alpha^2k\rho^2-(31\alpha+9\alpha^2)k\rho^3]T+(16+8k+8\alpha+4\alpha k-4\rho-42k\rho-4\alpha\rho-16\alpha k\rho+65k\rho^2)\lambda g}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} + \frac{(72-20k+24\alpha-4k\alpha-72\rho+90k\rho-24\alpha\rho+22\alpha k\rho-132k\rho^2-36\alpha k\rho^2+62k\rho^3+18\alpha k\rho^3)v}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} + \frac{2(-1+\rho)(-4-2k+3k\rho)c_r-(31k\rho^3+9\alpha k\rho^3-21\alpha k\rho^2)\lambda g}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} + \frac{\{56+16\alpha-92\rho-28\alpha\rho+k(-1+\rho)[28-148\rho+155\rho^2+\alpha(8-42\rho+45\rho^2)]\}c_g}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$a_r{}^{L*} = \frac{(2-4\alpha-2\alpha^2-2\rho+7\alpha\rho+3\alpha^2\rho)\mathrm{T}-(4+2\alpha-7\rho-3\alpha\rho)\lambda g-2(1-\rho)c_r-c_g[2+\rho(7+3\alpha)]}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} - \frac{(6+2\alpha-6\rho-2\alpha\rho)v}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The best wholesale prices for green express packaging and ordinary express packaging are:

$$w_r^{L*} = -\frac{(48-36k+16\alpha-(4\alpha-12\alpha^2-4\alpha^3)k+(98+8\alpha-38\alpha^2-12\alpha^3)k\rho-(68+3\alpha-30\alpha^2-9\alpha^3)k\rho^2]\mathrm{T}}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{16(3+\alpha)c_r-2[14-39\rho+28\rho^2+\alpha(2-7\rho+6\rho^2)]kc_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}-\frac{(1+\alpha)(-2+3\rho)[2+(7+3\alpha)\rho]kc_g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{[8k+(12\alpha+4\alpha^2)k-(26+38\alpha+12\alpha^2)k\rho+(21+30\alpha+9\alpha^2)k\rho^2]\lambda g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{(12+16\alpha+4\alpha^2)k-(30+40\alpha+10\alpha^2)k\rho+(18+24\alpha+6\alpha^2)k\rho^2]v}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$w_g^{L*} = \frac{[2k-12\alpha+4\alpha k-4\alpha^2-5k\rho-9\alpha k\rho+3k\rho^2+5\alpha k\rho^2]\mathrm{T}+kc_r(-2+5\rho-3\rho^2)}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$
$$+\frac{(-12+4k-4\alpha-9k\rho+5k\rho^2)\lambda g-4c_g(3+\alpha)+[6-26\rho+26\rho^2+\alpha(2-9\rho+9\rho^2)]kc_g}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$
$$+\frac{(-6k-2\alpha k+15k\rho+5\alpha k\rho+9k\rho^2+3\alpha k\rho^2)v}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$

The best retail prices for green express packaging and regular express packaging are:

$$p_r^{L*} = \frac{[-80+56k-16\alpha-(154-2\alpha^2)k\rho+(108-\alpha-3\alpha^2)k\rho^2]\mathrm{T}}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(16-16k+48k\rho+2\alpha k\rho-37k\rho^2-3\alpha k\rho^2)\lambda g-(8k-22k\rho-2\alpha k\rho+14k\rho^2+2\alpha k\rho^2)v}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{2[-8+k(4-11\rho+8\rho^2)]c_r+\{-16+k[8-34\rho+(37+3\alpha)\rho^2]\}c_g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$p_g^{L*} = \frac{[-16+12k-64\alpha+40\alpha k-16\alpha^2+4\alpha^2k-(34+106\alpha+12\alpha^2)k\rho+(24+71\alpha+9\alpha^2)k\rho^2]\mathrm{T}}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(-64+40k-16\alpha+4\alpha k-106k\rho-12\alpha k\rho+71k\rho^2+9\alpha k\rho^2)\lambda g+16c_r-2kc_r(6-17\rho+12\rho^2)}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{-16(2+\alpha)c_g+kc_g[20-60\rho+53\rho^2+\alpha(8-30\rho+27\rho^2)]}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(-4k-4\alpha k+14k\rho+10\alpha k\rho-10k\rho^2-6\alpha k\rho^2)v}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The recycling volume of green express packaging is:

$$G^{L*} = \frac{k\{(2-4\alpha-2\alpha^2-2\rho+7\alpha\rho+3\alpha^2\rho)\mathrm{T}-(4+2\alpha-7\rho-3\alpha\rho)\lambda g-2(1-\rho)c_r\}}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{[2+\rho(7+3\alpha)]kc_g+(6+2\alpha-6\rho-2\alpha\rho)kv}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The total profit of the supply chain is:

$$\pi_{SC}^{L*} = \pi_M^{L*} + \pi_R^{L*} + \pi_Z^{L*}$$

Social benefits are:

$$SW^{M*} = \pi_{SC}^{L*} + CS^{L*} + RS^{L*} - GS^{L*}$$

Corollary 2: When the government subsidizes the recycling price of logistics enterprises, the pricing decision of green express packaging changes with the government subsidy as: （1）$\frac{\partial {a_h}^{M*}}{\partial v} > 0$，$\frac{\partial {a_f}^{M*}}{\partial v} > 0$，$\frac{\partial {a_r}^{M*}}{\partial v} > 0$；（2）$\frac{\partial {w_r}^{M*}}{\partial v} > 0$，$\frac{\partial {w_g}^{M*}}{\partial v} > 0$，$\frac{\partial {p_r}^{M*}}{\partial v} < 0$，$\frac{\partial {p_g}^{M*}}{\partial v} < 0$；（3）$\frac{\partial {G}^{M*}}{\partial v} > 0$，$\frac{\partial {q_r}^{M*}}{\partial v} > 0$，$\frac{\partial {q_g}^{M*}}{\partial v} > 0$。

Corollary 2 shows that government subsidies for logistics companies can motivate recyclers to increase recycling efforts and can also help manufacturers scale up remanufacturing. With the increase of government subsidies for recycling prices for logistics enterprises, the recycling prices of logistics enterprises have increased, and the recycling prices of recyclers and manufacturers have also increased. This is because government subsidies are equivalent to bearing part of the cost of logistics enterprises, so logistics companies can increase sales by reducing the sales price of green express packaging, and at the same time increase the amount of recycling of green express packaging. Recyclers have more discarded green express packaging that can be resold to manufacturers and logistics companies. For ordinary packaging, the decline in the sales price of green express packaging has prompted more people to buy green express packaging, and ordinary express packaging needs to reduce prices to improve competitiveness if they want to obtain the market, and consumers' demand for ordinary packaging will also increase.

3.4. The government subsidizes recyclers (Z)

Considering that the government subsidizes the recycling price a_r recyclers, the profit functions of manufacturers and logistics enterprises are Equation (1) and Equation (2) respectively, then the profit function of recyclers is:

$$\pi_z = (a_f - a_r + v)(1-\rho)G + (a_h - a_r + v)\rho G \quad (6)$$

Proposition 4: In the case of government subsidies to recyclers, the optimal recycling price of manufacturers, the optimal recycling price of logistics enterprises and the

optimal recovery price of recyclers are:

$$a_h{}^{Z*} = \frac{[(-4+8\alpha+4\alpha^2)k+24\alpha\rho+8\alpha^2\rho+(10-16\alpha^2-42\alpha)k\rho-(6-65\alpha-21\alpha^2)k\rho^2-31\alpha k\rho^3]\mathrm{T}}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(8k+4\alpha k+24\rho-42k\rho+8\alpha\rho-16\alpha k\rho+65k\rho^2+21\alpha k\rho^2-31k\rho^3-9\alpha k\rho^3)\lambda g-9\alpha^2 k\rho^3\mathrm{T}}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{-8(3+\alpha)(-2+5\rho)c_g+k(-1+\rho)[28-148\rho+155\rho^2+\alpha(8-42\rho+45\rho^2)]c_g}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{2(2-5\rho+3\rho^2)kc_r+18\alpha k\rho^3 v}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(48-20k+16\alpha-4\alpha k-48\rho+90k\rho-16\alpha\rho+22\alpha k\rho-132k\rho^2-36\alpha k\rho^2+62k\rho^3)v}{4\rho[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$a_f{}^{Z*} = -\frac{(8+4k)(1-2\alpha-\alpha^2)-4(2-\alpha-\alpha^2)\rho-2(5-21\alpha-8\alpha^2)k\rho+(6-65\alpha)k\rho^2+(31\alpha+9\alpha^2)k\rho^3}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{21\alpha^2 k\rho^2 T+(16+8k+8\alpha+4\alpha k-4\rho-42k\rho-4\alpha\rho-16\alpha k\rho+65k\rho^2+21\alpha k\rho^2)\lambda g}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{2(-1+\rho)(-4-2k+3k\rho)c_r-(31k\rho^3+9\alpha k\rho^3)\lambda g-18\alpha k\rho^3 v}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{\{56+16\alpha-92\rho-28\alpha\rho+k(-1+\rho)[28-148\rho+155\rho^2+\alpha(8-42\rho+45\rho^2)]\}c_g}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(-24+44k-8\alpha+12k\alpha+24\rho-150k\rho+8\alpha\rho-42\alpha k\rho+168k\rho^2+48\alpha k\rho^2-62k\rho^3)v}{4(-1+\rho)[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$a_r{}^{Z*} = \frac{(2-4\alpha-2\alpha^2-2\rho+7\alpha\rho+3\alpha^2\rho)\mathrm{T}-(4+2\alpha-7\rho-3\alpha\rho)\lambda g-2(1-\rho)c_r}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(6+2\alpha-6\rho-2\alpha\rho)v-[2+\rho(7+3\alpha)]c_g}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The best wholesale prices for green express packaging and ordinary express packaging are:

$$w_r^{Z*} = -\frac{(48-36k+16\alpha-(4\alpha-12\alpha^2-4\alpha^3)k+(98+8\alpha-38\alpha^2-12\alpha^3)k\rho]\mathrm{T}}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{(68+3\alpha-30\alpha^2-9\alpha^3)k\rho^2\mathrm{T}+16(3+\alpha)c_r-2[14-39\rho+28\rho^2+\alpha(2-7\rho+6\rho^2)]kc_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{kc_g(1+\alpha)(-2+3\rho)[2+(7+3\alpha)\rho]}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{[8k+(12\alpha+4\alpha^2)k-(26+38\alpha+12\alpha^2)k\rho+(21+30\alpha+9\alpha^2)k\rho^2]\lambda g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{(12+16\alpha+4\alpha^2)k-(30+40\alpha+10\alpha^2)k\rho+(18+24\alpha+6\alpha^2)k\rho^2]v}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$w_g^{Z*} = \frac{[2k-12\alpha+4\alpha k-4\alpha^2-5k\rho-9\alpha k\rho+3k\rho^2+5\alpha k\rho^2]\mathrm{T}+kc_r(-2+5\rho-3\rho^2)}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$
$$+\frac{(-12+4k-4\alpha-9k\rho+5k\rho^2)\lambda g-4c_g(3+\alpha)+[6-26\rho+26\rho^2+\alpha(2-9\rho+9\rho^2)]kc_g}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$
$$+\frac{(-6k-2\alpha k+15k\rho+5\alpha k\rho-9k\rho^2-3\alpha k\rho^2)v}{-8(3+\alpha)+k[16+\alpha(2-3\rho)^2-44\rho+31\rho^2]}$$

The best retail prices for green express packaging and regular express packaging are:

$$p_r^{Z*} = \frac{[-80+56k-16\alpha-(154-2\alpha^2)k\rho+(108-\alpha-3\alpha^2)k\rho^2]\mathrm{T}}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(16-16k+48k\rho+2\alpha k\rho-37k\rho^2-3\alpha k\rho^2)\lambda g-(8k-22k\rho-2\alpha k\rho+14k\rho^2+2\alpha k\rho^2)v}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{2[-8+k(4-11\rho+8\rho^2)]c_r+\{-16+k[8-34\rho+(37+3\alpha)\rho^2]\}c_g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

$$p_g^{Z*} = \frac{[-16+12k-64\alpha+40\alpha k-16\alpha^2+4\alpha^2 k-(34+106\alpha+12\alpha^2)k\rho+(24+71\alpha+9\alpha^2)k\rho^2]\mathrm{T}}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{(-64+40k-16\alpha+4\alpha k-106k\rho-12\alpha k\rho+71k\rho^2+9\alpha k\rho^2)\lambda g+16c_r}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$-\frac{2(6-17\rho+12\rho^2)kc_r-[20-60\rho+53\rho^2+\alpha(8-30\rho+27\rho^2)]kc_g}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$
$$+\frac{16(2+\alpha)c_g+(-4k-4\alpha k+14k\rho+10\alpha k\rho-10k\rho^2-6\alpha k\rho^2)v}{4[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The recycling volume of green express packaging is:

$$G^{Z*} = \frac{k\{(2-4\alpha-2\alpha^2-2\rho+7\alpha\rho+3\alpha^2\rho)\mathrm{T}-(4+2\alpha-7\rho-3\alpha\rho)\lambda g-2(1-\rho)c_r\}}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]} + \frac{(6+2\alpha-6\rho-2\alpha\rho)kv-[2+\rho(7+3\alpha)]kc_g}{2[-8(3+\alpha)+k(16+\alpha(2-3\rho)^2-44\rho+31\rho^2)]}$$

The total profit of the supply chain is:

$$\pi_{SC}^{Z*} = \pi_M^{Z*} + \pi_R^{Z*} + \pi_Z^{Z*}$$

Social benefits are:

$$SW^{M*} = \pi_{SC}^{Z*} + CS^{Z*} + RS^{Z*} - GS^{Z*}$$

Corollary 3: When the government subsidizes the recycling price of recyclers, the pricing decision of green express packaging changes with the government subsidy as: （1）$\frac{\partial {a_h}^{M*}}{\partial v} > 0, \frac{\partial {a_f}^{M*}}{\partial v} > 0, \frac{\partial {a_r}^{M*}}{\partial v} > 0$;（2）$\frac{\partial {w_r}^{M*}}{\partial v} > 0, \frac{\partial {w_g}^{M*}}{\partial v} > 0$ ， $\frac{\partial {p_r}^{M*}}{\partial v} < 0$， $\frac{\partial {p_g}^{M*}}{\partial v} < 0$；（3）$\frac{\partial {G}^{M*}}{\partial v} > 0$ ， $\frac{\partial {q_r}^{M*}}{\partial v} < 0$， $\frac{\partial {q_g}^{M*}}{\partial v} > 0$。

Corollary 3 shows that government subsidies for recyclers have an incentive effect on consumers' willingness to use green express packaging, which can reduce resource waste and improve the greening of the entire system. With the increase of government subsidies for recycling prices for recyclers, the recycling price of recyclers increases, and the recycling price of manufacturers and the recycling price of logistics enterprises also increase. Government subsidies for recyclers are equivalent to bearing part of the cost, making recyclers profitable, recyclers in order to achieve more profits will increase the price of recycling, so that manufacturers to ensure their own profits also increase the price, but because of the increase in demand for green express packaging and ordinary express packaging, logistics companies can "small profits but quick turnover", reduce the sales price of green express packaging and ordinary express packaging to increase profits, but also can increase the amount of recycling of green express packaging. Recyclers have more green express packaging that can be resold to manufacturers and logistics companies, indicating that subsidies for recyclers are conducive to incentivizing recyclers to increase their willingness to recycle. For ordinary express packaging, the decline in the sales price of green express packaging has prompted more people to buy green express packaging, and the demand for ordinary express packaging has decreased.

Through the comparison of three different government subsidy strategies, it can be found that the government's subsidies to manufacturers are not conducive to the development of the entire green express packaging recycling system, indicating that the government cannot subsidize manufacturers indefinitely, which will lead manufacturers to think that it is profitable to promote green express packaging, thereby raising prices and causing damage to other industries. Although the government's subsidies for logistics enterprises can promote more consumers to use green express packaging, the use rate of ordinary express packaging will also increase, which is not conducive to the promotion of green express packaging. The government's subsidies for recyclers are most conducive to the development of the entire green express packaging recycling system, which can not only improve the utilization rate of green express packaging, but also reduce the demand for ordinary express packaging, which is conducive to the government's promotion of green policies.

4. Model Comparison and Description

Corollary 4: Under different subsidy strategy scenarios, compare the optimal equilibrium solution of various recycling prices: (1) the size of the recovery price from the recycler is ${a_h}^{N*} < {a_h}^{L*} = {a_h}^{Z*} < {a_h}^{M*}$; (2) The size of the price recovered by the logistics enterprise from the recycler is ${a_f}^{N*} = {a_f}^{M*} > {a_f}^{L*} = {a_f}^{Z*}$; (3) the size of the price recovered by the recycler from the consumer is $a_r^{N*} = a_r^{M*} < a_r^{L*} = a_r^{Z*}$; (4) The size of the total recovered amount is $G^{N*} < G^{M*} < G^{\mathrm{L}*} = G^{\mathrm{Z}*}$.

Corollary 4 shows that government subsidies have an incentive effect on whether subsidies are given to manufacturers, logistics companies, or recyclers, and that subsidizing recyclers or logistics companies is better than subsidizing manufacturers. The recycling price and total recycling amount of recyclers from consumers are larger than when they are not subsidized, indicating that the economic benefits of recycling are increasing, which can always motivate recyclers to increase their willingness to recycle, and manufacturers and logistics enterprises are also larger than when they are not subsidized, indicating that recycling profits are increasing, and manufacturers can remanufacture and logistics enterprises reuse scale. Among the three subsidy strategies, when subsidizing recyclers or logistics enterprises, the recovery price of manufacturers from recyclers and the recovery price of logistics enterprises from recyclers are lower than the recovery price of subsidized manufacturers, but the amount of recycling is higher than that of subsidized manufacturers, indicating that compared with subsidizing manufacturers, the other two subsidy strategies can make the recycler's expenditure cost lower and profit increase. For the government, subsidizing recyclers or subsidizing logistics enterprises is more beneficial to various industries involved in green express packaging recycling.

Corollary 5: Under different subsidy strategy scenarios, compare the optimal equilibrium solution of each sales price: (1) the size of the retail price of green packaging is $p_g^{N*} = p_g^{M*} > p_g^{L*} = p_g^{Z*}$; (2) The size of the retail price of ordinary packaging is $p_r^{N*} = p_r^{M*} > p_r^{L*} = p_r^{Z*}$; (3) The size of the green packaging demand is $q_g^{N*} < q_g^{M*} < q_g^{L*} = q_g^{Z*}$; (4) The size of the ordinary packaging demand is $q_r^{N*} < q_r^{M*} = q_r^{L*} = q_r^{*Z}$.

Corollary 5 shows that the price decisions of each participant under the three subsidy strategies show different trends. For subsidizing manufacturers, the retail price is no different from the retail price when subsidizing logistics companies and recyclers, combined with corollary 4 to prove that the government cannot subsidize manufacturers, although it can stimulate the rise in green demand, but it is far less than the other two strategies. Subsidizing recyclers or subsidizing logistics enterprises can stimulate the rise in demand for green express packaging and ordinary express packaging, obviously this increase is not as large as the increase in green demand, indicating that subsidized recyclers

or subsidized logistics enterprises can not only make the demand of the entire industry rise, make the entire industry more sustainable development, but also promote the entire industry to develop in a greener direction.

Corollary 6: Under different subsidy strategy scenarios, compare the optimal equilibrium solution of various profits and social welfare: (1) the size of the manufacturer's profit is $\pi_M^{N*} < \pi_M^{L*} = \pi_M^{Z*} < \pi_M^{M*}$; (2) The size of the profit of the logistics enterprise is $\pi_R^{M*} < \pi_R^{N*} < \pi_R^{L*} = \pi_R^{Z*}$; (3) The size of the recycler's profit is $\pi_Z^{N*} < \pi_Z^{L*} = \pi_Z^{Z*} < \pi_Z^{M*}$; (4) The size of the total profit of the system is $\pi^{N*} < \pi^{M*} < \pi^{L*} = \pi^{Z*}$; (5) The size of the social welfare is $SW^{N*} < SW^{M*} < SW^{L*} < SW^{Z*}$.

Corollary 6 shows that in the case of subsidizing manufacturers, although both manufacturers and recyclers are profitable, the profits of logistics enterprises are lower than when they are not subsidized, and the government subsidizing manufacturers will cause losses to the profits of logistics enterprises; In the case of subsidizing logistics enterprises and recyclers, the profits of manufacturers, logistics enterprises and recyclers all increase with the increase of subsidies, and they are higher than when the government subsidizes manufacturers, indicating that these two subsidy strategies can improve the total profit and social welfare of the green express packaging recycling system, which is more beneficial to all decision-makers.

5. Numerical Simulation

In order to verify the feasibility of the model, according to the prerequisites for satisfying the constraint conditions, set the parameters as follows: $T = 100, \alpha = 0.5, k = 0.5, c_g = 35, c_r = 20, \lambda = 2, g = 5, v \in [0,10], \rho \in (0,1)$. The impact of government subsidies and the proportion of recyclers refurbishing and selling recyclable green express packaging on the profits, total profits and social welfare of all parties was discussed to verify the validity of the conclusions. The simulation results are shown in Figure 2-6:

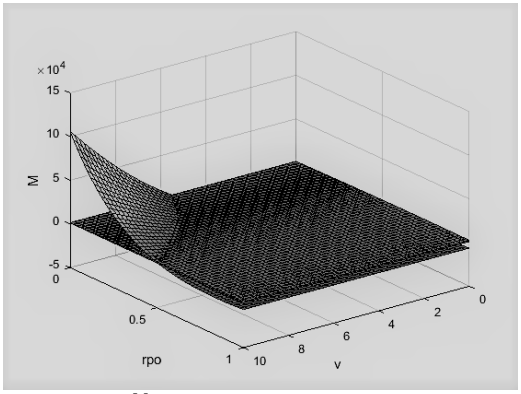

Figure 2. π^{M*} with v sum ρ Change trend of

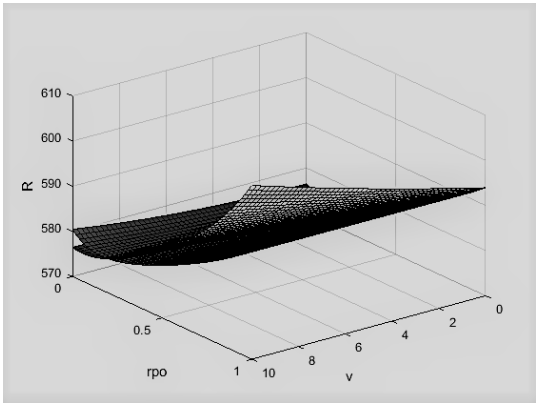

Figure 3. π^{R*} with v sum ρ Change trend of

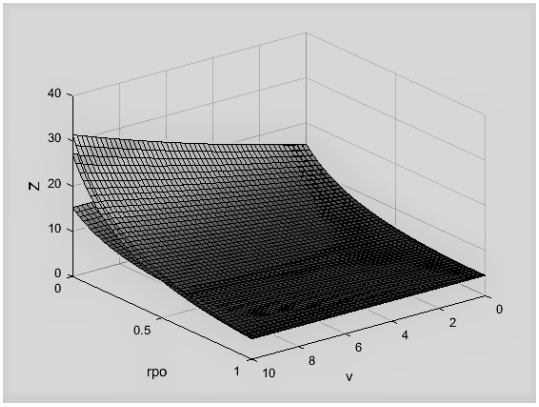

Figure 4. π^{Z*} with v sum ρ Change trend of

As can be seen from Figure 2, when the government subsidizes logistics enterprises and recyclers, the profits of manufacturers change slowly as government subsidies increase, further verifying that government subsidies have little impact on manufacturers' profits. When the government subsidizes manufacturers, the proportion of recyclers refurbishing and selling recyclable green express packaging has a greater impact on manufacturers' profits. As can be seen from Figure 3, compared with the unsubsidized situation, regardless of which party the government subsidizes, the profits of logistics companies have increased, and the greater the proportion of recyclers refurbishing and selling recyclable green express packaging, the higher the government subsidy, the greater the profit obtained by logistics companies. As can be seen from Figure 4, when the proportion of recyclers refurbishing and selling recyclable green express packaging remains unchanged, the government subsidy strategy has little impact on the profits of recyclers, and when the government subsidies remain unchanged, the greater the proportion of recyclers reselling green express packaging to manufacturers for dismantling and remanufacturing, the lower the profit obtained by recyclers, indicating that a better way for recyclers to obtain more profits is to improve the recycling rate of green express packaging.

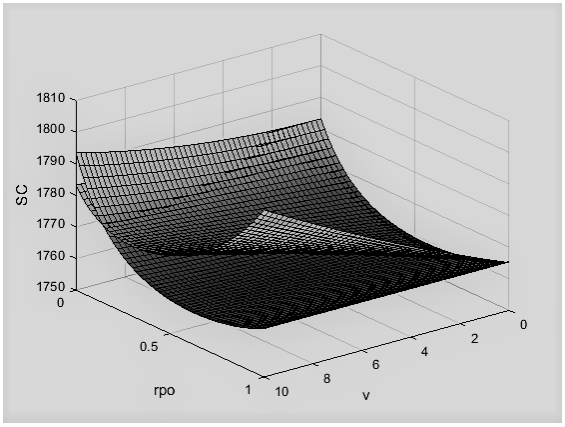

Figure 5. π^{M*} with v sum ρ Change trend of

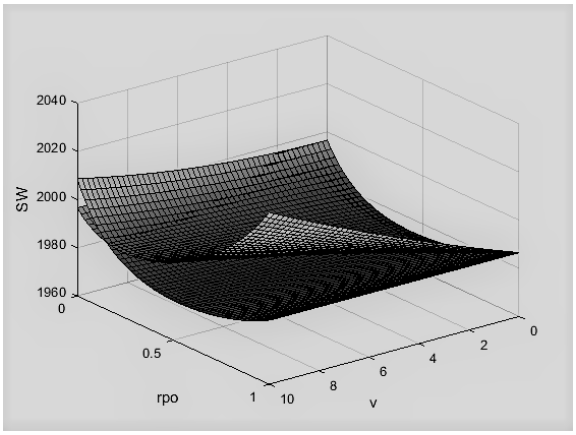

Figure 6. SW* with v sum ρ Change trend of

As can be seen from Figure 5, when $\rho > 0.5$, the total profit of the entire system is higher than that of the government subsidized by the manufacturer in the case of government subsidies to logistics enterprises and recyclers, which is the same as the conclusion of inference 2(4), and the greater the government subsidy, the higher the total profit of the system. As can be seen from Figure 6, it can be seen that the smaller the proportion of recyclable green express packaging sold by recyclers, that is, the greater the proportion of green express packaging for secondary use, the lower the total profit and social welfare of the system in the case of government subsidies to manufacturers, and the verifiable conclusion 2(5) is valid.

6. Conclusion

The recycling and remanufacturing of green express packaging can not only produce economic benefits, but also help to achieve sustainable development of society and rational allocation of resources. A large number of waste packaging market has spawned recyclers, recyclers in promoting the use of green express packaging, improve the recycling of green express packaging and other important roles, in order to continue to promote the utilization rate of green express packaging and the recycling rate of waste green express packaging, the government should choose what kind of subsidy strategy, different subsidy strategies will affect the pricing of green express packaging and the profits of all members have become new research questions. This paper considers two scenarios, namely recyclers refurbishing and selling recyclable packaging and recyclers reselling resale to manufacturers for dismantling and remanufacturing, constructs a green express packaging pricing model composed of manufacturers subsidized by the government, logistics enterprises and recyclers, and compares and analyzes the differential impact of different government subsidy strategies (no government subsidies, government-subsidized

manufacturers, government-subsidized logistics enterprises and government-subsidized recyclers) on the pricing decisions of green express packaging.

The main conclusions of this paper are: (1) Different government subsidy strategies cannot increase the willingness of recyclers to recycle. Under the strategy of government subsidizing manufacturers, it is easy to cause profit losses of logistics enterprises, logistics enterprises in order to avoid losses, will reduce the recycling of green express packaging, so the recycling volume of green express packaging has not increased, but under the strategy of government subsidies logistics enterprises and recyclers, the recycling amount of green express packaging has been increased, which is conducive to the circular development of green express packaging. (2) The profit of each participant will change according to the proportion of recyclers who resell green packaging to manufacturers for dismantling and remanufacturing. When the government subsidizes logistics enterprises, as the proportion of recyclers reselling green packaging to manufacturers for dismantling and remanufacturing increases, that is, the proportion of secondary use of green express packaging decreases, the profits obtained by each participant are increasing, but it is not conducive to the secondary recycling of green packaging. When the government subsidizes recyclers, as the proportion of recyclers reselling green packaging to manufacturers for dismantling and remanufacturing decreases, the profits obtained by all parties are increasing, which is more conducive to promoting the recycling of green express packaging. (3) In the government subsidy strategy, the profit and social welfare level of the entire decision-making system are the highest in the case of subsidizing logistics enterprises and recyclers. In the case of government subsidies to manufacturers, the recycling volume of green express packaging does not change, and manufacturers continue to raise prices in order to obtain more profits, which in turn affects the profits of other enterprises and even the profits of the entire system. In the case of subsidizing logistics companies and recyclers, the profits of each party increase with the increase in subsidies, which is profitable for all three parties. Both subsidy strategies can increase the total profit and social welfare of green express packaging recycling systems and are higher than when subsidizing manufacturers.

According to the conclusion of this article, some enlightenment can be obtained, specifically in the following aspects: (1) Government subsidies can promote the development of green express packaging and improve the recovery rate and utilization rate of green express packaging. The government should increase subsidies for logistics enterprises or recyclers to encourage similar enterprises to actively participate in recycling activities. When formulating specific subsidy policies, relevant government departments from different perspectives, the subsidy policies made are not the same, if you want to stimulate the development of the entire manufacturing industry, you should be more inclined to subsidize logistics enterprises, if you want to effectively protect the environment and promote the sustainable development of green express packaging, you should be more inclined to subsidize recyclers. (2) Recyclers should increase the recycling of green packaging, try to increase the proportion of secondary use of green express packaging, and reduce the proportion of green express packaging remanufacturing. In order to improve the overall profit of the green express packaging pricing decision-making system, recyclers should encourage consumers not to destroy the green express packaging from many aspects, actively participate in the recycling system, and improve the overall recovery level and secondary recycling level of green express packaging. (3) Manufacturers should continuously improve the level of remanufacturing technology, reduce remanufacturing costs, and promote the sustainable development of green packaging. Manufacturers cannot rely on government subsidies alone to increase profits, which will damage the profits of other industries in the decision-making system, and cannot effectively promote the recycling and secondary use of green express packaging.

The research on green express packaging recycling pricing in this paper is based on a series of assumptions, and there are still many factors that are not considered in practice, and further in-depth research is needed, including the following aspects: (1) This paper is relatively single when considering all participants. There are many stakeholders involved in green express packaging recycling, such as manufacturers, e-commerce enterprises, consumers, logistics companies, recycling manufacturing enterprises, etc., and the participants are not single, and the interest relationship between them is also relatively complex, and there are many influencing factors. When constructing the model, this paper only considers the profit impact of government subsidies on a single part of the stakeholders, and the model setting is not perfect. (2) This article considers only one party when considering recycling by recyclers. In the actual process of green express packaging recycling, there are many recyclers for recycling, and there are competing behaviors among recyclers, so this paper has certain limitations in the modeling process, and the selection and influencing factors of the model body need to be further studied. (3) In this paper, only the model is simulated and analyzed, and no empirical analysis is carried out. In the modeling process lack of actual data, so lack of empirical testing, in the future with the promotion of green express packaging in China, should be combined with actual data for empirical analysis, can better improve the existing model.

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