Design of Contract Considering Manufacturers' Moral Hazard for Carbon Emission Reduction under Government Punishment Mechanism

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***Abstract*—Aiming at the two-stage supply chain composed of manufacturers and retailers, it is assumed that all enterprises upstream and downstream strive to implement carbon emission reduction. Because of information asymmetry, manufacturers have a moral hazard in reducing carbon emissions. At the same time, the government decides whether to implement punishment or not by testing the carbon emission reduction standards of the product declared by manufacturers and retailers. This paper focuses on the impact of manufacturers' moral hazard probability and government punishment level on carbon emission reductions and profits of upstream and downstream enterprises. The study results show that when the government penalty intensity acts only on the retailer, the manufacturer must have an incentive for moral hazard behavior. The higher its moral hazard probability, the greater the retailer's expected profit loss. Therefore, a linear incentive contract design with fixed payments and adjustable incentive coefficients for retailers and an external loss-sharing contract design are investigated as a way to resolve the possible losses from moral hazards. The before and after comparison with the profit level and emission reductions also confirm the effectiveness of the contract design, which can ensure the manufacturer's expected profit. Achieve Pareto improvement of retailers' profits simultaneously. Linear incentive contracts have some limitations compared to external loss-sharing contracts. The analysis of examples further verifies the validity of the relevant conclusions.**

***Index Terms*—Information Asymmetry, Moral Hazard; Carbon Emission Reduction, Principal-agent, Incentive Contract**

I. Introduction

A. Motivation

Global warming is becoming increasingly severe, and extreme climate phenomena occur frequently. Reducing carbon emissions has become the consensus of all countries. Governments have also introduced environmental protection policies and regulations to help reduce carbon emissions. For example, the Chinese government has proposed more robust policies and measures to peak carbon dioxide emissions by 2030 and strives to achieve carbon neutrality by 2060. In the current context, the low-carbon supply chain has become a hot topic for scholars to study. As an essential subject of carbon emissions, physical enterprises produce most of the greenhouse gas emissions in the production process. Therefore, we must start from the product's whole life cycle and require each node in the supply chain to cooperate in emission reductions. But in practice, the information exchange between upstream and downstream enterprises is limited, and information asymmetry is widespread, which can easily lead to a performance loss in the supply chain system. Specifically, when the retailer entrusts the manufacturer to provide products that meet the procurement standards and falsely claims that the product meets the standards, the retailer's interests will be damaged. Suppose the retailer does not detect unqualified products. In that case, the product is sold to the consumer, and the consumer's interests are damaged. Therefore, the government must take specific measures to protect the interests of consumers from infringement, such as testing products. The manufacturer will be fined if they do not meet the emission reduction standards. The impact of information asymmetry in a particular link will be transmitted to the various participants in the supply chain. How to coordinate information asymmetry and study how enterprises make decisions to reduce emissions under incomplete information has practical significance.

Based on the above description, this paper will discuss the impact of a manufacturer's moral hazard behavior on carbon emission reduction in the supply chain. Moreover, consider how the government's punishment mechanism affects the performance of the supply chain. Further, analyze the decision-making behavior of the manufacturer's moral hazard and the retailer's response to the manufacturer's decision-making, and explore the optimal decision of the government.

B. Literature Review

The research on carbon emission reduction in the supply chain has become one of the hot issues in academia. The fields related to this study mainly involve information asymmetry, emission reduction behavior and investment, and the application of government environmental protection policies in the supply chain.

Scholars study the issues related to carbon emission reduction in the supply chain, mainly from the following aspects: consumers ' green preference, enterprises '

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investment in emission reduction, and the government's environmental protection policy. Some scholars have studied the degree and source of consumers ' awareness of green products and believe that consumers ' willingness to pay for green products increases with their environmental preferences (Chitra 2007) [1]. Carbon emission factors will affect supply chain management and decision-making (Benjaafar, et al. 2013) [2]. The low-carbon preference of consumers and the cost of carbon emission reduction of enterprises will affect the benefits of supply chain members (Ghosh and Shah 2012) [3]. Cooperation among supply chain members is the only effective way to achieve carbon emission reduction targets (Matthews, et al. 2008) [4]. (Sun, et al. 2020) [5] analyzed the problem of carbon emission transfer and emission reduction among enterprises in the supply chain. The lag time of emission reduction technology and the low carbon preference of consumers have a positive impact on manufacturers' carbon emission transfer levels. (Wang, et al. 2019) [6] consider manufacturers ' nearsighted and farsighted decision-making on carbon emission reduction levels, and analyze the impact of different behaviors on carbon emission reduction levels and supply chain members ' profits. Some scholars have constructed a dynamic game model of a three-level supply chain composed of suppliers, manufacturers, and retailers to analyze the changes in the optimal emission reductions (Chen, et al. 2022) [7]. The above research is based on the assumption of complete information. In reality, due to the institutional environment and the differences in corporate decision-making goals, the phenomenon of bilateral information asymmetry in the supply chain is widespread, and there is a phenomenon that supply chain members conceal or misrepresent their own decisions.

Most of the literature on information asymmetry considers demand information asymmetry, cost information asymmetry, and risk aversion information asymmetry between manufacturers and retailers. Supply chain contracts are widely studied to solve information asymmetry. Information asymmetry can affect the efficiency of supply chain contracts, and vertically integrated supply chains can solve this problem (Pishchulov, et al. 2022). [8] Studying partially integrated supply chain models, they describe the sensitivity of supply chain performance to the degree of integration. (Ha 2001) [9] The perishable goods supply chain was studied. (Mukhopadhyay, et al. 2009) [10] studied how manufacturers design incentive contracts when a retailer's private service cost information. (Zhou, et al. 2019) [11] analyzed the dynamic incentive of the supply chain under information asymmetry, and studied how the supply chain cooperates to improve the allocation efficiency of the supply chain through information screening in the long run. (Shao, et al. 2020) [12] analyzed the procurement competition mechanism of the two types of suppliers, deterministic cost and uncertain cost, under information asymmetry. In a dual-channel supply chain, information asymmetry benefits dealers but negatively impacts manufacturers and the entire supply chain (Lai, et al. 2018) [13]. Some scholars have analyzed the signal transmission model under asymmetric fairness concern information. Only when the signal transmission cost is different can the type of different retailers be revealed (Qin, et al. 2019) [14].

The government's environmental protection measures are mainly through carbon taxes, establishing carbon trading markets, and subsidies for enterprises to reduce emissions. The relevant literature mainly incorporates these three types of government measures into the supply chain system. (Wang, et al. 2017) [15] used a three-stage Stackelberg game model with a decentralized supply chain and a two-stage Stackelberg game model with a centralized supply chain to examine the government's carbon emission tax policy. (Zakeri, et al. 2015) [16] Analyzing both carbon trading and carbon tax policies through actual data, they argue that carbon trading mechanisms deliver better supply chain performance in terms of emissions, costs, and service levels. In contrast, carbon taxes may be more valuable in uncertain market conditions. Based on these two policies, (Pan, et al. 2020) [17] proposed a production inventory model that considers the co-investment of buyers and sellers to reduce carbon emissions. The government subsidizes enterprises or imposes a carbon tax. (Yin, et al. 2020) [18] believed that if consumers are susceptible to green and the environmental impact caused by corporate carbon emissions is very serious, the government should adopt tax policies, otherwise, subsidize companies. The above literature studies the deterministic demand market, (Li, et al. 2022) [19] studied the impact of different carbon policies on supply chain emission reduction levels and optimal decisions in uncertain demand markets. Other scholars have studied how mixed carbon tax and low-carbon subsidy policies affect carbon emissions and the profits of supply chain members (Wu, et al. 2022) [20].

This paper mainly to answer the following four questions: (1) How to design incentive contracts to avoid losses when the manufacturer has a moral hazard; (2) How does the manufacturer's moral hazard affect the retailer's incentive decision; (3) The impact of government punishment on manufacturer's moral hazard; (4) How the government punishment affects the retailer's optimal profit under the incentive contract.

The arrangement of the article is as follows. The "Problem Description And Hypothesis" section introduces the model's basic context and related assumptions. "The Solution And Analysis Of The Model" section constructs the model under information symmetry and asymmetry. The "Contract Design" section designs a linear incentive contract and an external loss-sharing contract to coordinate the supply chain "Numerical Example And Sensitivity Analysis" section supplements the relevant conclusions through assignment and drawing. The "Conclusion" section summarizes the article and looks forward to the future research direction.

II. Problem Description And Hypothesis

Consider a two-stage supply chain composed of a manufacturer and a retailer. Both the manufacturer and the retailer invest in carbon emission reductions. Because of information asymmetry, the retailer, as a principal, does not know the information about the manufacturer's emission reductions. The final products need the retailer and manufacturer's joint emission reductions. There is a moral hazard problem because of the asymmetric information about emission reductions. The government regulatory authorities will cooperate with the third party to spot-check the product and judge whether the product's carbon emission meets the product's production standard. It takes the emission reductions declared by the retailer to consumers as the detection standard and the probability of detecting the product in a production and sales cycle is θ. If the product is detected not to meet the standard, the retailer selling the product will be given one-time punishment T.

Assumption 1: Government penalties are imposed only on the retailer, and the fines T are borne entirely by the retailer.

Assumption 2: Assuming that manufacturers' and retailers' emission reductions are respectively e_m and e_r, referring to relevant literature(Liu, et al. 2017)[21], the cost of emission reductions of manufacturers and retailers is a quadratic function of emission reductions, which is: $C=\frac{1}{2}\delta_i e_i^2, i=m,r$.

Assumption 3: Referring to relevant literature(Achtnicht 2012)[22], assuming that the demand function for this product is $q=a+k\left(e_m+e_r\right)$, and excluding the influence of price on demand, let a represent the market capacity and k represent the consumer's preference coefficient of emission reductions.

Assumption 4: Assuming the unit product revenue of manufacturers and retailers, respectively m_A、m_B.

Assumption 5: Because the manufacturer has moral hazard, it is assumed that the probability of moral hazard of the manufacturer is γ.

Assumption 6: Assuming that the manufacturer and retailer are risk-neutral.

The notation used in the model is summarized in Table 1.

TABLE 1
NOTATION.

Notation	Meaning
a	The market capacity
T	Government punishment
k	Consumer's preference coefficient of emission reduction
γ	Probability of moral hazard of the manufacturer
θ	Probability of the government detecting the product
δ_i	Carbon reduction cost factor $i=m,r$
$e_i^{\,j}$	Emission reduction $i=m,r$, $j=S,A,M,T$
$E_S^{\,j}$	Supply chain emission reduction $j=S,A,M,T$
m_i	Unit product revenue of retailer and manufacturer $i=A,B$
$\pi_i^{\,j}$	The profit function $i=m,r$, $j=S,A,M,T$
α	Fixed payment
β	Incentive coefficient
ρ	manufacturers' actual emission reduction deviation factor
ω	External loss-sharing ratio

III. THE SOLUTION AND ANALYSIS OF THE MODEL

A. The model under complete information (MODEL S)

Because the supply chain information is complete, the manufacturer does not have a moral hazard, and each supply chain member decides the emission reduction by maximizing their profits. The profit functions of the manufacturer and the retailer under the condition of no moral hazard can be obtained as follows:

$$\pi_m^S=m_A\left(a+k\left(e_m^S+e_r^S\right)\right)-\frac{1}{2}\delta_m e_m^{S^2} \tag{1}$$

$$\pi_r^S=m_B\left(a+k\left(e_m^S+e_r^S\right)\right)-\frac{1}{2}\delta_r e_r^{S^2} \tag{2}$$

By solving (1) and (2), According to the first-order condition:

$$\frac{\partial \pi_m^S}{\partial e_m^S}=km_A-\delta_m e_m^S$$

$$\frac{\partial \pi_r^S}{\partial e_r^S}=km_B-\delta_r e_r^S$$

Let $\frac{\partial \pi_m^S}{\partial e_m^S}=0$, $\frac{\partial \pi_r^S}{\partial e_r^S}=0$, and the optimal emission reduction can be solved as follows:

$$e_m^{S*}=\frac{km_A}{\delta_m} \tag{3}$$

$$e_r^{S*}=\frac{km_B}{\delta_r} \tag{4}$$

Substitute (3) and (4) into (1) and (2) to obtain The optimal profits of manufacturers and retailers are respectively:

$$\pi_m^{S*}=am_A+\frac{k^2 m_A{}^2}{2\delta_m}+\frac{k^2 m_A m_B}{\delta_r} \tag{5}$$

$$\pi_r^{S*}=am_B+\frac{k^2 m_B{}^2}{2\delta_r}+\frac{k^2 m_A m_B}{\delta_m} \tag{6}$$

Proposition 1: When there is no moral hazard, the manufacturer's claimed emissions reduction to the retailer is e_m^{S*} , the retailer's claimed emissions reduction to the consumer is $E_S=e_m^{S*}+e_r^{S*}$, the market demand $q_S=a+k(e_m^{S*}+e_r^{S*})$, and the actual supply chain emissions reduction is $E_S=e_m^{S*}+e_r^{S*}$.

Based on the above solution results and proposition, it is known that the higher the revenue per unit of product, the higher the emission reduction input of manufacturers and retailers; and the higher the low carbon preference coefficient of consumers, the higher the overall emission reduction input of the supply chain. Under complete information, the optimal profit of manufacturers and retailers is inversely proportional to the emission reduction cost coefficient, which is in line with the actual situation.

B. Manufacturers have moral hazard (MODEL A)

Due to the existence of moral hazard, manufacturers' probability of moral hazard is γ. If the manufacturers' actual emission reductions are e_m^{A*}, and $e_m^{A*}=\rho e_m^{S*}$, $0\le\rho\le1$, ρ represents the manufacturers' real emission reduction deviation factor. It is further assumed that when the manufacturer has a moral hazard $\rho=0$, manufacturers have enough temptation not to implement emission reductions, thus the actual emission reductions $e_m^{A*}=0$. While their cleared emission reductions are e_m^S, therefore, the manufacturers' actual profit function is:

$$\pi_m^A = m_A\left(a+k\left(e_m^S+e_r^A\right)\right) \tag{7}$$

Under the situation where manufacturers have moral hazard, and there exists government punishment, the profit function of retailers is:

$$\pi_r^A = m_B\left(a+k\left(e_m^S+e_r^A\right)\right)-\frac{1}{2}\delta_r e_r^{A^2}-T \tag{8}$$

By the first-order condition:

$$\frac{\partial\pi_r^A}{e_r^A}=km_B-\delta_r e_r{}^A=0$$

The optimal emission reduction of the retailer can be obtained as follows:

$$e_r^{A*}=\frac{km_B}{\delta_r} \tag{9}$$

Substituting (9) into (7)(8), we can obtain the profits of the manufacturer and the retailer under moral hazard, respectively.

$$\pi_m^{A*}=am_A+\frac{k^2m_A{}^2}{\delta_m}+\frac{k^2m_Am_B}{\delta_r} \tag{10}$$

$$\pi_r^{A*}=am_B+\frac{k^2m_B{}^2}{2\delta_r}+\frac{k^2m_Am_B}{\delta_m}-T \tag{11}$$

The following proposition and corollary can be obtained from the above solution results.

Proposition 2: Under moral hazard, the actual emission reduction of the manufacturer is $e_m^{A*}=0$, the claimed emission reduction to the retailer is e_m^{S*}, the retailer emission reduction is the same as the emission reduction under complete information, there is $e_r^{A*}=e_r^{S*}$, the retailer's claimed emission reduction to the consumer is $E_A=e_m^{S*}+e_r^{A*}$, the market demand $q_A=a+k(e_m^{S*}+e_r^{A*})$, the actual supply chain emission reduction is $E_A=e_r^{A*}$.

Corollary 1: By comparing the actual emission reductions of the supply chain, there are $E_A<E_S$, and the emission reductions of the supply chain under information asymmetry are smaller than those under complete information. By comparing the profits under the two scenarios, there are $\pi_m^{S*}<\pi_m^{A*}$, $\pi_r^{S*}>\pi_r^{A*}$, the profits gained from the manufacturer's implementation of moral hazard are more significant than the case of complete information, and the retailers' earnings under full information are more significant than the case of the manufacturer's moral hazard.

Corollary 1 suggests that with information asymmetry, manufacturers are incentivized to misrepresent emission reductions, resulting in moral hazard behavior that can harm retailers' profits.

Then, we can derive the manufacturer's expected return. In the principal-agent model, the retailer entrusts the manufacturer with the emission reduction, the moral hazard behavior occurs after the contract is signed, the manufacturer's moral hazard probability is γ, and the manufacturer's expected return is the weighted average of the two cases, i.e.

$$\Pi_{\bar{m}}=\left(1-\gamma\right)\pi_m^S+\gamma\pi_m^A \tag{12}$$

Substituting (5) and (10) into (12), we can obtain.

$$\Pi_{\bar{m}}=am_A+\frac{\left(1+\gamma\right)k^2m_A{}^2}{2\delta_m}+\frac{k^2m_Am_B}{\delta_r}$$

This is the manufacturer's expected profit, i.e., the minimum profit expected by the manufacturer under information asymmetry, and is called the reserved profit, so the manufacturer's reserved profit is $\Pi_{\bar{m}}$.

C. Expected profit under information asymmetry (MODEL E)

Under information asymmetry, the probability of moral hazard for the manufacturer is γ, and the probability of government testing of product standards is θ. From the above description and assumptions, the expected profit functions for the manufacturer and retailer are obtained as:

$$\Pi_m^E=\left(1-\gamma\right)\pi_m^S+\gamma\pi_m^A \tag{13}$$

$$\Pi_r^E=\left(1-\gamma\theta\right)\pi_r^S+\gamma\theta\pi_r^A \tag{14}$$

Both manufacturers and retailers are rational economic agents, and under information asymmetry, the optimal decision is to maximize the expected profit, i.e.

$$\max\Pi_m^E$$

$$\max\Pi_r^E$$

Substituting (1)(2)(7)(8) into (13) and (14), we can obtain:

$$\Pi_m^E=m_A\left(a+k\left(e_m^E+e_r^E\right)\right)-\frac{1-\gamma}{2}\delta_m e_m^{E^2} \tag{15}$$

$$\Pi_r^E=m_B\left(a+k\left(e_m^E+e_r^E\right)\right)-\frac{1}{2}\delta_r e_r^{E^2}-\gamma\theta T \tag{16}$$

From the first-order conditions,

$$\frac{\partial\Pi_m^E}{\partial e_m^{E*}}=km_A-\left(1-\gamma\right)\delta_m e_m^{E*}=0$$

$$\frac{\partial\Pi_r^E}{\partial e_r^{E*}}=km_B-\delta_r e_r^{E*}=0$$

The actual optimal emission reductions of manufacturers and retailers can be obtained as:

$$e_m^{E*}=\frac{km_A}{(1-\gamma)\delta_m} \tag{17}$$

$$e_r^{E*}=\frac{km_B}{\delta_r} \tag{18}$$

Substituting (17)(18) into (15)(16), we obtain the optimal expected profit for the manufacturer and the retailer, respectively:

$$\Pi_m^{E*}=am_A+\frac{k^2m_A{}^2}{2\left(1-\gamma\right)\delta_m}+\frac{k^2m_Am_B}{\delta_r}$$

$$\Pi_r^{E*}=am_B+\frac{k^2m_B{}^2}{2\delta_r}+\frac{k^2m_Am_B}{\delta_m}-\gamma\theta T$$

From the above solution results, the following proposition can be obtained

Proposition 3: Under information asymmetry, the manufacturer's actual emission reduction is e_m^{E*}, the claimed emission reduction to the retailer is e_m^{E*}, the retailer's emission reduction is the same as the emission reduction under complete information, there is $e_r^{E*}=e_r^{S*}$, the retailer's claimed emission reduction to the consumer is $E_E=e_m^{E*}+e_r^{E*}$, the market demand $q_E=a+k(e_m^{E*}+e_r^{E*})$, the actual supply chain emission reduction is $E_E=e_m^{E*}+e_r^{E*}$.

Under information asymmetry, the manufacturer's expected profit is Π_m^{E*}, the retailer's expected profit is Π_r^{E*}, and the higher the probability of moral hazard for the manufacturer, the greater the manufacturer's expected profit and the greater the loss suffered by the retailer. Therefore, information asymmetry will cause loss of benefits to the party with information disadvantage, and the party with information can obtain higher expected returns by implementing moral hazard behavior. The next section will analyze the optimal decision results under different models.

D. Analysis of model results

This section will summarize the results of the above three models and draw relevant theorems.

Theorem 1: manufacturers' actual emission reductions: $0=e_m^{A*}<e_m^{S*}<e_m^{E*}$; retailers' actual emission reductions: $e_r^{S*}=e_r^{A*}=e_r^{E*}$;

Theorem 1 shows that the manufacturer's emission reduction under moral hazard is 0. In the case of information symmetry, the manufacturer and the retailer maximize their profits to make decisions on emission reductions, which will undoubtedly cause a double marginalization effect. In the case of information asymmetry, the manufacturer's emission reductions are more significant than in the case of complete information, and information asymmetry can reduce the impact of double marginalization. Since only the manufacturer's moral hazard behavior is considered, the retailer's emission reductions are the same in the three models.

Theorem 2: Supply chain claimed emission reductions $E_S=E_A<E_E$: Supply chain actual emission reductions: $E_A<E_S<E_E$, Market demand: $q_S=q_A<q_E$.

Theorem 2 shows that under the manufacturer's moral hazard behavior, the actual emission reduction of the supply chain is less than the case of complete information, while the declared emission reduction of the supply chain is equal to the case of complete information, and the lying behavior damages the interests of the government and consumers; in the case of information asymmetry, the expected emission reduction of the supply chain is higher than that in the case of complete information, and information asymmetry can reduce the impact of dual marginalization of the supply chain. Market demand depends on the emission reductions declared by supply.

Theorem 3: Profit of the manufacturer: when $0<\gamma<\frac{1}{2}$, there is $\pi_m^{S*}<\Pi_{\bar{m}}<\Pi_m^E<\pi_m^{A*}$; when $\frac{1}{2}<\gamma<1$, there is $\pi_m^{S*}<\Pi_{\bar{m}}<\pi_m^{A*}<\Pi_m^E$. Retailer's profit: $\pi_r^{A*}<\Pi_r^E<\pi_r^{S*}$.

Prove: $\Pi_m^{E*}-\pi_m^{A*}=\frac{(2\gamma-1)k^2{m_A}^2}{2(1-\gamma)\delta_m}$, because $0<\gamma<1$, according to the calculation, we can get the above Theorem.

Theorem 3 shows that the manufacturer's profit under complete information is the smallest. The lying behavior can always obtain higher profit, which is always higher than the manufacturer's retained profit. The higher the probability of moral hazard of the manufacturer, the greater the expected profit under information asymmetry. The retailer's profit is the largest under complete information, and the manufacturer's behavior will always damage the retailer's profit under asymmetric information. This is because the retailer entirely bears the government punishment so the retailer will bring risk loss because of the manufacturer's behavior.

The retailer is the principal, and the manufacturer is the agent of emission reduction. Due to information asymmetry, the manufacturer's moral hazard behavior will damage the retailer's profit. Therefore, the retailer must design contracts to constrain the manufacturer's behavior. The next part will discuss the retailer's design of linear incentive contracts and external loss-sharing contracts to coordinate the supply chain and avoid profit loss.

IV. CONTRACT DESIGN

A. Linear incentive contract （CONTRACT M）

Based on the principal-agent theory, the retailer entrusts the manufacturer to invest a certain unit of emission reduction in the product. The retailer designs an incentive and restraint mechanism to give the manufacturer incentive and reward for their emission reduction. The incentive contract is based on the final demand of the product q after the manufacturer and retailer make emission reductions and assumes that the incentive reward function is:

$$F(q)=\alpha+\beta q=\alpha+\beta\left(a+k\left(e_m^M+e_r^M\right)\right)$$

Which α represents the fixed payment given by retailers to manufacturers, β represents the incentive coefficient of retailers to manufacturers. Under the incentive contract, the profit functions of manufacturers and retailers are respectively:

$$\pi_m^M=m_A\left(a+k\left(e_m^M+e_r^M\right)\right)-\frac{1}{2}\delta_m {e_m^M}^2+F \tag{19}$$

$$\pi_r^M=m_B\left(a+k\left(e_m^M+e_r^M\right)\right)-\frac{1}{2}\delta_r {e_r^M}^2-F \tag{20}$$

From the incentive contract, the following optimal planning problem can be obtained:

$$\max\ \pi_r^M$$
$$s.t.\begin{cases}\pi_m^M\geq\Pi_{\bar{m}}\\ e_m^M=\arg\max\pi_m^M\\ e_r^M=\arg\max\pi_r^M\end{cases}$$

The above expressions are the retailer's objective function, manufacturer's rational constraint, and incentive compatibility constraint. Under the incentive compatibility constraint, both manufacturers and retailers make decisions based on their profit maximization, and the optimal emission reductions can be obtained through the first-order condition as follows:

$$e_m^{M*} = \frac{k\left(m_A + \beta\right)}{\delta_m} \tag{21}$$

$$e_r^{M*} = \frac{k\left(m_B - \beta\right)}{\delta_r} \tag{22}$$

Under the optimal conditions, there is $\pi_m^M = \Pi_{\bar{m}}$, the following conditions can be obtained:

$$F = E\left(\Pi_m^A\right) - m_A\left(a + k\left(e_m^M + e_r^M\right)\right) + \frac{1}{2}\delta_m {e_m^M}^2 \tag{23}$$

Substituting (21)(22)(23) into the retailer's objective function, Through the first-order condition.:

$$\frac{\partial \pi_r^M}{\partial \beta} = \left(\delta_r m_B - \delta_m m_A\right) - \left(\delta_m + \delta_r\right)\beta$$

Let $\frac{\partial \pi_r^M}{\partial \beta} = 0$, The optimal incentive coefficient of the retailer is:

$$\beta^* = \frac{\delta_r m_B - \delta_m m_A}{\delta_m + \delta_r} \tag{24}$$

Substituting (24) into (21)(22), the optimal emission reductions of manufacturers and retailers can be obtained :

$$e_m^{M*} = \frac{k\delta_r\left(m_A + m_B\right)}{\delta_m\left(\delta_m + \delta_r\right)} \tag{25}$$

$$e_r^{M*} = \frac{k\delta_m\left(m_A + m_B\right)}{\delta_r\left(\delta_m + \delta_r\right)} \tag{26}$$

By substituting (25)(26) into (19)(20), the optimal profits of retailers and manufacturers are :

$$\pi_r^M = \frac{k^2\left(m_A + m_B\right)^2\left(\delta_m^2 + 2\delta_r^2\right) + 2a\delta_m\delta_r\left(\delta_m + \delta_r\right)\left(m_A + m_B\right)}{2\delta_r\left(\delta_m + \delta_r\right)^2} - \alpha \tag{27}$$

$$\pi_m^M = \frac{k^2\left(m_A + m_B\right)^2\left(2\delta_m^3 - \delta_r^3 + 2\delta_m\delta_r^2\right) + 2a\delta_m^2\delta_r\left(\delta_m + \delta_r\right)\left(m_A + m_B\right)}{2\delta_m^2\left(\delta_m + \delta_r\right)^2} + \alpha \tag{28}$$

Because under the optimal planning condition, there is $\pi_m^M = \Pi_{\bar{m}}$, and thus the optimal fixed payment of the retailer can be obtained:

$$\alpha^* = \frac{a\left(\delta_m m_A - \delta_r m_B\right)}{\delta_m + \delta_r} + \frac{\left(1+\gamma\right)k^2 {m_A}^2}{2\delta_m} + \frac{k^2 m_A m_B}{\delta_r} - \frac{k^2\left(m_A + m_B\right)^2\left(2\delta_m^2 + \delta_r^2\right)}{2\delta_m\left(\delta_m + \delta_r\right)^2} \tag{29}$$

Substituting (29) into (27), the optimal profit of the retailer under the linear incentive contract can be obtained :

$$\pi_r^{M*} = am_B + \frac{k^2\delta_m^2\left({m_A}^2 + {m_B}^2\right) + 2k^2\delta_r^2 m_A m_B + k^2\delta_r\left(\delta_m + \delta_r\right)\left({m_B}^2 - \gamma {m_A}^2\right)}{2\delta_m\delta_r\left(\delta_m + \delta_r\right)}$$

The following theorems can be obtained based on the above solution results.

By analyzing the optimal incentive coefficient of retailers, we can get Theorem 4 and Theorem 5:

Theorem 4: If $\beta = m_B$, then $e_r^{M*} = 0$, the retailer's marginal revenue is 0, the manufacturer undertakes all the emission reductions; if $\beta = -m_A$, then $e_m^{M*} = 0$, the manufacturer's marginal revenue is 0, and the retailer undertakes all the emission reductions. The range of incentive coefficients is $-m_A \le \beta \le m_B$.

Theorem 5: $\frac{\partial \beta^*}{\partial \delta_m} < 0$, $\frac{\partial \beta^*}{\partial \delta_r} > 0$. If $\delta_m m_A < \delta_r m_B$, then $\beta^* > 0$, it indicates that the proceeds are transferred from the retailer to the manufacturer; if $\delta_m m_A > \delta_r m_B$, then $\beta^* < 0$, it indicates that the revenue is transferred from the manufacturer to the retailer.

Theorem 5 shows that the optimal incentive coefficient depends on the manufacturer and retailer's unit product income and emission reduction cost coefficient. The higher the manufacturer's emission reduction cost coefficient, the smaller the optimal incentive coefficient, and the higher the retailer's emission reduction cost coefficient, the greater the incentive coefficient. If the manufacturer's emission reduction cost coefficient is small, the manufacturer's emission reductions are more conducive to the whole supply chain, retailers will tend to increase the incentive coefficient; if the retailer's emission reduction cost coefficient is high, the manufacturer's emission reduction cost is more favorable to the supply chain than the retailer's emission reduction input, so the retailer tends to increase the incentive coefficient.

By analyzing the emission reductions of manufacturers and retailers under the linear incentive contract and the total emission reductions of the supply chain, the following proposition can be obtained:

Proposition 4: Manufacturer's claimed emission reductions to retailers is e_m^{M*}, retailers ' claimed emission reductions to consumers is $E_M = e_m^{M*} + e_r^{M*}$, market demand $q_M = a + k(e_m^{M*} + e_r^{M*})$, and actual emission reductions $E_M^* = e_m^{M*} + e_r^{M*}$.

Theorem 6: Under the linear incentive contract, the manufacturer and retailer's emission reductions depend on the relative emission reduction cost coefficient. If $\delta_m < \delta_r$, the manufacturer has higher emission reduction efficiency than the retailer, the manufacturer undertakes more emission reductions; if $\delta_m > \delta_r$, retailers are more efficient in reducing emissions than manufacturers, they will undertake more efforts.

Theorem 7: If the optimal incentive coefficient $\beta^* > 0$, when $\delta_m > \delta_r$, there is $E_S > E_M$; when $\delta_m < \delta_r$, there is $E_S < E_M$; If the optimal incentive coefficient $\beta^* < 0$, when $\delta_m > \delta_r$, there is $E_S < E_M$; when $\delta_m < \delta_r$, there is $E_S > E_M$.

Proof: Because $E_S - E_M = \frac{k\left(\delta_m - \delta_r\right)}{\delta_m\delta_r}\beta^*$, it can be proved.

Theorem 7 shows that the emission reduction of the supply chain under linear incentive contract is greater than that under complete information only if certain conditions are satisfied.

Proposition 5: Under the retailer linear incentive contract, the manufacturer obtains the retained profit $\Pi_{\bar{m}}$, and the retailer's profit is π_m^{M*}. The retailer's optimal fixed payment increases with the manufacturer's moral hazard probability, and the retailer's optimal profit decreases with the increase of the manufacturing moral hazard probability under the linear incentive constraint.

By comparing the optimal profit obtained by the retailer under the linear constraint with the profit under full information. We can obtain:

Theorem 8: If, $\beta^* > 0$, there are $\pi_r^{M*} < \pi_r^{S*}$; if $\delta_m m_A > \delta_r m_B$, $\beta^* < 0$: when $\gamma < \frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B)}{m_A{}^2\delta_r(\delta_m+\delta_r)}$, there are $\pi_r^{M*} > \pi_r^{S*}$; when $\gamma < \frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B)}{m_A{}^2\delta_r(\delta_m+\delta_r)} < 1$, there are $\pi_r^{M*} < \pi_r^{S*}$.

Proof:

because $\pi_r^{M*} - \pi_r^{S*} = \frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B) - \gamma m_A{}^2\delta_r(\delta_m+\delta_r)}{2\delta_m\delta_r(\delta_m+\delta_r)}$, the proof can be obtained.

Comparing the optimal profit obtained by retailers under linear constraints with the expected profit under asymmetric information. we can obtain

Theorem 9: if $\delta_m m_A < \delta_r m_B$, $\beta^* > 0$, when $T < \frac{m_A{}^2}{2\theta\delta_m}$, there are $\pi_r^{M*} < \Pi_r^{E*}$; when $T > \frac{m_A{}^2}{2\theta\delta_m}$, if $\gamma < \frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B)}{\delta_r(\delta_m+\delta_r)(m_A{}^2 - 2\theta T\delta_m)}$, there are $\pi_r^{M*} < \Pi_r^{E*}$, if $\frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B)}{\delta_r(\delta_m+\delta_r)(m_A{}^2 - 2\theta T\delta_m)} < \gamma < 1$, there are $\pi_r^{M*} > \Pi_r^{E*}$;

If $\delta_m m_A > \delta_r m_B$, $\beta^* < 0$, when $T > \frac{m_A{}^2}{2\theta\delta_m}$, there are $\pi_r^{M*} > \Pi_r^{E*}$; when $T < \frac{m_A{}^2}{2\theta\delta_m}$, if $\gamma < \frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B)}{\delta_r(\delta_m+\delta_r)(m_A{}^2 - 2\theta T\delta_m)}$, there is $\pi_r^{M*} > \Pi_r^{E*}$, if $\frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B)}{\delta_r(\delta_m+\delta_r)(m_A{}^2 - 2\theta T\delta_m)} < \gamma < 1$, there is $\pi_r^{M*} < \Pi_r^{E*}$;

Proof:

because $\pi_r^{M*} - \Pi_r^{E*} = \frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B) - \gamma\delta_r(\delta_m+\delta_r)(m_A{}^2 - 2\theta T\delta_m)}{2\delta_m\delta_r(\delta_m+\delta_r)}$, the proof can be obtained.

From the above two theorems, we can obtain:

Corollary 2: When $\beta^* > 0$, the government penalties $T > \frac{m_A{}^2}{2\theta\delta_m}$ and manufacturer's moral hazard probability $\gamma > \frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B)}{\delta_r(\delta_m+\delta_r)(m_A{}^2 - 2\theta T\delta_m)}$, retailer's profit $\Pi_r^{E*} < \pi_r^{M*} < \pi_r^{S*}$, linear incentive contract can realize the Pareto improvement of retailer's profit, effectively coordinate the supply chain; if $\beta^* < 0$, the manufacturer's moral hazard probability $\gamma < \frac{k^2\delta_m^2(\delta_m m_A - \delta_r m_B)}{m_A{}^2\delta_r(\delta_m+\delta_r)}$, retailer's profit $\pi_r^{M*} > \Pi_r^{E*}$, $\pi_r^{M*} > \pi_r^{S*}$, Linear incentive contract can realize Pareto improvement of retailer's profit, and retailer's profit under linear incentive contract is not only higher than expected profit under asymmetric information but also higher than profit under complete information, which effectively realizes supply chain coordination. Under other conditions, linear incentive contracts cannot achieve Pareto improvement of retailers' profits.

B. *External loss-sharing contract （CONTRACT T）*

In the case of the manufacturer's moral hazard, if the government detects the products with unqualified emission reduction standards and punishes the retailer, the retailer's profit is damaged due to the manufacturer's moral hazard behavior. In this section, we study the supply chain coordination under the external loss-sharing contract. The retailer transfers external loss to manufacturer according to a certain proportion, which the manufacturer and the retailer share. Assuming that the proportion of external loss-sharing is ω, under the external loss-sharing contract, the expected profits of manufacturers and retailers are, respectively $E(\Pi_m^T), E(\Pi_r^T)$.

Manufacturers have moral hazard behavior, the probability of false carbon emission reductions is γ, the probability of government detection of products is θ, therefore, the probability of external loss in the supply chain is $\gamma\theta$, by the external loss-sharing contract, the manufacturer and retailer's profit function are :

$$\pi_m^T = m_A\left(a + k\left(e_m{}^S + e_r{}^T\right)\right) - \omega T \tag{30}$$

$$\pi_r^T = m_B\left(a + k\left(e_m{}^S + e_r{}^T\right)\right) - \frac{1}{2}\delta_r e_r^{T^2} - (1-\omega)T \tag{31}$$

Further, under the external loss-sharing contract, the expected profit functions of manufacturers and retailers are:

$$E(\Pi_m^T) = (1-\gamma)\pi_m^S + \gamma\theta\pi_m^T + \gamma(1-\theta)\pi_m^A \tag{32}$$

$$E(\Pi_r^T) = (1-\gamma\theta)\pi_r^S + \gamma\theta\pi_r^T \tag{33}$$

By substituting (1)(2)(7)(30)(31) into (32)(33), the expected profit functions of manufacturers and retailers can be obtained.

$$E(\Pi_m^T) = m_A\left(a + k\left(e_m^T + e_r^T\right)\right) - \frac{1-\gamma}{2}\delta_m e_m^{T2} - \gamma\theta\omega T \tag{34}$$

$$E(\Pi_r^T) = m_B\left(a + k\left(e_m^T + e_r^T\right)\right) - \frac{1}{2}\delta_r e_r^{T^2} - \gamma\theta(1-\omega)T \tag{35}$$

By solving the first-order optimal conditions:

$$\frac{\partial E(\Pi_m^T)}{\partial e_m^T} = km_A - (1-\gamma)\delta_m e_m^T = 0$$

$$\frac{\partial E(\Pi_r^T)}{\partial e_r^T} = km_B - \delta_r = 0$$

The optimal emission reductions for manufacturers and retailers can be obtained as follows:

$$e_m^{T*} = \frac{km_A}{(1-\gamma)\delta_m} \tag{36}$$

$$e_r^{T*} = \frac{km_B}{\delta_r} \tag{37}$$

Substituting (36)(37)into (34)(35), through simplification, the expected profits of manufacturers and retailers are as follows :

$$E\left(\Pi_m^T\right) = am_A + \frac{k^2 m_A^2}{2(1-\gamma)\delta_m} + \frac{k^2 m_A m_B}{\delta_r} - \gamma\theta\omega T \tag{38}$$

$$E\left(\Pi_r^T\right) = am_B + \frac{k^2 m_A m_B}{(1-\gamma)\delta_m} + \frac{k^2 m_B^2}{2\delta_r} - \gamma\theta(1-\omega)T \tag{39}$$

If $E\left(\Pi_m^T\right) = \Pi_{\bar{m}}$, the external loss shared by the manufacturer is $\gamma\theta\omega T = \frac{\gamma^2 k^2 m_A^2}{2(1-\gamma)\delta_m}$. Therefore, the proportion of external loss-sharing can be obtained as :

$$\omega^* = \frac{\gamma k^2 m_A^2}{2\theta T(1-\gamma)\delta_m} \tag{40}$$

Substituting (40) into (39), the retailer's profit under external loss-sharing can be obtained as follows :

$$E\left(\Pi_r^T\right)^* = am_B + \frac{k^2 m_A\left(\gamma^2 m_A + 2m_B\right)}{2(1-\gamma)\delta_m} + \frac{k^2 m_B^2}{2\delta_r} - \gamma\theta T$$

According to the above results, the following proposition and theorems can be obtained:

Proposition 6: The manufacturer's claimed emission reductions to the retailer under the external loss-sharing contract are e_m^{T*}, the retailer's claimed emission reductions to the consumer is $E_T = e_m^{T*} + e_r^{T*}$, market demand $q_T = a + k(e_m^{T*} + e_r^{T*})$, the actual supply chain's claimed emission reductions are $E_T = e_m^{T*} + e_r^{T*}$, under the external loss-sharing contract, the supply chain's claimed emission reductions are the same as MODEL E.

Theorem 10: Under the supply chain external loss-sharing contract, the manufacturer obtains the retained earnings $\Pi_{\bar{m}}$, and the retailer obtains the earnings $E\left(\Pi_r^T\right)^*$. Compared with the retailer's profit under complete information and information asymmetry, there are $E\left(\Pi_r^T\right)^* - \Pi_r^{E*} = \frac{k^2 m_A\left(\gamma^2 m_A + 2\gamma m_B\right)}{2(1-\gamma)\delta_m} > 0$; $E\left(\Pi_r^T\right)^* - \pi_r^{S*} = \gamma\left(\frac{k^2 m_A\left(\gamma m_A + 2m_B\right)}{2(1-\gamma)\delta_m} - \theta T\right)$; when $T \le \frac{k^2 m_A\left(\gamma m_A + 2m_B\right)}{2\theta(1-\gamma)\delta_m}$, there are $E\left(\Pi_r^T\right)^* \ge \pi_r^{S*}$.

From the above propositions and theorems, the following corollary can be obtained:

Corollary 3: Under the external loss-sharing contract, the retailer's profit is greater than the optimal profit under information asymmetry. The contract can achieve Pareto's improvement of the retailer's profit and coordinate the negative impact of information asymmetry on the retailer. Moreover, only when the government penalties $T \le \frac{k^2 m_A\left(\gamma m_A + 2m_B\right)}{2\theta(1-\gamma)\delta_m}$ can the retailer ensure that the retailer's profit is greater than the optimal profit under complete information.

V. Numerical Example And Sensitivity Analysis

To more intuitively verify the above conclusions and the relevant measures adopted by the government to punish enterprises for emission reduction, it uses MATLAB software to assign relevant parameters, for example, analysis in this section.

A. The Impact of the Cost Coefficient of Emission reductions on the Optimal Incentive Coefficient β

It is assumed $m_A = 3$, $m_B = 5$, to study the influence of the change of cost coefficient of manufacturers' and retailers' emission reduction on the optimal incentive coefficient.

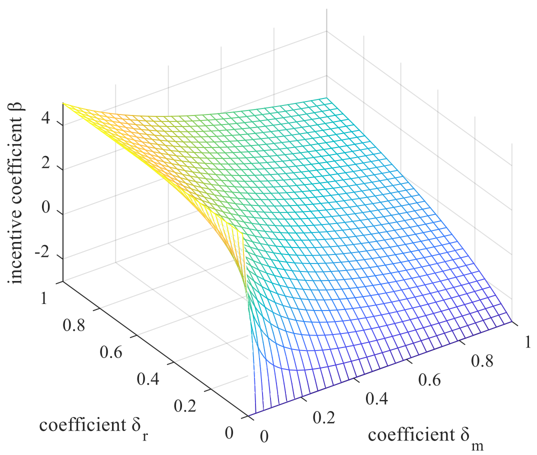

Fig. 1. The impact of the cost coefficient of manufacturer's and retailer's emission reductions on the incentive coefficient

It can be seen from Fig. 1 that as δ_m increases, the smaller the optimal incentive coefficient, and as δ_r increases, the larger the optimal incentive coefficient. This is because in the process of product production, if the cost coefficient of retailers' emission reduction is larger than that of the manufacturers, the cost of retailers' emission reduction is higher, thus retailers are more willing to pass on the emission reduction task to manufacturers through incentive contract, and manufacturers invest in emission reductions at a relatively small cost, to coordinate the production of supply chain products and improve the supply chain income; If the cost coefficient of retailers' emission reductions is low, while the cost coefficient of manufacturers' emission reductions is high, the incentive coefficient designed by retailers will be small. For the supply chain, the retailer's investment in emission reduction can save costs, while the manufacturer's emission reductions have higher costs and lower inputs. Therefore, the retailer does not need to share more revenue with the manufacturer, only to ensure that the manufacturer can obtain the retained revenue under the contract.

B. Effect of retailer incentive coefficient on emission reductions

This section analyzes the influence of retailer incentive coefficient on emission reductions under linear incentive contract and assigns parameters. It is assumed that $k=1, m_A=3, m_B=5$, $\delta_m=0.8, \delta_r=0.4$, we can get the interval of $\beta \in [-3,5]$, the results shown in Fig. 2 can be obtained.

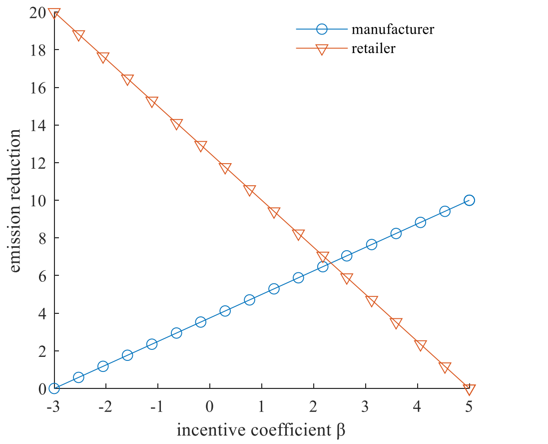

Fig. 2. The influence of incentive coefficient on emission reductions

Fig. 2 shows that under the retailer linear incentive contract, the manufacturer's emission reductions increase with the incentive coefficient, and the retailer's emission reductions decrease with the increase of incentive coefficient. The higher the incentive coefficient, the higher the manufacturer's unit product revenue, and manufacturers are willing to invest more in emission reductions. If retailers give manufacturers too much revenue incentives, retailers' profits will decline, which is not conducive to retailers ' investment in emission reductions.

C. Sensitivity Analysis of Optimal Fixed Payment under Linear Incentive Contract

By assigning relevant parameters, this paper analyzes the impact of the cost coefficient of emission reductions on the optimal fixed payment. Assuming $k=1$, $m_A=3$, $m_B=5$, $\gamma=0.5$, $a=100$, and we can obtain:

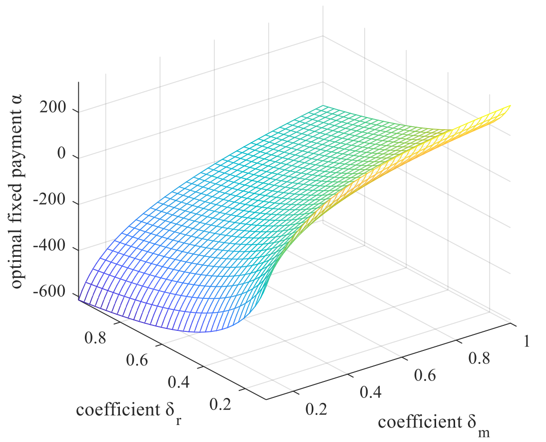

Fig. 3. Influence of Emission Reduction Cost Coefficient on α

Under the linear incentive contract, the optimal fixed payment is derived, and the following results are obtained: $\frac{\partial \alpha^*}{\partial \gamma}>0$. The results show that the higher the probability of moral hazard of manufacturers is, the higher the optimal fixed payment is. And Fig. 3 shows that the optimal fixed payment decreases with the retailer's emission reduction cost coefficient and increases with the manufacturer's emission reduction cost coefficient. It can be seen from Fig. 3 that under the linear constraint contract, when the retailer 's emission reduction cost coefficient is small and the manufacturer 's emission reduction cost coefficient is large, the optimal fixed payment is positive, which means that the retailer transfers the revenue to the manufacturer. When the retailer 's emission reduction cost coefficient is large and the manufacturer 's emission reduction cost coefficient is small, the optimal fixed payment is negative, which means that the manufacturer transfers the revenue to the retailer. This also reflects that the purpose of the linear incentive contract is to redistribute the profits of supply chain members and promote the consistency of the purpose of supply chain members ' behavior under the premise of maximizing the income of the whole supply chain.

D. Sensitivity analysis of external loss share

The following results are obtained according to the optimal expression of the proportion of external loss-sharing: $\frac{\partial \omega^*}{\partial \gamma}>0$, $\frac{\partial \omega^*}{\partial T}<0$, $\frac{\partial \omega^*}{\partial \theta}<0$.

The results show that the higher the probability of manufacturer's moral hazard, the higher the proportion of the manufacturer's external loss-sharing, which is in line with realistic logic. The higher the probability of manufacturer's moral hazard, the greater the probability of external loss in the supply chain. The greater the proportion of the loss that manufacturers need to bear for their moral hazard behavior to coordinate the supply chain. Since the external loss shared by manufacturers only depends on the probability of moral hazard of manufacturers, the marginal revenue of products, the preference coefficient of consumers' emission reductions, and the cost coefficient of emission reductions, when the total amount of external loss shared by manufacturers is constant, the probability of government punishment and detection is inversely proportional to the proportion of external loss shared by manufacturers.

VI. Conclusion

This paper mainly discusses the moral hazard of manufacturers in the decision-making of emission reductions under the condition of asymmetric information between manufacturers and retailers. Retailers avoid the profit loss caused by the moral hazard of manufacturers by designing linear incentive contracts and external loss-sharing contracts. The conclusions are as follows:

(1) Under asymmetric information, the manufacturer's moral hazard behavior can always benefit itself, while its moral hazard behavior will always damage the retailer's profit. The higher the moral hazard probability of the manufacturer, the greater the expected profit of the manufacturer, and the greater the loss suffered by the retailer. The retailer must design relevant contracts to avoid losses.

(2) Linear incentive contracts can guarantee the expected profits of manufacturers and the Pareto improvement of retailer profits only under certain conditions. The external loss-sharing contract can effectively coordinate the supply

chain, making the retailer's profit achieve Pareto improvement. When the government's punishment is small, the retailer's profit is higher than that under complete information. The application scope of linear incentive contracts is narrow, and the external loss-sharing contract is more applicable.

(3) The emission reductions of the supply chain under the external loss-sharing contract are the same as the expected emission reductions under the information asymmetry. The emission reductions of the supply chain under the linear incentive contract depend on the unit product income of manufacturers and retailers and the cost coefficient of emission reductions.

(4) The optimal incentive coefficient under the retailer incentive contract is inversely proportional to the manufacturer's emission reduction cost coefficient and is proportional to the retailer's emission reduction cost coefficient;

(5) The higher the probability of the manufacturer's moral hazard, the higher the optimal fixed payment given to the manufacturer by the retailer to design a linear incentive contract, and the optimal fixed payment may be negative.

(6) Under the external loss-sharing contract, the external loss shared by the manufacturer depends on the probability of moral hazard of the manufacturer, and the proportion of external loss-sharing is inversely proportional to the intensity of government punishment.

According to the conclusion of this paper, when the government's punishment mechanism only acts on the retailer, the manufacturer's moral hazard behavior will damage the overall profits of the retailer and the supply chain. The retailer and the consumer bear the cost of the manufacturer's moral hazard. The retailer needs to choose to design reasonable contracts to coordinate the supply chain and avoid losses. This paper still has the following deficiencies: (1) only considering the government punishment of retailers, not considering the government punishment of manufacturers, and (2) The impact of manufacturer moral hazard on social welfare is not studied.

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