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Research on Supply Chain Management Considering Consumer Heterogeneity under Different Carbon Tax Return Policies

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***Abstract*—The carbon tax return policy is a carbon control policy that combines incentives and constraints, which can alleviate the short-term economic negative effects. In order to understand the behaviors of the company in the carbon tax return policy, with consumers have heterogeneous low-carbon preference. The paper uses the master-slave game to explore. The study found that the return of carbon tax to consumers is more significant for the profit incentives of the supply chain. When the carbon tax is returned to the manufacturer, the supply chain has a better emission reduction rate. And when the consumer has no difference intention to purchase low-carbon products or common products, the return of carbon tax to consumers can increase the enthusiasm of manufacturers to reduce emissions.**

Keywords—carbon tax return; consumer heterogeneity; master-slave game

I. INTRODUCTION

In the face of increasingly serious environmental pollution problems, China has been committed to promoting low-carbon development in recent years. In order to achieve environmental commitment, all countries in the world will also guide and restrict the production decisions of companies by corresponding carbon regulations[1]. Therefore, the carbon tax has entered the public's vision. As a carbon control policy with lower implementation cost, carbon tax has a positive effect on increasing government's macro-control carbon emission reduction and optimizing the green tax system, but Liu Jie [2]and Wei Lang [3] show that the short-term carbon tax will reduce the CO2 emissions and bring adverse impacts on China's economy and employment. In order to effectively solve the economic side effects of carbon tax, Liu Yu [4] and Xu Shichun [5] use dynamic CGE model simulation to find that the carbon tax return policy can alleviate the negative effect of carbon tax to a certain extent, and can promote the reduction.

As the micro-subject of resource utilization and carbon emission, enterprises are the direct targets of emission reduction policies. Under the constraints of relevant policies, enterprises must take into account the dual roles of rational economic people and socially responsible persons. Faced with the pressures and challenges of the two roles, companies must adjust their decision-making behavior according to the real environment. Gongxi Ting [6] studied how a single manufacturing company makes production decisions under the carbon cap trading policy. However, the independent research on the role of carbon regulation in a single enterprise is blind, and the influence of externality on the enterprise cannot be ignored. Therefore, it is necessary to put the enterprise into the supply chain for research.

Scholars Mingzhou Jin et al. [7] analyzed the impact of carbon-free emission constraints, carbon tax and carbon cap and trade policies on supply chain carbon emission reduction.

The above research show that the binding carbon emission policy can promote the carbon emission reduction behavior of supply chain members, but the excessive external cost will also inhibit the emission reduction motivation of enterprises. In fact, the implementation of some incentive policies can prompt the enterprise to increase their carbon reduction inputs.Scholar Cao Xiyu et al. [8] studied the impact of changes in the proportion of government subsidies on the optimal emission reduction rate and optimal order quantity in the supply chain.

It is concluded from the above literature that the incentive and restraint policies will have an impact on the production and emission reduction decisions of the members of the supply chain. Therefore, the combined influence of the two on the supply chain members has also attracted the attention of relevant scholars. So this paper we will consider consumer preference heterogeneity conditions, study the effects of two different carbon tax return policies on the decision-making of supply chain members' emission reduction behavior.

II. MODEL DESCRIPTION AND BASIC ASSUMPTIONS

A. Model Description

In this paper, a secondary supply chain consisting of suppliers and manufacturers is considered. Distributors are omitted here, and manufacturers directly adopt the direct selling mode. Manufacturers are divided into general manufacturers that do not adopt low-carbon technology and low carbon manufacturers that adopt low-carbon technology. Consumers' willingness to pay is heterogeneous, and they have different willingness to consume products with different carbon emissions. The mutual game relationship can be represented by Fig. 1.

This paper focuses on the following three issues. Firstly, we study the optimal overall profit and emission reduction rate of the supply chain in the centralized decision-making under the two carbon tax return policies, and the respective optimal profit and the optimal emission reduction rate of the common manufacturers, low-carbon manufacturers and suppliers under decentralized decision-making. Secondly, by comparing the results of the model, we judge the effect of the two carbon tax return policies on the optimal overall income and emission reduction rate of the supply chain. Finally, numerical simulations are conducted to study the manufacturer's enthusiasm for emission reduction under the circumstances of return, which provides a basis for the government to formulate policies.

B. Model Hypothesis

Suppose that the strategy of a single consumer in the demand market is to buy at most one product. And the consumer buys common product, the utility function is $U_H = \mu\alpha - P_H$, and purchasing the low-carbon product, the utility function is

$U_L = \alpha - P_L (0 < \mu < 1,\ 0 < \alpha < 1)$, and μ reflects the preference of the consumer. when μ tends to 1, the utility of consumers buying ordinary products tends to purchase low-carbon products, so that the sensitivity of products to low-carbon is not high. α is the consumer's willingness to pay for low-carbon products, and P_H and P_L are the sales prices of ordinary products and low-carbon products, respectively.

Ordinary and low-carbon manufacturers produce homogenous products with different carbon emissions, but consumers can identify the carbon content of products through carbon labels. Suppose the average manufacturer's unit product carbon emissions are e_H, and the low carbon manufacturer's unit product carbon emissions are e_L , where $e_H > e_L$ and $e_L = (1-\beta)e_H (0 < \beta < 1)$), β means low Carbon manufacturer's emission reduction rate. Therefore, the technology input cost of low-carbon manufacturers is $c_L = \frac{k}{2}(\beta e_H)^2$where $k(0 < k < 1)$is the abatement cost coefficient.

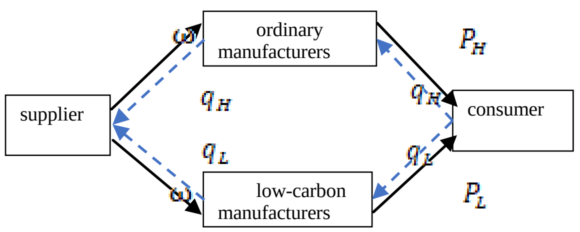

Fig. 1. Three-stage game structure.

The government levies a manufacturer's carbon tax at a fixed carbon tax rate, and adopts a carbon tax return subsidy strategy while charging a carbon tax. On the one hand, the government can subsidize the carbon emission reductions per unit of low-carbon manufacturers, the subsidy size is $a\beta e_H$, on the other hand, the government can subsidize individual consumers who buy low-carbon products through carbon tax rebates, at which point the utility function of the consumer purchasing the low carbon product becomes $U_{Lb} = \alpha - P_L + \mathrm{b}$.

Assume that the supplier's cost is 0, and its carbon emission is ignored. In addition, due to the dominant position of the manufacturer, the final surplus of the manufacturer can be directly returned to the supplier (without considering the refund cost). At this time, the order quantity of the manufacturer is directly related to the demand of the consumer. In addition, it is assumed that the unit product cost of both ordinary manufacturers and low-carbon manufacturers other than carbon tax is *c*.

III. Solution Method For Model

A. Return to the Manufacturer

When the carbon tax is directly returned to the manufacturer, according to the backward induction method, the demand of consumers for different products can be determined first.

When $\mu\alpha - P_H = \alpha - P_L$, consumers are at the critical point to buy low-carbon products and common products, the solution is:

$$\alpha_1 = \frac{P_H - P_L}{\mu - 1} \tag{1.1}$$

When $\mu\alpha - P_H = 0$, consumers are at the critical point of whether to buy products, the solution is:

$$\alpha_0 = \frac{P_H}{\mu} \tag{1.2}$$

Therefore, consumers in the interval $[0, \alpha_0]$ will not buy products, consumers in the interval $[\alpha_0, \alpha_1]$will buy ordinary products, and consumers in the interval $[\alpha_1, 1]$ will buy low-carbon products. The utility function of the consumer to buy low-carbon products and common products is drawn in the same graph, as shown in Fig. 2:

Then the demand for the two products is:

$$q_{Ha} = \int_{\alpha_0}^{\alpha_1} 1 d\alpha = \frac{P_H - \mu P_L}{\mu(\mu - 1)} \tag{1.3}$$

$$q_{La} = \int_{\alpha_1}^{1} 1 d\alpha = \frac{\mu - (P_H - P_L + 1)}{\mu - 1} \tag{1.4}$$

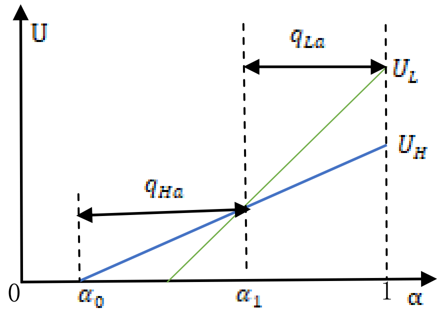

Fig. 2. Relationship between the willingness to pay and the utility of low-carbon products for consumers under the return of the manufacturer's scenario.

1) Centralized decision: When the carbon tax is directly returned to the manufacturer, the demand for low-carbon products in the consumer market is q_{La}, and the demand for ordinary products is q_{Ha}. The overall profit function of the supply chain is as follows:

$$\pi_{C1} = (P_{H1} - te_H - c)q_{Ha} + (P_{L1} - te_L - c + a\beta_1 e_H)q_{La} - \frac{k}{2}(\beta_1 e_H)^2 \tag{1.5}$$

Equation (1.5) is a binary quadratic function, where the first and second terms are the sales revenue of the average manufacturer and the low carbon manufacturer, the third is the cost of the supplier, and the fourth is the cost of abatement technology input of low carbon manufacturer. Among them, $a\beta_1 e_H$ represents the government's subsidy for low-carbon manufacturers' product units.

Since $B^2 - AC < 0$, and A<0, we know that the function π_{S1} has a maximum value, let the first derivative $\frac{\partial\pi_{S1}}{\partial P_{H1}}, \frac{\partial\pi_{S1}}{\partial P_{L1}}, \frac{\partial\pi_{S1}}{\partial \beta}$ in (1.5) are respectively equal to 0, which can be used to determine the optimal selling price of common products and low-carbon products when the supply chain is centralized in the carbon tax direct return manufacturer scenario, and also secure the manufacturer's optimal emission reduction rates,

$$P_{H1}^* = \frac{c+te_H+\mu}{2} \tag{1.6}$$

$$P_{L1}^* = \frac{2k(\mu-1)(1+te_H+c)+a(a+t)(c+te_H-\mu)}{4k(\mu-1)+2a(a+t)} \tag{1.7}$$

$$\beta_1^* = \frac{a(\mu-1)}{[2k(\mu-1)+a(a+t)]e_H} \tag{1.8}$$

According to P_{H1}^* and P_{L1}^*, the demand for common products and low-carbon products are q_{H1}^* and q_{L1}^*, respectively, and P_{H1}^*, P_{L1}^*, q_{H1}^*, q_{L1}^*, β_1^* Enter (1.5) to find the optimal overall profit π_{C1}^* of the supply chain in the context of centralized decision making and the carbon tax return manufacturer.

$$q_{La}^* = \frac{k(\mu-1)^2-a(a+t)}{[2k(\mu-1)+a(a+t)](\mu-1)} \tag{1.9}$$

$$q_{Ha}^* = \frac{a(a+t)(1+\mu)}{2[2k(\mu-1)+a(a+t)](\mu-1)} - \frac{c+te_H}{2\mu} \tag{1.10}$$

$$\pi_{C1}^* = \frac{1}{4} + \frac{a(\mu-1)[2(a+t)(\mu-1)-a]}{4[2k(\mu-1)+a(a+t)]} + \frac{(c+te_H)(c+te_H-2\mu)}{4\mu} + \frac{a^2(a+t)[4a-t(\mu+1)(\mu-3)]}{4[2k(\mu-1)+a(a+t)]^2(\mu-1)} \tag{1.11}$$

2) Decentralized decision making: Members in the supply chain are pursuing their own profit maximization when decentralized decision-making. The following three formulas are the profit functions of suppliers, general manufacturers and low-carbon manufacturers:

$$\pi_{S2} = \omega(q_{H2} + q_{L2}) \tag{2.1}$$

$$\pi_{H2} = (P_{H2} - c - te_H - \omega)q_{H2} \tag{2.2}$$

$$\pi_{L2} = (P_{L2} - c - te_L - \omega + a\beta_2 e_H)q_{L2} - \frac{k}{2}(\beta_2 e_H)^2 \tag{2.3}$$

It can be seen from the above that the demand of consumers in this scenario is respectively $q_{H2} = q_{Ha}$ and $q_{L2} = q_{La}$.

So the first derivative of ordinary manufacturers and low-carbon manufacturers about product sales prices and low-carbon manufacturers on emission reduction rates are $\frac{\partial\pi_{H2}}{\partial P_{H2}}, \frac{\partial\pi_{L2}}{\partial P_{L2}}, \frac{\partial\pi_{L2}}{\partial \beta_2}$, Let them be zero, so get

$$P_{H2}^* = \frac{(te_H+c+\omega)[(a+t)^2+k(\mu-1)(2+\mu)]+\mu(1-\mu)[(a+t)^2+k(\mu-1)]}{k(\mu-1)(4-\mu)+(2-\mu)(a+t)^2} \tag{2.4}$$

$$P_{L2}^* = \frac{(te_H+c+\omega)[(a+t)^2+3k(\mu-1)]+2(1-\mu)[(a+t)^2+k(\mu-1)]}{k(\mu-1)(4-\mu)+(2-\mu)(a+t)^2} \tag{2.5}$$

$$\beta_2^* = \frac{(a+t)(1-\mu)(te_H+c+\omega-2)}{ke_H(\mu-1)(4-\mu)+(2-\mu)e_H(a+t)^2} \tag{2.6}$$

P_{H2}^*, P_{L2}^*, $\beta_2^*$are returned to the formula (2.1) (2.2) (2.3) to obtain the profit of the supplier, the general manufacturer and the low carbon manufacturer respectively:

$$\pi_{S2}^* = \frac{\mu\omega[(a+t)^2+3k(\mu-1)]}{k\mu(\mu-1)(4-\mu)+\mu(2-\mu)(a+t)^2} - \frac{(te_H+c+\omega)\omega[(a+t)^2+k(\mu-1)(2+\mu)]}{k\mu(\mu-1)(4-\mu)+\mu(2-\mu)(a+t)^2} \tag{2.7}$$

$$\pi_{H2}^* = \frac{(1-\mu)\{\mu[(a+t)^2+k(\mu-1)]-(te_H+c+\omega)[(a+t)^2+2k(\mu-1)]\}^2}{\mu[k(\mu-1)(4-\mu)+(2-\mu)(a+t)^2]^2} \tag{2.8}$$

$$\pi_{L2}^* = \frac{k(1-\mu)^2(te_H+c+\omega-2)^2[2k(1-\mu)-3(a+t)^2]}{2[k(\mu-1)(4-\mu)-(2-\mu)(a+t)^2]^2} \tag{2.9}$$

Therefore, the total profit of the supplier under the decentralized decision:

$$\pi_{C2}^* = 1-\frac{kM^2}{2(a+t)^2}-\frac{[A+M(\mu-2)+2(\mu-1)-A\mu]^2}{(\mu-4)^2(\mu-1)}+\frac{A(\mu+2)-\mu(M+\mu-1)}{(\mu-4)\mu}-\frac{[-2A(\mu-1)+\mu(\mu+M-1)]^2}{(\mu-4)^2(\mu-1)\mu} \tag{2.10}$$

Where

$$\mathrm{M} = \frac{e_H(A-2)(a+t)^2(1-\mu)}{e_H(a+t)^2(2-\mu)+e_Hk(4-\mu)(\mu-1)}$$

$$A = te_H + c + \omega$$

B. *Return to the Consumer*

When the carbon tax is directly returned to the consumer, the consumer utility function for purchasing the low carbon product becomes $U_{Lc} = \alpha - P_L + b$. At this point, consumers buy low-carbon products or the tipping point of ordinary products becomes:

$$\alpha_1{}' = \frac{P_H-P_L+b}{\mu-1} \tag{3.1}$$

Whether the consumer buys the product or the critical point is $\alpha_0{}' = \frac{P_H}{\mu}$, the utility function U_L of the low-carbon product consumer in Fig. 2 is moved up by b units to get U_{Lc}, and the willingness to pay for the low-carbon product under the returning consumer scenario is drawn. The relationship with utility, as shown in Fig. 3:

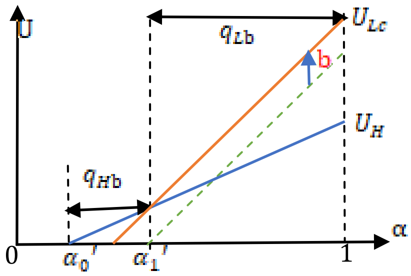

Fig. 3. Relationship between the willingness to pay and the utility of low-carbon products for consumers in the return to consumer scenario

Then the demand for the two products is:

$$q_{Hb} = \int_{\alpha_0{}'}^{\alpha_1{}'} 1d\alpha = \frac{P_H-\mu P_L+\mu b}{\mu(\mu-1)} \tag{3.2}$$

$$q_{Lb} = \int_{\alpha_1{}'}^{1} 1d\alpha = \frac{\mu-(P_H-P_L+1+b)}{\mu-1} \tag{3.3}$$

1) *Centralized decision:* According to the above, when the carbon tax is returned to consumers, the demand for low-carbon products in the consumer market is q_{Lb}, and the demand for ordinary products is q_{Hb}. Determine the maximum profit of the supply chain, the price of common products and low-carbon products based on product demand.

The overall profit function of the supply chain is as follows:

$$\pi_{C3} = (P_{H3} - te_H - c)q_{Hb} + (P_{L3} - te_L - c)q_{Lb} - \frac{k}{2}(\beta_3 e_H)^2 \tag{3.4}$$

The calculation of analogy 1 is available, the optimal overall profit of the supply chain when the carbon tax is returned to the consumer.

$$\pi_{C3}^* = \frac{(c+te_H-\mu)^2}{4\mu} + \frac{t^2(\mu-1-b)^2(k\mu-2k+t^2)}{2[2k(\mu-1)+t^2]^2} + \frac{(\mu-1-b)[(c-te_H+1+b)(k\mu-k+t^2)-k(c-te_H+\mu)]}{2[2k(\mu-1)+t^2]} \tag{3.5}$$

The price of ordinary products P_{H3}^*, the price of low-carbon products P_{L3}^* and the optimal emission reduction rate of low-carbon manufacturers β_3^* are:

$$P_{H3}^{*}=\frac{c+te_H+\mu}{2} \tag{3.6}$$

$$P_{L3}^{*}=\frac{2k(\mu-1)(1+te_H+c+b)+t^2(c+te_H-\mu+2+2b)}{2[2k(\mu-1)+t^2]} \tag{3.7}$$

$$\beta_3^{*}=\frac{t(\mu-1-b)}{[2k(\mu-1)+t^2]e_H} \tag{3.8}$$

2)Decentralized decision

When the carbon tax is returned to consumers, the profit function of suppliers, general manufacturers, and low-carbon manufacturers under decentralized decision-making is:

$$\pi_{S4}=\omega(q_{H4}+q_{L4}) \tag{4.1}$$

$$\pi_{H4}=(P_{H4}-c-te_H-\omega)q_{H4} \tag{4.2}$$

$$\pi_{L4}=(P_{L4}-c-te_L-\omega)q_{L4}-\frac{k}{2}(\beta_4 e_H)^2 \tag{4.3}$$

It can be seen from the above that the demand of consumers in this scenario is $q_{H4}=q_{Hb}$ and $q_{L4}=q_{Lb}$, respectively.

The first-order derivatives of general manufacturers and low-carbon manufacturers for product sales prices and low-carbon manufacturers on emission reduction rates are $\frac{\partial\pi_{H2}}{\partial P_{H2}},\frac{\partial\pi_{L2}}{\partial P_{L2}},\frac{\partial\pi_{L2}}{\partial\beta_4}$,Let them be zero, so get

$$P_{H4}^{*}=\frac{(te_H+c+\omega)(2+\mu)+\mu-\mu^2-\mu b-\mu t\beta e_H}{(4-\mu)} \tag{4.4}$$

$$P_{L4}^{*}=\frac{3(te_H+c+\omega)+(2+b)(1-\mu)-2t\beta e_H}{(4-\mu)} \tag{4.5}$$

$$\beta_4^{*}=\frac{(1-\mu)(te_H+c+\omega)+t(2\mu-2-3b+\mu b)}{ke_H(\mu-1)(4-\mu)+(2-\mu)e_H t^2} \tag{4.6}$$

Thus, the profits of ordinary and low-carbon manufacturers are:

$$\pi_{H4}^{*}=\frac{[-2(te_H+c+\omega)(\mu-1)+\mu(-1+b+\mu+N)]}{(\mu-4)^2(1-\mu)\mu}*\frac{[-2(te_H+c+\omega)(\mu-1)+\mu(-1+2b+\mu+N)]}{(\mu-4)^2(1-\mu)\mu} \tag{4.7}$$

$$\pi_{L4}^{*}=-\frac{kN^2}{t^2}-\frac{[-2+(te_H+c+\omega)-2N+b(\mu-3)+2\mu-\mu(te_H+c+\omega)+N\mu]}{(\mu-4)^2(\mu-1)}*\frac{[-2+(te_H+c+\omega)-2N+b(\mu-1)+2\mu-\mu(te_H+c+\omega)+N\mu]}{(\mu-4)^2(\mu-1)} \tag{4.8}$$

$$\pi_{S4}^{*}=[1-\frac{\mu-b\mu-N\mu-\mu^2+(te_H+c+\omega)(2+\mu)}{\mu(4-\mu)}]\omega \tag{4.9}$$

The supplier's profit π_{S4}^{*}, the average manufacturer's profit π_{H4}^{*}, and the low-carbon manufacturer's profit π_{L4}^{*} are summed to obtain the overall profit of the supply chain:

$$\pi_{C4}^{*}=\omega-\frac{ke_H{}^2[(te_H+c+\omega)(1-\mu)+t(-2-3b+2\mu+b\mu)]^2}{2[e_H t^2(2-\mu)+e_H k(4-\mu)(\mu-1)]^2}+\frac{[-2+(te_H+c+\omega)-2N+b(\mu-3)+2\mu-\mu(te_H+c+\omega)+N\mu]}{(\mu-4)^2(\mu-1)}*\frac{[-2+(te_H+c+\omega)-2N+b(\mu-1)+2\mu-\mu(te_H+c+\omega)+N\mu]}{(\mu-4)^2(\mu-1)}-\left[\frac{\mu-b\mu-N\mu-\mu^2+(te_H+c+\omega)(2+\mu)}{\mu(4-\mu)}\right]\omega-\frac{[-2(te_H+c+\omega)(\mu-1)+\mu(-1+b+\mu+N)]}{(\mu-4)^2(1-\mu)\mu}*\frac{[-2(te_H+c+\omega)(\mu-1)+\mu(-1+2b+\mu+N)]}{(\mu-4)^2(1-\mu)\mu} \tag{4.10}$$

Where

$$N=\frac{te_H[(te_H+c+\omega)(1-\mu)+t(-2-3b+2\mu+b\mu)]}{e_H t^2(2-\mu)+e_H k(4-\mu)(\mu-1)}$$

IV. MODEL ANALYSIS

According to Yao Yi[9] and Wei Lang- et al[10].The paper assume that the carbon tax rate is between the intervals [30, 50].By comparing the results of the above model solution, we can get the following conclusions.

Conclusion 1. Supply chain optimal overall profit π and carbon tax t, abatement cost coefficient k, ordinary manufacturer's unit product carbon emissions e_H , manufacturer's unit product cost c, consumer heterogeneity μ, and return to manufacturer ratio coefficient a is related to the proportional coefficient b of the returning consumer. When the centralized decision is made by $\pi_{C1}^{*}-\pi_{C3}^{*}<0$, the manufacturer's supply chain profit π_{C1}^{*} is less than the return of the consumer's supply chain profit π_{C3}^{*}, so the supply chain can be more motivated when the carbon tax is returned to the consumer. At the same time, when the carbon tax is returned to the consumer, the concentration of the decision-making supply chain profit π_{C3}^* is greater than the profit of the decentralized decision-making supply chain π_{C4}^*. Indeed, the members of the supply chain will damage the collective interest in pursuit of their own interests in the decentralized decision-making, so the supply chain's profit in centralized decision-making will be greater than the decentralized decision-making, which is in line with the practical significance.

Conclusion 2. Regardless of the return policy or decision-making model, the optimal emission reduction rate β of low-carbon suppliers represents the optimal emission reduction rate of the supply chain. After comparing the results of the above models, it is found that $\beta_1^* - \beta_3^* > 0$、 $\beta_2^* - \beta_4^* > 0$, that is, The manufacturer's optimal emission reduction rate when returning to manufacturer β_1^* is greater than the optimal emission reduction rate of low-carbon manufacturers when returning consumers β_3^*, under centralized decision. The emission reduction rate when returning to manufacturer β_2^* is greater than the optimal emission reduction rate of low-carbon manufacturers when returning consumers β_4^*, under decentralized decision-making. By comparing the optimal emission reduction rate β_1^* and the optimal emission reduction rate of decentralized decision-making β_2^* when returning to the manufacturer, it is found that the supply chain decentralized decision is optimal when the carbon tax is returned to the manufacturer. The emission reduction rate is the largest.

Conclusion3.When the carbon tax is returned to the manufacturer and under decentralized decision, regardless of the value of a, the low-carbon manufacturer's profit π_{L2}^* is always lower than the ordinary manufacturer's profit π_{H2}^*, which will to a certain extent dampen the manufacturer's efforts to reduce emissions. As a result, manufacturers in the supply chain tend to not participate in emission reductions in order to maximize their profits. But when the carbon tax is returned to the consumer, the size of the low-carbon manufacturer's optimal profit π_{L4}^* and the average manufacturer's profit π_{H4}^* varies with the returning consumer's proportionality factor b and consumer heterogeneity μ.

In order to further understand the impact of changes in b and μ on the profitability of supply chain members, the following data were selected to analyze the conclusions 3. Carbon tax t=40, k=0.6, e_H=10, c=0.3, ω=9. The simulation results shown in Fig. 4. It can be seen from the figure that the size of b decreases as μ increases as π_{L4}^*andπ_{H4}^* are equal.

Then the author selects two extreme points of μ=0.1 and μ=0.9 from Fig. 4. Concluded as follow:

When μ=0.1, and the carbon tax returned to the consumer, the difference between the optimal profit of the low-carbon manufacturer π_{L4}^* and the profit of the common manufacturer π_{H4}^* decreases first and then increases with the increase of b. When b>5919, π_{L4}^* starts to be larger than π_{H4}^*, which indicates that the return of carbon tax to consumers can dilute the negative effect of reducing emissions to low-carbon manufacturers to a certain extent.

When μ=0.9, and the carbon tax returned to the consumer, the trend of the profit gap between the common manufacturer and the low-carbon manufacturer is the same as μ=0.1 , but when b>40, the profit of the low-carbon manufacturer is higher than common manufacturer. Therefore, when the heterogeneity of consumers is small, the proportion of government tax rebates to consumers will improve the profit of low-carbon manufacturers, thereby increasing the enthusiasm of low-carbon manufacturers.

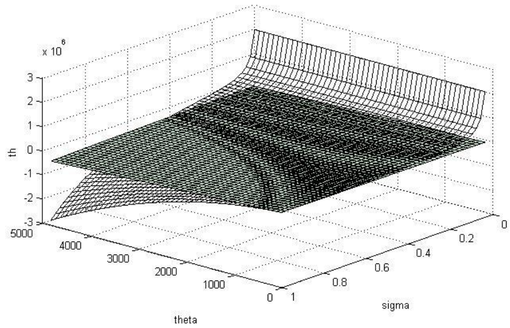

Fig. 4. The effect of the proportional coefficient b(o) of returning consumers and consumer heterogeneity μ(u) on $\pi_{L4}^* - \pi_{H4}^*$ (tl-th)

V. CONCLUSION

In light of Chinese national conditions, relevant scholars predict that environmental policies that combine incentives and constraints can promote the emission reduction behavior of Chinese companies. Therefore, this paper explore the impact of two return policies of carbon tax return manufacturers and consumers on the optimal carbon emission reduction and profit of the supply chain on the basis of consumer preference heterogeneity ,by constructing a secondary supply chain with two suppliers and one supplier.

From the perspective of government policy formulation, conclusions 1 and 2 show that the simultaneous pursuit of optimal profit and optimal emission reduction in the supply chain cannot be achieved. According to Conclusion 3, when consumers in the real world do not have low carbon awareness differences, the government can formulate a carbon tax return consumer policy to achieve the effect of promoting supply chain emission reduction, and the return ratio should consider the carbon tax and the costs of manufacturer.

From the point of view of corporate emission reduction, on the one hand, after the introduction of government policies, supply chain members should select appropriate emission reduction inputs and cost strategies according to the form and proportion of return, and achieve sustainable development, thus providing support for enterprises to conduct further low carbon promotion. On the other hand, supply chain members should actively carry out low-carbon transformation and explore the development of emission reduction technologies in the process of transformation and exploration, thus minimizing the cost of abatement.

Finally, this paper has a certain limitation, ignoring the impact of the dynamic variability of consumers' low-carbon awareness on supply chain emission reduction decisions, only considering the static preferences of consumers, ignoring the volatility of people's preferences over time. .

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