Research on the Impact of Government Carbon Tax and Subsidy Policies on Outsourcing Remanufacturing

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Abstract. In light of government carbon tax and subsidy policies, this paper builds a manufacturing/remanufacturing game model under outsouring remanufacturing, in order to analyze the influence of carbon tax and subsidy policies on outsourcing remanufacturing. By comparing and analyzing data, the influence of government carbon tax policies and subsidy manufacturing on outsourcing remanufacturing can be effectively promoted. However, when the carbon tax value is below a certain range, the recycling rate of waste products cannot be improved; Under government subsidy policies, original manufacturers can reduce the outsourcing costs of remanufacturing products in order to obtain profits;Under the carbon tax policy, Original manufacturers enhances product price to divert loss; Under the carbon tax policy, it can elevate the profits of remanufacturers. Only carbon tax amount exceeds a certain value will it increase the profits of original manufacturers, while subsidy policies can enhance the revenue of both original manufacturers and remanufacturers. The carbon tax policy has the smallest influence on environment. When the ratio of the impact of two products exceed a certain range, under the subsidy policy, the environment is most severely affected.

Keywords: carbon policy;subsidy policy;outsourcing remanufacturing

1 Introduction

With industrial progress and rapid economic development, the resources required by humans are increasing. However, resource waste and environmental pollution affect the environment [1]. Countries and enterprises are increasingly valuing energy and environmental issues, and have enacted a series of laws in developed countries such as Europe to promote sustainable development, recycling, reuse, and recycling. One of the effective ways to achieve resource recycling and sustainable economic development is through remanufacturing, which can efficiently achieve resource reuse and recycling[2].

Owing to the lack of specialized skill and equipment by original manufacturers, as well as a lack of channels for recycling waste products, and compared to new products, remanufactured products generate less revenue. In general, original manufacturers do not directly produce remanufactured products. Instead, based on the protection of

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intellectual property rights of the products, they transfer the production of remanufactured products to third parties with technology and recycling equipment, which is outsourcing remanufacturing.[3]At present, China is in the primary stage of remanufacturing development. To enhance economic prosperity and technological progress, promote green consumption, achieve resource recycling, a subsidy policy of exchanging old for new was adopted in 2013 to promote the sales of remanufactured products. In addition, in order to make original manufacturers pay attention to environmental protection, the government levy a portion carbon tax for new products produced by original manufacturers, increasing remanufactured items' basic competitiveness in the remanufacturing market and subtly altering their market competitiveness.

In the outsourcing remanufacturing model, the original manufacturer sells two products simultaneously, which means that the original manufacturer decides on the prices of both products. Thus, whether carbon tax or subsidy policy be choosed by government, it will directly affect the decision-making behavior of original manufacturers. Therefore, it is necessary to analyze the differences in decision-making behavior of original manufacturers under the two policies.

The influence of government carbon tax and subsidy policies on remanufacturing,as well as the outsourcing of remanufacturing,are the primary subjects of research on the influence of these policies about remanufacturing. The primary studies on how government carbon tax affect remanufacturing are: Wang Y [4]divides carbon emissions into unconstrained, carbon tax, carbon emission quota, carbon subsidy, and carbon trading,andanalyzes the impact of carbon reduction policies on manufacturing/remanufacturingdecisions. Wang Y [5] constructed a manufacturing/remanufacturing game model based on carbon emission constraints, and studied the influence of carbon emission quotas on the recycling rate and pricing of waste products. Ganda F [6]analyzed the optimal pricing and production decisions for manufacturing/remanufacturing under carbon tax and financial constraints. The study showed that an increase in carbon tax would constrain the production of new products and increase the output of remanufactured products. Dou G [7] constructed an optimization model for carbon reduction investment in steel remanufacturing, and analyzed the influence of carbon quotas, and carbon reduction investment on the profits and total carbon reduction of steel enterprises through data analysis. The study showed that under carbon trading, the profits of remanufacturing enterprises can be increased. Dou G[7] analyzed the influence of carbon tax on carbon reduction ,further, discovered carbon reduction increase in 2nd cycle, the total carbon reduction in manufacturing/remanufacturing may increase or decrease. Hu Xu[8] Based on game theory, Building a new model:a closed-loop supply chain. Carbon tax and carbon trading are treated as condition, and found that carbon trading can only diminish carbon emissions when the carbon quota level is high. Carbon tax policy not not enhance social welfare, but aslo consumer surplus.

The research on the influence of government subsidies on remanufacturing mainly includes: Zhou Xiaodong[9]studied two subsidy models of the government through a two-stage game model. One is to subsidize consumers who purchase remanufactured products, and the other is to subsidize consumers who donate waste products. The study found that government subsidies can raise revenue, and protect the environment. Based on government subsidies and patent fees, Guo D[10]analyzed the influence of different

subsidy recipients on patent fees, product recycling rate, product retail price, and sales profit. Hatcher G D [11]constructed a game model between original manufacturers and remanufacturers under three types of government subsidy policies, and contrasted and finded the effection of different allowance on wholesale prices.

The main research on outsourcing remanufacturing includes: Agrawal S [12] provides decision-makers with an efficient approach by constructing a multi-stage game model to compare and analyze outsourced remanufacturing and self remanufacturing. Li C [13]solved the optimal production problem of outsourcing remanufacturing through genetic algorithm and simulation analysis. Denizci Guillet B [14]used the revenue management method to analyze the necessary conditions for outsourcing remanufacturing, and the study showed that original manufacturers should choose third-party enterprises when facing market fluctuations. From the perspective of waste product recycling, John S [15]studied different recycling models,including find out their advantage and shortcoming and analyzed the conditions for outsourcing manufacturing.

From the above literature, it can be seen that domestic and foreign scholars have summarize a lot of inference on the impact of carbon tax and subsidy policies on the manufacturing/remanufacturing supply chain, as well as outsourcing remanufacturing policies, and have achieved many results. However, under outsourcing remanufacturing, there is little research on the comparative analysis of government carbon tax and subsidy policies. Therefore, this article uses game theory to construct a two cycle game model between original manufacturers and remanufacturers and the government takes two policies: carbon tax or subsidy, exploring the influence of adopting two policies on manufacturing/remanufacturing. Provide reference and basis for government to take relevant policies. This article mainly analyzes and solves the following problems：

(1) What influence will different policies have on the product recycling rate?

(2)What are the influence of two policies on original manufacturers and remanufacturers under the outsourcing remanufacturing model?(price, revenue, sales volume)

(3)What impact will the government have on the environment when adopting no policy, three policies under the outsourcing remanufacturing model.

2 Model Formulation

2.1 Problem Description

In the 1st cycle. Only new products exist in the market, which means only original manufacturer is engaged in new product production activities, and its decision variable is the unit retail price of new products(For the convenience of solving, the relationship between unit product retail price and demand is utilized in the solving process, and the decision variable is transformed into requirment for new products). In the 2nd cycle, There are two types of products in the market: new products and remanufactured products. However, due to the lack of proprietary technology and equipment for remanufacturer production by original manufacturers, as well as a lack of comprehensive channels for recycling waste products, original manufacturers entrust remanufacturer to remanufacturing enterprises with remanufacturing technology and equipment through intellectual property protection, which is outsourcing remanufacturing. The remanufacturer

first recycles the first cycle of waste products, and then proceeds with the production of remanufactured products. However, the remanufactured products must be handed over to the original manufacturer for sale. The government intervenes in remanufacturing through two policies: carbon tax and subsidies. The government can implement two policies: one is to impose a carbon tax on new products sold by original manufacturers; The second is to provide subsidies for the products of remanufacturers. According to the above description, it can be seen that the game diagram of outsourcing remanufacturing under two government policies,Please refer to figure 1 for details.

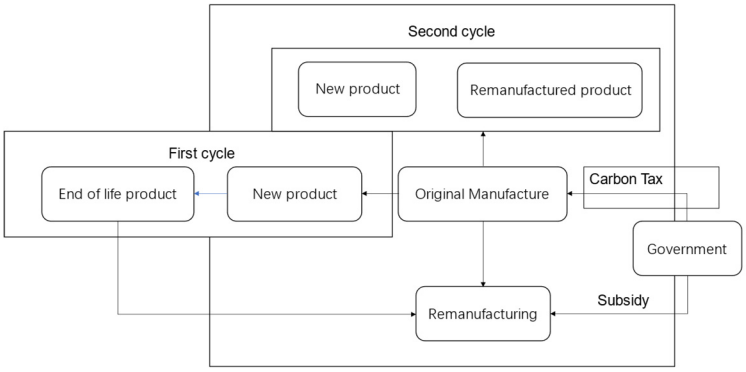

Fig. 1. Model diagram

2.2 Decision Sequence

Firstly, in the first cycle, the original manufacturer only needs to decide on the retail price of the new product for the decision-making unit,In the second cycle,the original manufacturer decides on new products,remanufactured products,and outsourcing costs for unit remanufacturing; Secondly, remanufacturers make decisions on the quantity of old product recycling based on the outsourcing cost of unit remanufactured products(Recycling rate of waste products). Firstly, The quantity of waste products are determined by the remanufacturer. Secondly, the original manufacturer decides on two product price, outsourcing cost of one remanufacturing product based on the amount of recycled waste products.

2.3 Model Symbol

Shown in Table 1.It is model symbol and definition.

Table 1. Notation summary.

Symbol	Definition
$\boldsymbol{n,r}$	Original Manufacturer, remanufacturer;

N, S, V	They respectively indicate that the government does not adopt policies, but adopts carbon tax policies and subsidy policies;
s	Adopt carbon tax quota for non remanufactured products;
v	When government takes subsidy policies, it provides units with a quota for remanufacturing products;
c_n, c_r	Unit production cost of new products and production cost of remanufactured products($c_n > c_r, s < c_n - c_r, v < c_n - c_r$);
w_i	Under outsourcing remanufacturing, the remanufacturer pays the original manufacturer outsourcing fees;
p_{i1}, q_{i1}	Represent the unit retail price and sales volume of two products ($i \in \{N, S, V\}$);
$p_{in}, q_{in}, p_{ir}, q_{ir}$	Represent the unit retail price and sales volume of two products respectively ($i \in \{N, S, V\}$);
π_{in}, π_{ir}	Represent the profits of the original manufacturer and remanufacturer respectively ($i \in \{N, S, V\}$);

2.4 Model Function

2.4.1. Model Demand Dunction.

Base on reference3, this article uses a relatively reliable demand function, which is being used by authoritative journals both domestically and internationally.The demand relationship between unit new products and unit remanufactured products in market competition is:

$$p_{\text{in}} = \delta(1 - q_{\text{in}} - q_{\text{ir}}), p_{\text{ir}} = \delta(1 - q_{\text{in}} - q_{\text{ir}}) i \in \{N, S, V\}$$

Where δ represents the relative discount, and represents the ratio of the price per unit of remanufactured products to the price per unit of new products. Similarly, the demand function for new products in the first week is:$p_n = 1 - q_n$.

2.4.2. Model Recycling Function.

Referring to reference 10, the cost of recycling waste products is related to the quantity of waste products recycled, and the cost of waste products is a convex function of the amountof recycling. The cost of recycling waste products is $\frac{k}{2}(\tau_i q_{i1})^2$, τ product recovery rate,k represents the cost of recycling waste products.

2.4.3. Model Assumption.

Based on previous literature, this article assumes that waste products that have not been involved in remanufacturing do not have economic value. Remanufacturing processes the collected waste products.Therefore,$q_{ir} = \tau_i q_{i1}$.

2.5 Research Hypothesis

Hypothesis 1. The original manufacturer uses Outsourcing methods. It gives production technology to remanufacturers, allowing remanufacturers to make remanufacturing products.The original remanufacturer pays the relevant outsourcing fees.The activity of remanufacturers is influenced by outsourcing unit cost.

Hypothesis2.10The impact of new products produced by original manufacturers and remanufactured products produced by remanufacturers on the environment is different. Taking the remanufactured engine of a certain enterprise as an example, compared to new engines, remanufactured engines can reduce carbon emissions by 60% per unit.

Hypothesis 3. Subsidies and carbon taxes are key policies that affect the growth of manufacturing industry. However, not only carbon taxe and subsidy policies have an influence on the manufacturing industry.For example carbon trading policy,carbon constraint policy,etc.

3 Model Analysis

3.1 Model Construction

Under the carbon tax policy, the profits of original manufacturers are shown in formula 1, The profit of remanufacturing is shown in formula 2.

$$\pi_{Sn} = (p_{S1} - c_n - s)q_{S1} + (p_{Sn} - c_n - s)q_{Sn} + (p_{Sr} - w_s)q_{Sr} \quad (1)$$

$$\pi_{Sr} = (w_s - c_r)q_{Sr} - \frac{k}{2}(\tau_s q_{s1})^2 \quad (2)$$

Under the subsidy policy, the profits of the original manufacturer are shown in formula 3, and the profits of the remanufacturer are shown in formula 4.

$$\pi_{Vn} = (p_{V1} - c_n)q_{V1} + (p_{Vn} - c_n)q_{Vn} + (p_{Vr} - w_V)q_{Vr} \quad (3)$$

$$\pi_{Vr} = (w_V - c_r + v)q_{Vr} - \frac{k}{2}(\tau_v q_{V1})^2 \quad (4)$$

When the government does not provide any subsidies, the profits of the original manufacturer are shown in formula 5, and the profits of the remanufacturer are shown in formula 6.

$$\pi_{Nn} = (p_{N1} - c_n)q_{N1} + (p_{Nn} - c_n)q_{Nn} + (p_{Nr} - w_N)q_{Nr} \quad (5)$$

$$\pi_{Nr} = (w_N - c_r)q_{Nr} - \frac{k}{2}(\tau_N q_{N1})^2 \quad (6)$$

3.2 Model Solving

To obtain the optimal solution under three government policies, this article takes the government's adoption of carbon tax policy as an example.

Lemma 1. π_{Sr} is a concave function for the recovery rate of waste products τ_s, The optimal solution obtained through π_{Sr} is brought into π_{Sn}, where π_{Sn} is a concave function with respect to q_{S1}, q_{Sn}, w_s;

Proof. Bringing $q_{\mathrm{sr}} = \tau_s q_{\mathrm{s1}}$ into formula 2:

$$\pi_{\mathrm{Sr}} = (w_s - c_r)\tau_s q_{\mathrm{s1}} - \frac{k}{2}\tau_s {q_{\mathrm{s1}}}^2 \tag{7}$$

The 1st and 2nd-order of π_{Sr} about τ_s as below:

$$\frac{\partial \pi_{\mathrm{Sr}}}{\partial \tau_s} = q_{\mathrm{s1}}(-c_r + w_s) - k q_{\mathrm{s1}}^2 \tau_s \tag{8}$$

$$\frac{\partial^2 \pi_{\mathrm{Sr}}}{\partial^2 \tau_s} = -k q_{\mathrm{s1}}^2 \tag{9}$$

According to formula 9: $\frac{\partial^2 \pi_{\mathrm{Sr}}}{\partial^2 \tau_s} = -k q_{\mathrm{s1}}^2 < 0$,It is known that formula 2 is a concave function for τ_s. Therefore, the optimal solution for τ_s is obtained through formula 7.

$$\tau_s = \frac{-c_r + w_s}{k q_{\mathrm{s1}}}$$

By substituting $\tau_s = \frac{-c_r + w_s}{k q_{\mathrm{s1}}}, p_{\mathrm{s1}} = 1 - q_{\mathrm{s1}}, p_{\mathrm{sn}} = 1 - q_{\mathrm{sn}} - \delta q_{\mathrm{sr}}, p_{\mathrm{sr}} = \delta(1 - q_{\mathrm{sn}} - q_{\mathrm{sr}})$, into formula 1, we can obtain:

$$\pi_{\mathrm{Sr}} = (1 - s - c_n - q_{\mathrm{s1}})q_{\mathrm{s1}} + q_{\mathrm{sn}}\left(1 - s - c_n - q_{\mathrm{sn}} - \frac{\delta(-c_r + w_s)}{k}\right) + \frac{(-c_r + w_s)(-w_s + \delta(1 - q_{\mathrm{sn}} - \frac{-c_r + w_s}{k}))}{k} \tag{10}$$

The 1st and 2nd order derivatives of $q_{\mathrm{s1}} q_{\mathrm{sn}}, w_s$, about τ_s as below:

$$\frac{\partial \pi_{\mathrm{Sn}}}{\partial q_{\mathrm{s1}}} = 1 - s - c_n - 2q_{\mathrm{s1}}, \frac{\partial^2 \pi_{\mathrm{Sn}}}{\partial^2 q_{\mathrm{s1}}} = -2$$

$$\frac{\partial \pi_{\mathrm{Sn}}}{\partial q_{\mathrm{sn}}} = 1 - s - c_n - 2q_{\mathrm{sn}} - \frac{2\delta(-c_r + w_s)}{k}, \frac{\partial^2 \pi_{\mathrm{Sn}}}{\partial^2 q_{\mathrm{sn}}} = -2$$

$$\frac{\partial \pi_{\mathrm{Sn}}}{\partial w_s} = \frac{k\delta + (k + 2\delta)c_r - 2k\delta q_{\mathrm{sn}} - 2k w_s - 2\delta w_s}{k^2}, \frac{\partial^2 \pi_{\mathrm{Sn}}}{\partial^2 w_s} = \frac{2(-1 - \frac{\delta}{k})}{k}$$

On the Hessian matrix of $q_{\mathrm{s1}} q_{\mathrm{sn}}, w_s$:

$$H = \begin{bmatrix} -2 & 0 & 0 \\ 0 & -2 & -\frac{2\delta}{k} \\ 0 & -\frac{2\delta}{k} & \frac{2(-1 - \frac{\delta}{k})}{k} \end{bmatrix}$$

$$|H|_1 = |-2| = 2 > 0$$

$$|H|_2 = \begin{vmatrix} -2 & 0 \\ 0 & -2 \end{vmatrix} = 4 > 0$$

$$|H|_3 = \begin{bmatrix} -2 & 0 & 0 \\ 0 & -2 & -\frac{2\delta}{k} \\ 0 & -\frac{2\delta}{k} & \frac{2(-1 - \frac{\delta}{k})}{k} \end{bmatrix} = -\frac{8(k + \delta - \delta^2)}{k^2} < 0$$

Therefore, formula 9 is concave to $q_{s1}q_{sn}, w_s$. Subsidy policies and non subsidy policies can also be similarly proven.

The proof of Lemma 1 is completed.

The optimal solution for the government to adopt subsidy policies and the government not to adopt policies is the same.

Conclusion 1. Under three policies, the optimal solution is as follows:

Shown in Table 2.It is optional solution.

Table 2. The optional solution

Equilibrium solution	Carbon tax policy(i=v)	Subsidy policy(i=s)	No policy(i=n)
w_i	$-\frac{-ks\delta - k\delta c_n - kc_r - 2\delta c_r + 2\delta^2 c_r}{2(k+\delta-\delta^2)}$	$\frac{k\delta c_n - (k-2(-1+\delta)\delta)(v-c_r)}{2(k+\delta-\delta^2)}$	$-\frac{-k\delta c_n - kc_r - 2\delta c_r + 2\delta^2 c_r}{2(k+\delta-\delta^2)}$
q_{in}	$-\frac{-k+ks-\delta+s\delta+\delta^2+kc_n+\delta c_n-\delta c_r}{2(k+\delta-\delta^2)}$	$-\frac{-k-\delta+v\delta+\delta^2+kc_n+\delta c_n-\delta c_r}{2(k+\delta-\delta^2)}$	$-\frac{-k-\delta+\delta^2+kc_n+\delta c_n-\delta c_r}{2(k+\delta-\delta^2)}$
q_{it1}	$\frac{1}{2}(1-s-c_n);$	$\frac{1}{2}(1-c_n);$	$\frac{1}{2}(1-c_n);$
q_{ir}	$\frac{s\delta+\delta c_n-c_r}{2(k+\delta-\delta^2)}$	$\frac{v+\delta c_n-c_r}{2(k+\delta-\delta^2)}$	$\frac{(1-c_n)(-\delta c_n+c_r)}{2(k+\delta-\delta^2)(-1+c_n)}$
p_{in}	$\frac{1}{2}(1+s+c_n)$	$\frac{1}{2}(1+c_n)$	$\frac{1}{2}(1+c_n)$
p_{ir}	$\frac{\delta(k+ks+\delta-\delta^2+kc_n-(-1+\delta)c_r)}{2(k+\delta-\delta^2)}$	$-\frac{\delta(-k+v-\delta-v\delta+\delta^2-kc_n+(-1+\delta)c_r)}{2(k+\delta-\delta^2)}$	$\frac{\delta(k+\delta-\delta^2+kc_n-(-1+\delta)c_r)}{2(k+\delta-\delta^2)}$
p_{it1}	$\frac{1}{2}(1+s+c_n)$	$\frac{1}{2}(1+c_n)$	$\frac{1}{2}(1+c_n)$
τ_i	$\frac{-s\delta-\delta c_n+c_r}{(k+\delta-\delta^2)(-1+s+c_n)}$	$\frac{-v-\delta c_n+c_r}{(k+\delta-\delta^2)(-1+c_n)}$	$\frac{-\delta c_n+c_r}{(k+\delta-\delta^2)(-1+c_n)}$
π_{in}	$\frac{A}{4(k+\delta-\delta^2)}$	$\frac{B}{4(k+\delta-\delta^2)}$	$\frac{C}{4(k+\delta-\delta^2)}$
π_{ir}	$\frac{k(s\delta+\delta c_n-c_r)^2}{8(k+\delta-\delta^2)^2}$	$\frac{k(v+\delta c_n-c_r)^2}{8(k+\delta-\delta^2)^2}$	$\frac{k(-\delta c_n+c_r)^2}{8(k+\delta-\delta^2)^2}$

A=$2(k+\delta-\delta^2)+(2k-(-2+\delta)\delta)c_n^2+c_r^2-2c_n(2(k+\delta-\delta^2)+\delta c_r)$

B= $2k+v^2+2\delta-2\delta^2+(2k-(-2+\delta)\delta)c_n^2-2vc_r+c_r^2-2c_n(2k-\delta(-2+v+2\delta)+\delta c_r$

C=$2(k+\delta-\delta^2)+(2k-(-2+\delta)\delta)c_n^2+c_r^2-2c_n(2(k+\delta-\delta^2)+\delta c_r)$

3.3 Model Analysis

Based on conclusion 1, Conclusion 2, Conclusion 3, and Conclusion 4 can be drawn

Conclusion 2. Analysis of the impact of Government Policies on Waste Recycling Rate:

(1)when $\delta > c_r, \frac{\partial \tau_s}{\partial s} > 0$,otherwise, $\frac{\partial \tau_s}{\partial s} \leq 0$

(2)$\frac{\partial \tau_v}{\partial v} > 0$

Proof: From conclusion 1, it can be concluded that:

$\frac{\partial \tau_s}{\partial s} = \frac{\delta - c_r}{(k+\delta-\delta^2)(-1+s+c_n)^2}$,when $\delta - c_r > 0$, $\frac{\partial \tau_s}{\partial s} > 0$,when $\delta \leq c_r, \frac{\partial \tau_s}{\partial s} \leq 0$.

$\frac{\partial \tau_v}{\partial v} = \frac{1}{(k+\delta-\delta^2)(1-c_n)} > 0$.

From conclusion 2, we can conclude that under the carbon tax policy, both the unit cost of remanufacturing and relative discount will impact the recycling rate of waste

products. When relative discount remains fixed, the lower the cost of remanufacturing products, the more actively remanufacturers are able to carry out waste product recycling, which increases the recycling rate of waste products. When the cost of remanufactured products produced by remanufacturers remains fixed, the greater the relative discount, which means that the circulation between remanufactured products and new products is stronger, and consumers are more enthusiastic about purchasing remanufactured products. The increasing demand from consumers for remanufactured products, so remanufacturers will have greater production enthusiasm and require more raw materials, which are waste products after the first cycle of use. Finally, the remanufacturer increased the recycling rate of waste products. Under the subsidy policy, the recycling rate of waste products will be improved. Because every time a remanufacturer produces a remanufactured product, the government provides a quota for the unit to remanufacture the product, which will improve enthusiasm of remanufacturer.In order to improve profits,remanufacturer will actively increase the waste recycling rate.

Management Implication 1: Although the carbon tax policy can effectively interfere with remanufacturing production activities, it can also consider how to diminish the production cost of remanufactured products and enhance relative discounts. For example, the government can indirectly improve product recovery rate by purchasing remanufactured products.

Conclusion 3. The influence of carbon tax and subsidy policies on outsourcing costs, unit product retail prices, and sales volume:

(1).$\frac{\partial w_s}{\partial s} > 0, \frac{\partial p_{S1}}{\partial s} > 0, \frac{\partial p_{Sn}}{\partial s} > 0, \frac{\partial p_{Sr}}{\partial s} > 0, \frac{\partial q_{Sr}}{\partial s} > 0, \frac{\partial q_{S1}}{\partial s} < 0, \frac{\partial q_{Sn}}{\partial s} < 0.$

(2).$\frac{\partial w_v}{\partial v} < 0, \frac{\partial p_{V1}}{\partial v} = \frac{\partial p_{Vn}}{\partial v} = 0, \frac{\partial p_{Vr}}{\partial v} < 0, \frac{\partial q_{Vr}}{\partial v} > 0, \frac{\partial q_{V1}}{\partial v} = 0, \frac{\partial q_{Vn}}{\partial v} < 0.$

From Conclusion 3, Under carbon tax policy, since remanufacturers are only responsible for producing remanufactured products, and original manufacturers are responsible for selling two types of products, in order to compensate for the losses caused by the carbon tax policy, original manufacturers will increase the retail price of new products and transfer their losses to consumers. Moreover, there is a competitive relationship between the two products, and the sales of remanufactured products do not decrease but increase, But the sales volume of the new product has decreased. Under the subsidy policy, original manufacturers will actively reduce outsourcing costs in order to obtain government subsidies. Subsidy policies are not related to product prices and sales volume in the 1st cycle, nor on the retail price of new products in the second cycle. The retail price of remanufactured products will all decreases.Due to the competitive relationship, thus, the advantage of remanufacturing products has increased their sales volume, leading to a decline in the sales volume of new products.

Management Implication 2: Original manufacturers can use outsourcing models to change the effection on themselves with subsidy or carbon tax policies. For example, under carbon tax policy, although carbon tax policy directly reduce some of the profits of original manufacturers, original manufacturers can not only divert the cost of carbon tax to consumers by increasing the retail price of products, but also increase their own profits by increasing outsourcing costs. Under the subsidy policy, original manufacturers can transfer government subsidies by reducing outsourcing costs, thereby increasing increased profits. From the perspective of manufacturer profits, although raising the

price of new products does not affect their own profits, it is not conducive to economic development in the long run. Therefore, the original manufacturer can bear part of the product recycling, repackaging the waste products to the remanufacturer, and charging corresponding fees.

Conclusion 3 leads to inference 1, which is as follows:

Corollary 1. The government policies rank outsourcing costs, unit retail prices, and sales volume as follows:

(1)$w_s > w_n > w_v$;

(2)$p_{\mathrm{S1}} > p_{\mathrm{V1}} = p_{\mathrm{N1}}$;

(3)$p_{\mathrm{Sn}} > p_{\mathrm{Vn}} > p_{\mathrm{Nn}}$;

(4)$q_{\mathrm{V1}} = q_{\mathrm{N1}} > q_{\mathrm{S1}}$;

(5)when $\frac{s}{v} < \frac{\delta}{\delta+k}$, $q_{\mathrm{Nn}} > q_{\mathrm{Sn}} > q_{\mathrm{Vn}}$,otherwise, $q_{\mathrm{Nn}} > q_{\mathrm{Vn}} \geq q_{\mathrm{Sn}}$;

(6) $p_{\mathrm{Sr}} > p_{\mathrm{Nr}} > p_{\mathrm{Vn}}$;

(7)when $\frac{s}{v} > \frac{1}{\delta}$, $q_{\mathrm{Sr}} > q_{\mathrm{Vr}} > q_{\mathrm{Nr}}$,otherwise, $q_{\mathrm{Vr}} \geq q_{\mathrm{Sr}} > q_{\mathrm{Sr}}$.

Conclusion 4: The impact of government policies on returns:

when $s > 1 - c_n + \frac{\delta c_r}{2k+2\delta-\delta^2}$,$\frac{\partial \pi_{Sn}}{\partial s} > 0$;otherwise, $\frac{\partial \pi_{Sn}}{\partial s} \leq 0$; $\frac{\partial \pi_{Sr}}{\partial s} > 0$.

$\frac{\partial \pi_{Vr}}{\partial v} > 0$, $\frac{\partial \pi_{Vn}}{\partial v} > 0$.

From conclusion 4, under carbon tax policy, the profits of original manufacturers decrease when carbon tax amount figure falls below a certain range. From conclusion 3, it can be concluded that the reason for the profit of original manufacturers is that, even though the prices of the two products have increased, the sales volume of new products has decreased, resulting in a decrease in profit from new product sales. Moreover, the decrease in profit from new product sales is bigger than the increase in yield from remanufactured products, finally leading to a decrease in profit for original manufacturers. On the contrary, when the carbon tax amount adopted by the government exceeds a certain value, the original manufacturer compensates for the losses caused by the carbon tax by remanufacturing products, ultimately leading to an overall increase in profits. For remanufacturers, under carbon tax policy, it will increase outsourcing costs and ultimately increase the profits of remanufacturers. Under the subsidy policy, original manufacturers enhance the two product price, while reducing outsourcing costs to remanufacturers, and the sales volume of both products increases, resulting in increased profits for original manufacturers. For remanufacturers, although the outsourcing costs obtained have been reduced, with government subsidy policies, the profits of remanufacturers ultimately increase.

Management Implication 3: Under carbon tax policy. Products has significantly increased. This means that remanufacturers has increased motivation. Of course, carbon tax valve can not necessarily the smaller the better, but outght to exceed a range. However, the carbon tax can not necessarily the bigger the better. If the carbon tax is too large, it will lead to the original manufacturer reducing the production of new products in the 1st cycle, directly leading to the production of remanufactured products in the 2nd cycle, and ultimately affecting the development of the remanufacturing industry.

Corollary 2. Ranking of the effection of three Policies on Income:

when $s < 1 - c_n + \frac{\delta c_r}{2k+2\delta-\delta^2}$,$\pi_{Vn} > \pi_{Nn} > \pi_{Sn}$,otherwise, $\pi_{Nn} \geq \pi_{Vn} > \pi_{Sn}$.

when$\frac{s}{v} > \frac{1}{\delta}$, $\pi_{Sr} > \pi_{Vr} > \pi_{Nr}$,otherwise, $\pi_{Vr} \geq \pi_{Sr} > \pi_{Nr}$.

In order to facilitate the analysis of the environmental influence of the three policies, when no policies are adopted is$E_n = e_n(q_{N1} + q_{Nn}) + e_r q_{Nr}$; Uner the carbon tax policy, environmental impact of two products is $E_s = e_n(q_{S1} + q_{Sn}) + e_r q_{Sr}$; In addition, Under the subsidy policies, environmental impact of two products is $E_v = e_n(q_{V1} + q_{Vn}) + e_r q_{Vr}$.

(1)$E_n = [\frac{1}{2}(1 - c_n) - \frac{-k-\delta+\delta^2+kc_n+\delta c_n-\delta c_r}{2(k+\delta-\delta^2)}] + \frac{(\delta c_n - c_r)e_r}{2(k+\delta-\delta^2)}$

(2)$E_s = [\frac{1}{2}(1 - s - c_n) + \frac{k-ks+\delta-s\delta-\delta^2-(k+\delta)c_n+\delta c_r}{2(k+\delta-\delta^2)}]e_n + \frac{(s\delta+\delta c_n-c_r)e_r}{2(k+\delta-\delta^2)}$

(3)$E_v = [\frac{1}{2}(1 - c_n) - \frac{-k-\delta+v\delta+\delta^2+kc_n+\delta c_n-\delta c_r}{2(k+\delta-\delta^2)}]e_n + \frac{(v+\delta c_n-c_r)e_r}{2(k+\delta-\delta^2)}$

Conclusion 5: Three policies have environmental impacts:

when$\frac{e_r}{e_n} > \delta$, $E_v > E_n > E_s$,otherwise, $E_n \geq E_v > E_s$.

Combining Conclusion 3 and Conclusion 5, it can be concluded that carbon tax have a positive influence on the circumstance. It is not difficult to analyze the reasons behind it,under carbon tax policy,the new product price will be enhanced, and consumers will not choose new products in pursuit of cost-effectiveness, ultimately leading to decrease the quantity of new products new products. Although under carbon tax policy, the price of remanufactured products has been raised, consumers have not reduced their purchases of remanufactured products due to market competition, the impact of remanufactured products on the environment by units is much smaller than that of new products by units. In the end.Carbon tax policy has the least influence on the environment.

Management Implication 4: When the government needs to govern the environment, it should adopt effective carbon tax policies, which can effectively diminish the influence of manufacturing industries on the circumstance. The carbon tax amount should not be too large or too small, and appropriate values should be adopted to achieve a win-win situation for all three parties.

4 Numerical Analysis

For the sake of further verify research conclusion of this article, a Chinese company's remanufactured engine was taken as an example to contrast and find the effection of two policies on outsourcing remanufacturing decision variables. According to literature and the actual production situation of enterprises, the production cost of remanufactured engines per unit was reduced by 50% compared to the production cost of new engines, the environmental impact was reduced by 60%,$c_r = 0.5c_n$,$e_r = 0.4e_n$. Further reference to literature2,$c_r = 0.1$, $c_n = 0.2$, $e_n = 1$, $e_r = 0.4$,$k = 1.1$. Due to the simplicity of the first cycle, this article only analyzes the second cycle.

4.1 The Influence of δ / s on Waste Recycling Rate

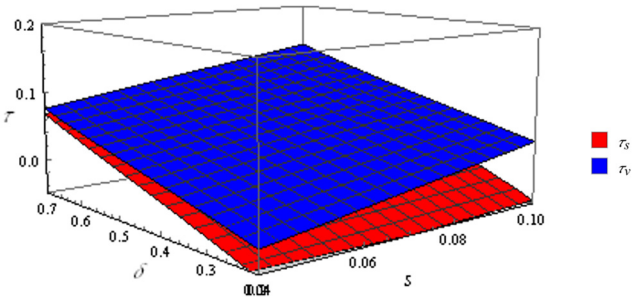

Fig. 2. The influence of δ / s on waste recycling rate.

From Figure 2, it can be analyzed that when carbon tax quota remains fixed, the higher the relative discount, the higher the recycling rate of remanufacturers. This is because the carbon tax remains unchanged, and the greater the relative discount, the higher the circulation between new products and remanufactured products. Remanufactured products are recognized by consumers and have higher purchasing enthusiasm, which leads to remanufactured product quantity will be enhanced, Increased enthusiasm among remanufacturers for recycling waste products. When the relative discount remains fixed, the higher the government's carbon tax amount, the product recycling rate will be increased. The reason is speculated that, when takes higher tax amount, non remanufactured products produced by original manufacturers are downstream in the competitive market, and consumers are more likely to purchase remanufactured products, leading to remanufactured product quantity will be enhanced. When the government's carbon tax amount and subsidy fees are the same, adopting a subsidy policy by the government is more conducive to promoting remanufacturers to recycle waste products.

Corollary 3. The influence of relative discounts on thte product recovery rate is:

$$\frac{\partial \tau_s}{\partial \delta} > 0$$

Management Implication 5. Under a certain policy, it should prioritize relative discounts and adopt corresponding policies based on the value of relative discounts. If the relative discount is less than a certain range, the government should adopt a subsidy policy, which is more conducive to the recycling of waste products by remanufacturers. Conversely, if the relative discount exceed a certain range, carbon tax policy should be given priority consideration.

4.2 The Influence of $\delta/\ s$ on Retail Price

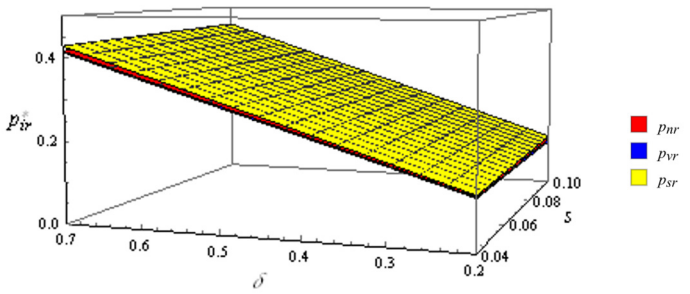

Fig. 3. The influence of relative discount δ and government carbon tax s on the retail price of unit remanufactured products.

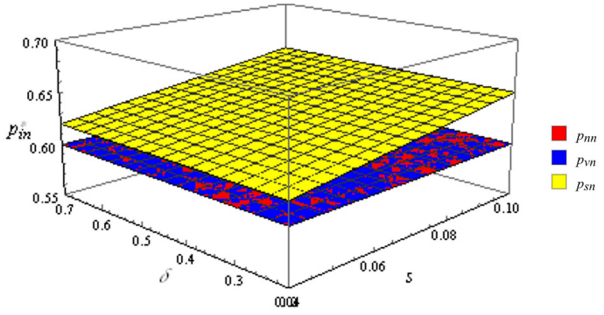

Fig. 4. The influence of relative discount δ and carbon tax s about retail products price.

From the analysis of Figures 3, 4, carbon tax policy will enhance the two products price. The specific reason for this is that under carbon tax policy, original manufacturer is not produce remanufacturing products, but instead adopts outsourcing remanufacturing, and the original manufacturer is responsible for the sales of both products. The prices of the two products are set by the original manufacturer. At this time, the original manufacturer will increase the retail price of the new product to transfer the impact of carbon tax on themselves, let consumers to bear carbon tax. Due to the market competition, consumers will tend to choose remanufactured products, ultimately the sales of remanufactured products will enhance, leading to remanufactured products price has been raised

Corollary 4. The influence of relative discounts on retail prices:

$$\frac{\partial p_{Nn}}{\partial \delta} < 0, \frac{\partial p_{Sn}}{\partial \delta} < 0, \frac{\partial p_{Vn}}{\partial \delta} < 0$$
$$\frac{\partial p_{Nr}}{\partial \delta} > 0, \frac{\partial p_{Sr}}{\partial \delta} > 0, \frac{\partial p_{Vr}}{\partial \delta} > 0$$

Management Implication 6. For remanufacturing enterprises, the greater the relative discount, the stronger the purchasing power of consumers towards remanufactured products, and the remanufacturing profits will also increase. However, the two products in the market are in a competitive relationship, and when remanufactured products are in a strong position, new products are in a weak position, which undoubtedly

undermines the enthusiasm of original manufacturers for new product production. Remanufactured products are waste products from the first cycle of new product elimination, due to new product reduction,lead to remanufacture product reduction. The government should take appropriate measures to maintain a balance in the quantity of products between the two.

4.3 The Influence of δ and s on the Profits of Two Manfufacturer

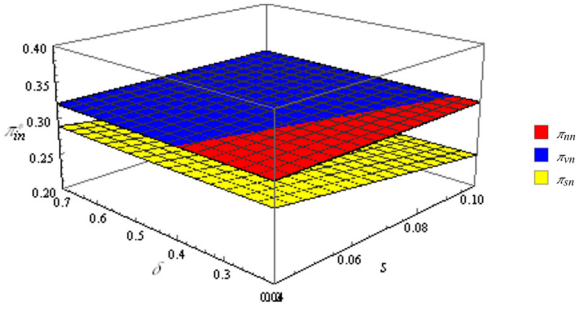

Fig. 5. The influence of relative discounts δ and government carbon taxes s on the profits of original manufacturer

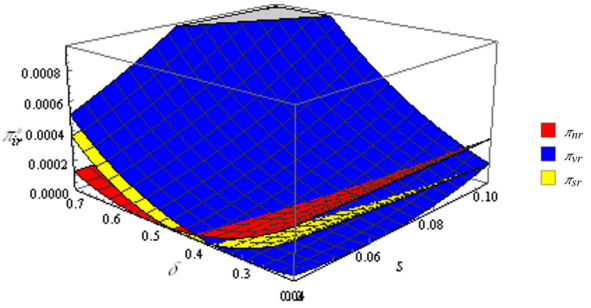

Fig. 6. The influence of relative discounts δ and government carbon taxes s on the profits of remanufacturers

From the analysis in Figures 5 and 6, under carbon tax policy. Although original manufacturers divert carbon tax amount by improving two products price, the revenue from the sales volume of remanufactured products is less than the revenue from the reduction of new products, which is not conducive to the development of original manufacturers and will also undermine their enthusiasm. Under subsidy policies, original manufacturers transfer government subsidies by increasing retail prices, which can increase the revenue of original retailers. For remanufacturers, when the relative discount and carbon tax exceed a certain value, regardless of what policies the government adopts, it will increase the profits of remanufacturers, and the benefits of adopting subsidy policies are more obvious.

Corollary 5. The influence of relative discounts on the profits of two manfufacturer.

$$\frac{\partial \pi_{Nn}}{\partial \delta} > 0, \frac{\partial \pi_{Vn}}{\partial \delta} > 0, \frac{\partial \pi_{Sn}}{\partial \delta} > 0$$
$$\frac{\partial \pi_{Nr}}{\partial \delta} > 0, \frac{\partial \pi_{Vr}}{\partial \delta} > 0, \frac{\partial \pi_{Sr}}{\partial \delta} > 0$$

Management Implication 7. Original manufacturers and remanufacturers, in order to increase their own profits, will find ways to increase relative discounts, such as promoting the quality and performance of remanufactured products through television, or adopting a seven day no reason return and exchange model when selling remanufactured products, eliminating consumer concerns about remanufactured products, indirectly increasing consumer trust of remanufactured products, and ultimately increasing relative discounts.

5 Conclusion

The government's carbon tax and subsidy policies are both effective ways for the government to indirectly participate in remanufacturing. But different policies have different effects.. This article constructs a game model of the original manufacturer and remanufacturing cycles through two policies, To facilitate contrast and find the influcence of the different policies on manufacturing/remanufacture. The main conclusions and management insights obtained through research are as follows:

(1) Under the outsourcing and remanufacturing model adopted by the original manufacturer and under carbon tax policy. Original manufacturer can raise outsourcing costs to increase the amount of waste recycling for remanufacturers, thereby increasing their enthusiasm for producing remanufactured products, and ultimately remedy profit by generating more profits from remanufactured products. Meanwhile, original manufacturers transfer some carbon taxes to consumers. Adopting a method of increasing retail prices. Under the subsidy policy, original manufacturer raises profits by reducing outsourcing costs and increasing the retail prices of two products in order to obtain subsidies.

(2) The government's two policies can improve the advancement of manufacturing/remanufacturing industries, simultaneously, diminish their influence on the environment. Through comparative analysis, under carbon tax policy.The manufacturing industry has the lowest influence on the environment. This is because the new products reduce, while the sales number of remanufactured products enhance, and the influence of remanufactured products on the environment is lower than that of new products on the environment.

(3) Management inspiration: Under two policies, original manufacturers can divert carbon tax or obtain government subsidies by enhancing the retail prices of two products; Under carbon tax policy, it is beneficial to raise the enthusiasm of remanufacturers to recycle waste products, indirectly promoting the production of remanufactured products. However, the carbon tax collection is not necessarily better, nor is it necessarily better to be smaller. It should be within a certain numerical range. When the government attaches importance to environmental protection issues, priority should be given to carbon tax policy.

(4) This article studies subsidy and carbon tax policy, providing relevant reference basis for the government. In order to achieve higher economic and environmental benefits, the government should choose carbon tax policy. Further refinement of research can divide manufacturing enterprises into high emission enterprises and low emission enterprises, adopt historical emission method for high carbon emission enterprises, adopt benchmark method for low carbon enterprises, and influence and guide low-carbon remanufacturing behavior of enterprises through reasonable setting of carbon trading prices, thereby promoting the good promotion of manufacturing enterprises.

The premise of this study is that remanufactured products and new products have the same quality and function, and there is no distinction between the two. Further research and analysis can be conducted on products of different qualities. For the remanufacturing model, further research can be conducted on the impact of authorized remanufacturing in the future. Explore the difference between outsourcing and authorization. For carbon policies, further consideration can be given to carbon trading, the impact of carbon quotas on manufacturing, and the impact on the environment in the future.

Reference

1. Sun Hao, Wang Lei, Li Chen, et al. Research on the competition model of retailer-led closed-loop supply chain with different recycling modes[J]. Chinese Journal of Management Science, 2020, 28(4): 86-98.
2. Zou Z B, Wang J J, Deng G S, et al. Third-party remanufacturing mode selection: Outsourcing or authorization?[J]. Transportation Research Part E: Logistics and Transportation Review, 2016, 87: 1-19.
3. Bian J, Zhang G, Zhou G. Manufacturer vs. consumer subsidy with green technology investment and environmental concern[J]. European Journal of Operational Research, 2020, 287(3): 832-843
4. Wang Y, Chen W, Liu B. Manufacturing/remanufacturing decisions for a capital-constrained manufacturer considering carbon emission cap and trade[J]. Journal of Cleaner Production, 2017, 140: 1118-1128.
5. Wang Y, Chen W. Effects of emissions constraint on manufacturing/remanufacturing decisions considering capital constraint and financing[J]. Atmospheric Pollution Research, 2017, 8(3): 455-464.
6. Ganda F. The impact of innovation and technology investments on carbon emissions in selected organisation for economic Co-operation and development countries[J]. Journal of cleaner production, 2019, 217: 469-483.
7. Dou G, Guo H, Zhang Q, et al. A two-period carbon tax regulation for manufacturing and remanufacturing production planning[J]. Computers & Industrial Engineering, 2019, 128: 502-513.
8. Hu X, Yang Z, Sun J, et al. Carbon tax or cap-and-trade: Which is more viable for Chinese remanufacturing industry?[J]. Journal of Cleaner Production, 2020, 243: 118606.
9. Zhu X, Wang Z, Wang Y, et al. Incentive policy options for product remanufacturing: subsidizing donations or resales?[J]. International Journal of Environmental Research and Public Health, 2017, 14(12): 1496.
10. Guo, D.; He, Y.; Wu, Y.; Xu, Q. Analysis of Supply Chain under Different Subsidy Policies of the Government. *Sustainability* **2016**, *8*, 1290. https://doi.org/10.3390/su8121290

11. Hatcher G D, Ijomah W L, Windmill J F C. Design for remanufacture: a literature review and future research needs[J]. Journal of Cleaner Production, 2011, 19(17-18): 2004-2014.
12. Agrawal S, Singh R K, Murtaza Q. Outsourcing decisions in reverse logistics: Sustainable balanced scorecard and graph theoretic approach[J]. Resources, Conservation and Recycling, 2016, 108: 41-53.
13. Li C, Liu F, Cao H, et al. A stochastic dynamic programming based model for uncertain production planning of re-manufacturing system[J]. International Journal of Production Research, 2009, 47(13): 3657-3668.
14. Denizci Guillet B, Shi X. Can revenue management be integrated with customer relationship management?[J]. International Journal of Contemporary Hospitality Management, 2019, 31(2): 978-997.
15. John S T, Sridharan R, Kumar P N R, et al. Multi-period reverse logistics network design for used refrigerators[J]. Applied Mathematical Modelling, 2018, 54: 311-331.