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Research on Low-carbon Service Outsourcing Supply Chain with Overconfidence of Manufacturers under Carbon Trading Regulation

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Abstract

This paper considers the influence of manufacturers' overconfidence behavior on the members of low-carbon service outsourcing supply chain and the whole supply chain under the regulation of carbon trading, and constructs a Stackelberg game model dominated by low-carbon service providers. Then, through comparative analysis and numerical analysis, the following conclusions are drawn: the manufacturer's overconfidence will lead to the manufacturer's profit and the overall profit of the supply chain being lower than that of the manufacturer and the overall profit of the supply chain under complete rationality. On the contrary, when the manufacturer is overconfident, the profit of low-carbon service providers is higher than that when the manufacturer is completely rational.

Keywords

Carbon Trading; Overconfidence; Low Carbon Service Outsourcing.

1. Introduction

Since the industrial age, the contradiction between human development and global climate problems has become increasingly prominent, especially the impact of carbon emissions generated by human activities on global warming. In order to solve the serious problem of climate warming, General Secretary Xi Jinping proposed at the 75th session of the United Nations General Assembly that China will increase its nationally determined contributions, adopt more favorable policies and measures, strive to peak carbon dioxide emissions before 2030, and strive to achieve carbon neutrality before 2060[1]. With the clear proposal of the "dual carbon" goal, under the carbon trading regulation, how to reduce emissions and increase efficiency has gradually become an urgent problem for their development.

Due to the technical barriers, differences in industrial cost structure and limitations on emission reduction operation capacity in the process of emission reduction, the high investment in independent emission reduction of enterprises is low and the emission reduction efficiency is low. At this time, low-carbon service outsourcers that provide enterprises with "one-stop carbon management" such as guidance and consultation on energy-saving and emission technology came into being. Manufacturers have reached cooperation with low-carbon service providers by signing mutually beneficial outsourcing service contracts for emission reduction. For example, in June 2022, Qian'an Iron and Steel Co., Ltd., a subsidiary of Shougang Co., Ltd., and new energy vehicle manufacturers jointly developed an electrical steel product for the drive motor of new energy vehicles, which has greatly improved its efficiency after inspection, and can save 375 kWh of electricity per year[2].

However, psychological research confirms that humans exhibit many psychological biases, but the most consistent[3], powerful, and prevalent of them is overconfidence, which can be overestimated by supply chain members, who may overestimate market demand and consumers' green preference levels due to overconfidence. So when there is overconfidence in

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the low-carbon service outsourcing supply chain, how will it affect the members of the supply chain? It has become a hot topic of discussion in academic research.

2. Literature Review

The research literature highly related to this paper mainly focuses on the following two aspects:

2.1. Research on Supply Chain Management of Low-carbon Service Outsourcing under Carbon Trading RegulationSection Headings

In recent years, many scholars at home and abroad have studied the decision of manufacturers to outsource emission reduction services. Zhou Yanju, Wu Jiepeng and others designed different contracts to coordinate the supply chain aiming at the output decision, carbon purification level selection and income distribution of low-carbon service providers and manufacturers of embedded low-carbon services, and analyzed the designed contracts, and found that manufacturers and service providers can maximize profits under the carbon purification cost-benefit sharing contract[4]; Then they analyze the influence of embeddedness on the optimal incentive contract and find that a high level of embeddedness can improve the emission reduction efficiency of embedded low-carbon services[5]; Many foreign scholars have also made a series of studies on the influence of external factors on low-carbon service outsourcing supply chain. Dong Qian and Jueguo analyzed the influence of energy price, risk-adjusted discount rate and accidents on the bargaining strategy of energy service companies by establishing a revenue-sharing negotiation model between energy service companies and energy-using organizations, and found that under the revenue-sharing contract, the introduction of fines and commitments can eliminate the influence of uncertain energy saving on contract execution to a certain extent[6]; Huiping Ding, Hua Huang ,Ou Tang, etc. take government policies into consideration when studying, and find that the outsourcing price of emission reduction services is related to government incentive policies[7]; In the same year, Qinpeng Wang and Longfei He established a supply chain game model considering risk aversion by using the mean-variance model, and respectively investigated the influence of risk aversion of suppliers and manufacturers on the performance of low-carbon supply chain, and found that the risk aversion of supply chain members did not affect the profit ratio of manufacturers and contractors[8];

2.2. Consider Overconfident Supply Chain Management Research

Xianjin Du, Huimin Zhan et al. considered the overconfidence bias in the supply chain innovation scenario, overestimated the impact of innovation on increasing demand, and studied the impact of manufacturers' overconfidence on supplier innovation and supply chain profits in the case of wholesale price contract and cost-sharing contract, showing that overconfidence is not conducive to supplier innovation under wholesale price contract. Under the cost-sharing contract, overconfidence is conducive to supplier innovation[9]; Zhongyuan Hao et al. further explored the impact of overconfidence on the allocation of inventory liability and profitability by one or both parties. It is found that under certain conditions, the existence of overconfident channel side does weaken the negative effect of ambidextrous marginalization[10]. Then, Samuel Nathan Kirshner Lusheng Shao developed a newsboy model model of overconfidence and optimism, and analyzed overconfidence and optimism by applying the probability weighting function of prospect theory (PT), and found that overconfidence and regret usually lead to lower profit margins and higher inventories, and the increase in optimism has a similar effect on inventory levels and pricing[11]; Jian Liu et al. studied the effect of overconfidence on product greenness based on the newsboy-based model, and found that overconfident manufacturers will provide greener products to the market, and

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overconfidence makes the manufacturer's actual profit smaller than the optimal profit of rational manufacturers[12].

2.3. Literature Review and Academic Contributions

Closely related to this paper are Xia Liangjie et al. (2022, China Management Science: A Study on the Emission Reduction Game between Overconfident Manufacturers and Emission Reduction Service Providers under Carbon Trading Regulation) and Zhou Yanju et al. (2016, Systems Engineering Theory and Practice), the former focuses on the over-accurate behavior of manufacturers in their perception of uncertain market demand for low-carbon products, while this paper discusses the behavior of manufacturers in overestimating the market price of low-carbon products, and the former focuses on the choice of cooperation mode between manufacturers and emission reduction service providers. That is, the question of choosing to order or customize, and this article discusses the analysis of the effect of different contracts between manufacturers and low-carbon service providers under the subscription model. The latter compares and analyzes the decision-making of manufacturers and low-carbon service providers under different contracts, but the latter does not take into account the cognitive behavior of low-carbon manufacturers that overestimate the low-carbon market. Based on this, this paper considers these two aspects at the same time, studies the coordination of low-carbon service outsourcing supply chain when manufacturers are overconfident under carbon trading regulation, analyzes the changes in manufacturers' output and profits, service providers' emission reduction efforts and service remuneration under the influence of manufacturers' overconfidence, and then designs three contracts for coordination, and compares and analyzes the coordination of the three contracts and the effect of constraints on manufacturers' overconfidence behavior.

3. Problem Description and Basic Assumptions

3.1. Problem Description

In the secondary supply chain composed of manufacturers and low-carbon service outsourcers, manufacturers are a kind of enterprises with emission reduction needs, and low-carbon service providers only help manufacturers to provide emission reduction technical services, without process optimization and other services, and promise that the target value of carbon emission reduction per unit product is. In this low-carbon service outsourcing supply chain, low-carbon service providers are dominant, and the decision-making order is: low-carbon service providers determine the reward of emission reduction services per unit product, and then manufacturers determine the optimal output and the realization ratio of emission reduction targets per unit product according to their investment level.

3.2. Basic Hypothesis

Hypothesis 1: The manufacturer entrusts the low-carbon service outsourcer to carry out emission reduction services for it through low-carbon service outsourcing. While the manufacturer is producing, the low-carbon service outsourcer provides supporting emission reduction services and bears the variable cost of emission reduction. Low-carbon service providers charge manufacturers a reward of v for emission reduction services per unit product, and their input variable cost of emission reduction per unit product is c_e, which is the supporting input of emission reduction in the production process and does not affect the emission reduction level of products.

Hypothesis 2: The initial investment cost I required for emission reduction is borne by the manufacturer. The functional relationship between the initial investment cost I and the

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realization ratio of emission reduction target quantity per unit product λ: $I = \varepsilon\lambda^2$, ε is the scale coefficient.

Hypothesis 3: The manufacturer contracts with low-carbon service providers in the form of service outsourcing, assuming that the carbon emissions per unit product without emission reduction service are E_0. Low-carbon service providers help manufacturers reduce the carbon emissions of their products through emission reduction efforts. At this time, the target amount of emission reduction per unit product can be characterized as: E. After emission reduction, the carbon emission per unit product is $E_0 - \lambda\mathrm{E}$, When the output is q, the total carbon emission is $q(E_0 - \lambda\mathrm{E})$.

Hypothesis 4: Under the carbon trading regulations, the carbon emission quota of manufacturers is bound by the government, and the carbon quota of enterprises is E_{g}, The price of carbon emission right in the market transaction is p_c, That is, if the actual carbon emission $q(E_0 - \lambda\mathrm{E})$ is higher than the government quota E_0 during the quota performance period, the manufacturer should buy the carbon emission right in the carbon trading market; If the carbon quota is surplus, you can sell the excess carbon quota in the carbon trading market to make a profit, that is $E_p = E_{\mathrm{g}} - q(E_0 - \lambda\mathrm{E})$, E_p is the trading volume of carbon emission rights of manufacturers in the carbon market.

Hypothesis 5: Considering the complete rationality of manufacturers, the product output is the market demand, and the product price p is a function of the market demand and the realization rate λ of emission reduction targets. When the manufacturer is completely rational, the market price of low-carbon products is: $p = A + c - \eta q + k\lambda E$, In which: $A(A > p_c E_0 + c_e > 0)$ Represents the maximum unit profit that can be obtained by products without emission reduction treatment, $c(c > 0)$ represents the unit production cost of the product, $\eta(\eta > 0)$ represents the elasticity of the price with respect to the production quantity, and $k(k > 0)$ represents the degree of consumers' preference for low-carbon products, that is, the greater the k, the more consumers can accept low-carbon products with higher prices.

Hypothesis 6: Assume that manufacturers overestimate consumers' low-carbon preferences, which leads to manufacturers' overestimation of market prices. Assume that $r(r \geq 0)$ is the manufacturer's overconfidence level on product price. The greater r, the higher the manufacturer thinks that consumers will pay for their products, and the higher the manufacturer's overconfidence level. $r = 0$ means that the manufacturer does not have overconfidence and is completely rational. Therefore, manufacturers' overconfidence in the market price of products can be expressed as: $p_r = A + c - \eta q + (1+r)k\lambda E$. Relevant parameters and their meanings are shown in Table 2:

4. Model Construction and Solution Analysis

Based on the above assumptions, this section first studies the emission reduction decision-making problems under the condition of complete rationality of manufacturers, with and without service providers participating. Then, the decision-making problem of manufacturers under overconfidence is studied, and the influence of overconfidence on the decision-making of supply chain members is analyzed.

4.1. Completely Rational Situation of Manufacturer

In this section, manufacturers are completely rational. Firstly, the decision-making of manufacturers without low-carbon service providers and those with low-carbon service providers are analyzed respectively. Then, when low-carbon service providers participate, the

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centralized decision-making and decentralized decision-making modes are compared and analyzed.

4.1.1. Without the Participation of Low-carbon Service Providers

When no low-carbon service provider participates in the manufacturer's low-carbon emission reduction, at this time, the manufacturer's product emission reduction is 0, that is: $\lambda E = 0$, the product marginal profit is $s_0 = p - c = A - \eta q_0$. At this time, the manufacturer's profit maximization model is:

$$\begin{aligned} \max_{q_0} \pi_{m0} &= q_0 s_0 + p_c E_p \\ &= q_0(A - \eta q_0) + p_c(E_g - q_0 E_0) \end{aligned} \tag{1}$$

Obtained, the optimal solution q_0^* is:

$$q_0^* = \frac{A - p_c E_0}{2\eta} \tag{2}$$

Under the complete rationality of the manufacturer, the optimal profit of the manufacturer without the participation of low-carbon service providers is:

$$\pi_{mo}^* = \frac{(A - p_c E_0)^2}{4\eta} + p_c E_g \tag{3}$$

See the appendix for the solution process.

4.1.2. Participation of Low-carbon Service Providers

(1) Centralized decision-making

In the case of centralized decision-making, the optimal value of each decision variable is determined based on the maximum profit of supply chain system. At this time, the profit maximization model of emission reduction supply chain is:

$$\begin{aligned} \max_{q_{cl}, \lambda_{cl}} \pi_{scl} &= q_{cl}(s_{cl} - c_e) + p_c E_p - I_{cl} \\ &= q_{cl}\left(A - \eta q_{cl} + k\lambda_{cl} E - c_e\right) + p_c[E_g - q_{cl}(E_0 - \lambda_{cl} E)] - \varepsilon \lambda_{cl}^2 \end{aligned} \tag{4}$$

It is found that the optimal solution q_{cl}^*, λ_{cl}^* is:

$$q_{cl}^* = \frac{2\varepsilon(A - p_c E_0 - c_e)}{4\varepsilon\eta - (kE + p_c E)^2} \tag{5}$$

$$\lambda_{cl}^* = \frac{\left(KE + p_c E\right)(A - p_c E_0 - c_e)}{4\varepsilon\eta - (kE + p_c E)^2} \tag{6}$$

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The optimal profit of supply chain under centralized decision-making under the complete rationality of manufacturers is:

$$\pi_{scl}^{*}=\frac{\varepsilon(A-p_cE_0-c_e)^2}{4\varepsilon\eta-(kE+p_cE)^2}+p_cE_g \tag{7}$$

See the appendix for the solution process.

(2) Decentralized decision-making

In decentralized decision-making, it is labeled as fl. In this low-carbon service outsourcing supply chain, service providers play a dominant role. The decision-making order is that low-carbon service providers determine the service reward v per unit product emission reduction, and then manufacturers determine the optimal output q^* and the realization ratio λ per unit product emission reduction target according to their investment level.

At this point, the manufacturer's profit maximization model is:

$$\begin{aligned}\max_{q_{fl},\lambda_{fl}}\pi_{mfl}&=q_{fl}[s_{fl}-v_{fl}]+p_cE_p-I\\&=q_{fl}(A-\eta q_{fl}+k\lambda_{fl}E-v_{fl})+p_c[E_g-q_{fl}(E_0-\lambda_{fl}E)]-\varepsilon\lambda_{fl}^2\end{aligned}. \tag{8}$$

The profit maximization model of low-carbon service providers is:

$$\max_{v_{fl}}\pi_{bfl}=q_{fl}(v_{fl}-c_e)=q_{fl}v_{fl}-q_{fl}c_e \tag{9}$$

It is found that the optimal solution q_{fl}^*, λ_{fl}^*, v_{fl}^* is:

$$q_{fl}^*=\frac{\varepsilon(A-p_cE_0-c_e)}{4\varepsilon\eta-\left(kE+p_cE\right)^2} \tag{10}$$

$$\lambda_{fl}^*=\frac{\left(kE+p_cE\right)\left(A-p_cE_0-c_e\right)}{2[4\varepsilon\eta-\left(kE+p_cE\right)^2]} \tag{11}$$

$$v_{fl}^*=\frac{A-p_cE_0+c_e}{2} \tag{12}$$

The manufacturer's optimal profit under decentralized decision-making under complete rationality is:

$$\pi_{mfl}^*=\frac{\varepsilon(A-p_cE_0-c_e)^2}{4[4\varepsilon\eta-(kE+p_cE)^2]}+p_cE_g \tag{13}$$

The optimal profit of the service provider is:

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$$\pi_{bfl}^{*}=\frac{\varepsilon\left(A-p_{c}E_{0}-c_{e}\right)^{2}}{2[4\varepsilon\eta-(kE+p_{c}E)^{2}]} \tag{14}$$

The overall optimal profit of the supply chain is:

$$\pi_{sfl}^{*}=\frac{3\varepsilon(A-p_{c}E_{0}-c_{e})^{2}}{4[4\varepsilon\eta-(kE+p_{c}E)^{2}]}+p_{c}E_{g} \tag{15}$$

See the appendix for the solution process.

Proposition 1:

The manufacturer's output is about the increasing function of consumers' low-carbon preferences, that is: $\partial q_{cl}^{*}/\partial k>0$, $\partial q_{fl}^{*}/\partial k>0$. And the realization ratio of emission reduction target per unit product is also the increasing function of consumers' low-carbon preference. that is: $\partial\lambda_{cl}^{*}/\partial k>0$, $\partial\lambda_{fl}^{*}/\partial k>0$. See the appendix for the solution process.

Proposition 1 shows that when low-carbon service providers participate, the output of manufacturers will increase with the increase of consumers' low-carbon preference, whether under decentralized decision-making or centralized decision-making That is, the higher consumers' desire to buy low-carbon products, the more they can stimulate manufacturers to produce low-carbon products. And manufacturers are willing to pay more investment costs, so the realization ratio of emission reduction target per unit product also increases with the increase of consumers' low-carbon preference coefficient.

Proposition 2:

When low-carbon service providers participate in cooperative emission reduction, the manufacturer's optimal profit, the low-carbon service provider's optimal profit and the supply chain's optimal profit under centralized decision-making are all about consumers' low-carbon preference increasing function, that is:, $\partial\pi_{mfl}^{*}/\partial k>0$, $\partial\pi_{bfl}^{*}/\partial k>0$, $\partial\pi_{scl}^{*}/\partial k>0$, See appendix a for the proof process.

Proposition 2 shows that the optimal profits of manufacturers, low-carbon service providers and supply chain under centralized decision-making all increase with the increase of consumers' desire to buy low-carbon products. That is, consumers have a high preference for low-carbon products and are willing to pay higher prices for low-carbon products, which stimulates manufacturers to produce more low-carbon products, and the optimal profits of manufacturers and low-carbon service providers will increase accordingly.

4.2. The Manufacturer is Overconfident about the Price of the Product

In the process of cooperative emission reduction, it is assumed that manufacturers overestimate consumers' low-carbon preferences and think that consumers are willing to accept higher prices for low-carbon products, so the pricing of low-carbon products is biased.

The foregoing assumes that the manufacturer has overconfidence in the product price, and the manufacturer predicts as follows:

The manufacturer's marginal profit is: $s_{fr}=A-\eta q_{fr}+(1+r)k\lambda_{fr}E$

The manufacturer's profit maximization model is:

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$$\begin{aligned}\max_{q_{fr},\lambda_{fr}} \pi_{mfr} &= q_{fr}[s_{fr}-v_{fr}]+p_cE_p-I \\ &= q_{fr}[A-\eta q_{fr}+(1+r_{fr})k\lambda_{fr}E-v_{fr}]+p_c[E_g-q_{fr}(E_0-\lambda_{fr}E)]-\varepsilon\lambda_{fr}^2\end{aligned} \tag{16}$$

The profit maximization model of low-carbon service providers is:

$$\max_{v_{fr}} \pi_{bfr} = q_{fr}(v_{fr}-c_e) = q_{fr}(v_{fr}-c_e) \tag{17}$$

At this time, the manufacturer obtains the optimal solution $q_{fr}^*,\lambda_{fr}^*,v_{fr}^*$ according to the prediction:

$$q_{fr}^* = \frac{\varepsilon\left(A-p_cE_0-c_e\right)}{4\varepsilon\eta-[(1+r)kE+p_cE]^2} \tag{18}$$

$$\lambda_{fr}^* = \frac{\left(A-p_cE_0-c_e\right)[\left(1+r\right)kE+p_cE]}{2\left(4\varepsilon\eta-[\left(1+r\right)kE+p_cE]^2\right)} \tag{19}$$

$$v_{fr}^* = \frac{A-p_cE_0+c_e}{2} \tag{20}$$

See appendix a for the proof process.

But at this time, the actual product price is different from the manufacturer's forecast. At this time, the manufacturer's real marginal profit is:

$$s^1 = A-\eta q_{fr}+k\lambda_{fr}E$$

At this point, the manufacturer's real optimal profit function is:

$$\pi_{mfr}^1 = q_{fr}(A-\eta q_{fr}+k\lambda_{fr}E-v_{fr})+p_c[E_g-q_{fr}(E_0-\lambda_{fr}E)]-\varepsilon\lambda_{fr}^2 \tag{21}$$

The real optimal profit function of low-carbon service providers is:

$$\pi_{bfr}^1 = q_{fr}(v_{fr}-c_e) \tag{22}$$

Substituting formula (18)(19)(20) into formula (21), we can get the real optimal profit of the manufacturer as follows:

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$$\pi_{mfr}^{*}=\frac{\varepsilon\left(A-p_{c}E_{0}-c_{e}\right)^{2}}{4\left(4\varepsilon\eta-[(1+r)kE+p_{c}E]^{2}\right)^{2}}\begin{Bmatrix}2\left(4\varepsilon\eta-[(1+r)kE+p_{c}E]^{2}\right)-4\varepsilon\eta\\+2E^{2}(k+p_{c})[(1+r)k+p_{c}]\\-E^{2}[(1+r)k+p_{c}]^{2}\end{Bmatrix}+p_{c}E_{g} \tag{23}$$

Substituting formula (18)(19)(20) into formula (21), The real optimal profit of available low-carbon service providers is:

$$\pi_{bfr}^{*}=\frac{\varepsilon\left(A-p_{c}E_{0}-c_{e}\right)^{2}}{2\left(4\varepsilon\eta-[(1+r)kE+p_{c}E]^{2}\right)} \tag{24}$$

At this time, the overall profit of the supply chain is:

$$\pi_{sfr}^{*}=\frac{\varepsilon\left(A-p_{c}E_{0}-c_{e}\right)^{2}}{4\left(4\varepsilon\eta-[(1+r)kE+p_{c}E]^{2}\right)^{2}}\begin{Bmatrix}2\left(4\varepsilon\eta-[(1+r)kE+p_{c}E]^{2}\right)-4\varepsilon\eta\\+2E^{2}(k+p_{c})[(1+r)k+p_{c}]\\-E^{2}[(1+r)k+p_{c}]^{2}+2\end{Bmatrix}+p_{c}E_{g} \tag{25}$$

Proposition 3:

In the state of overconfidence, the optimal output of manufacturers and the realization ratio of the optimal emission reduction target per unit product are positively correlated with the level of overconfidence.that is: $\partial q_{fr}^{*}/\partial r>0$, $\partial\lambda_{fr}^{*}/\partial r>0$. See appendix a for the proof process.

Proposition 3 shows that when manufacturers cooperate with low-carbon service providers to reduce emissions under overconfidence, the optimal output of manufacturers increases with the increase of overconfidence level of product prices. This is because manufacturers think that consumers are willing to pay higher prices for low-carbon products, and they can get higher profits from premium products. Therefore, manufacturers choose to produce more products and are willing to pay more investment costs, thus improving the realization rate of the optimal emission reduction target per unit product.

Proposition 4:

The optimal profit of manufacturers in decentralized decision-making under overconfidence state is the increasing function of overconfidence level, and the optimal profit of low-carbon service providers in decentralized decision-making under overconfidence state is the increasing function of overconfidence level. that is: $\partial\pi_{mfr}^{*}/\partial r>0$, $\partial\pi_{bfr}^{*}/\partial r>0$. See appendix a for the proof process.

Proposition 4 shows that when manufacturers are overconfident, they think that consumers are willing to pay higher prices for low-carbon products and they can get higher profits from premium goods, so manufacturers produce more products and are willing to pay higher service remuneration, and the profits of low-carbon service providers will rise accordingly.

4.3. Contrastive Analysis

By comparing and analyzing the models in Section 4.1 and 4.2, this section discusses the influence of overconfidence on the decision variables of supply chain, and analyzes the influence of manufacturer overconfidence on the profit of supply chain members and the overall profit of supply chain.

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Proposition 5:

Under overconfidence, the manufacturer's optimal profit under decentralized decision-making is less than that under complete rationality, and the overall profit of supply chain under overconfidence is less than that under complete rationality.that is: $\pi_{mfr}^{*} < \pi_{mfl}^{*}$, $\pi_{sfr}^{*} < \pi_{sfl}^{*}$. See appendix a for the proof process.

Proposition 5 shows that when manufacturers cooperate with low-carbon service providers to reduce emissions in an overconfident state, they think that consumers are willing to pay higher prices for low-carbon products, and they can get higher profits from premium goods, and they choose to produce more products and pay more investment costs. However, this is not the case in reality. However, manufacturers have paid more investment costs, so the profits of manufacturers in an overconfident state are lower than those in a completely rational state, and the overall profits of supply chains in an overconfident state are lower than those in a completely rational state.

Proposition 6:

The optimal profit of service providers in decentralized decision-making under overconfidence is greater than that in decentralized decision-making under complete rationality, that is: $\pi_{bfr}^{*} > \pi_{bfl}^{*}$. See appendix a for the proof process.

Proposition 6 shows that when manufacturers cooperate with low-carbon service providers to reduce emissions under overconfidence, manufacturers think that consumers are willing to pay higher prices for low-carbon products and they can get higher profits from premium goods. Therefore, manufacturers choose to produce more products and are willing to pay more investment costs for green emission reduction, so the profits of service providers under overconfidence are greater than those under complete rationality.

5. Conclusion

Based on the two-level supply chain environment composed of manufacturers and low-carbon service providers, this paper analyzes the influence of overconfidence on decision variables such as manufacturers' output and service providers' achievement rate of emission reduction targets, and the influence of overconfidence on manufacturers' profits, service providers' profits and the overall profits of the supply chain. It is found that with the increase of manufacturer's overconfidence level, the decision variables such as manufacturer's output and the realization rate of emission reduction targets of service providers will increase. The profit of manufacturer under overconfidence state is less than that under complete rationality state, the profit of service providers under overconfidence state is greater than that under complete rationality state, and the overall profit of supply chain under overconfidence state is less than that under complete rationality state.

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Appendix

1) Low-carbon service providers are not involved in the state of complete rationality:
At this time, the manufacturer's profit maximization model is:

$$\max_{q_0} \pi_{m0} = q_0 s_0 + p_c E_p \\ = q_0(A-\eta q_0) + p_c(E_g - q_0 E_0) \tag{26}$$

The second derivative of manufacturer's profit about output is obtained as follows:

$$\frac{\partial^2 \pi_{m0}}{\partial {q_0}^2} = -2\eta < 0 \tag{27}$$

It can be judged that this function is convex and the manufacturer has the maximum profit. The first derivative of manufacturer's profit with respect to output is obtained as follows:

$$\frac{\partial \pi_{m0}}{\partial q_0} = A - 2\eta q_0 - p_c E_0 \tag{28}$$

When $\partial \pi_{m0} / \partial q_0 = 0$,Find the optimal yield:

$$q_0^* = \frac{A - p_c E_0}{2\eta} \tag{29}$$

Substituting Formula (29) into Formula (26) for the manufacturer's maximum profit:

$$\pi_{mo}^* = \frac{(A - p_c E_0)^2}{4\eta} + p_c E_g \tag{30}$$

2) The participation of low-carbon service providers (centralized decision-making) in a completely rational state:
The optimal profit of supply chain under centralized decision-making under the complete rationality of manufacturers is:
At this time, the profit function of emission reduction supply chain is:

$$\max_{q_{cl}, g_{cl}} \pi_{scl} = q_{cl}(s_{cl} - c_e) + p_c E_p - I_{cl} \\ = q_{cl}\left(A - \eta q_{cl} + k\lambda_{cl} E - c_e\right) + p_c[E_g - q_{cl}(E_0 - \lambda E)] - \varepsilon \lambda_{cl}^2 \tag{31}$$

The first derivative of π_{scl} to q_{cl} and λ_{cl} is obtained as follows:

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$$\frac{\partial \pi_{scl}}{\partial q_{cl}} = A + k\lambda E - 2\eta q_{cl} - c_e - p_c(E_0 - \lambda E) \tag{32}$$

$$\frac{\partial \pi_{scl}}{\partial \lambda_{cl}} = kq_{cl}E + p_c q_{cl}E - 2\varepsilon\lambda_{cl} \tag{33}$$

The Hesse matrix $H(q_{cl}, \lambda_{cl})$ about π_{scl} is obtained as follows:

$$H\left(q_{cl}, \lambda_{cl}\right) = \begin{pmatrix} \frac{\partial^2 \pi_{scl}}{\partial q^2_{cl}} & \frac{\partial^2 \pi_{scl}}{\partial q_{cl} \partial \lambda_{cl}} \\ \frac{\partial^2 \pi_{scl}}{\partial q_{cl} \partial \lambda_{cl}} & \frac{\partial^2 \pi_{scl}}{\partial \lambda^2_{cl}} \end{pmatrix} = 4\varepsilon\eta - (kE + p_c E)^2$$

Specify that $4\varepsilon\eta > (kE + p_c E)^2$, It can be seen that the Hesse matrix is a semi-negative definite matrix, and the low-carbon service provider has the maximum profit at this time, and the simultaneous equation is:

$$\partial \pi_{scl} / \partial q_{cl} = 0$$
$$\partial \pi_{scl} / \partial \lambda_{cl} = 0$$

Find the optimal solution , q^*_{cl}, λ^*_{cl} is:

$$q^*_{cl} = \frac{2\varepsilon(A - p_c E_0 - c_e)}{4\varepsilon\eta - (kE + p_c E)^2} \tag{34}$$

$$\lambda^*_{cl} = \frac{E\left(K + p_c\right)(A - p_c E_0 - c_e)}{4\varepsilon\eta - (kE + p_c E)^2} \tag{35}$$

Substituting (34) and (35) into (31), we can get the optimal solution of supply chain profit when the manufacturer makes centralized decision under complete rationality:

$$\pi^*_{scl} = \frac{\varepsilon(A - p_c E_0 - c_e)^2}{4\varepsilon\eta - (kE + p_c E)^2} + p_c E_g \tag{36}$$

3) The participation of low-carbon service providers (decentralized decision-making) in a completely rational state:

The manufacturer's profit maximization model is:

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$$\begin{aligned}\max_{q_{fl},\lambda_{fl}} \pi_{mfl} &= q_{fl}[s_{fl}-v_{fl}]+p_c E_p - I \\ &= q_{fl}(A-\eta q_{fl}+k\lambda_{fl}E-v_{fl})+p_c[E_g-q_{fl}(E_0-\lambda_{fl}E)]-\varepsilon\lambda_{fl}^2\end{aligned} \quad (37)$$

The first derivative of π_{mfl} to q_{fl} and λ_{fl} is obtained as follows:

$$\frac{\partial \pi_{fl}}{\partial q_{fl}} = A + k\lambda E - 2\eta q - v - p_c\left(E_0 - \lambda E\right) \quad (38)$$

$$\frac{\partial \pi_{fl}}{\partial \lambda_{fl}} = q_{fl}Ek + p_c q_{fl}E - 2\varepsilon\lambda_{fl} \quad (39)$$

The Hesse matrix $H(q_{fl},\lambda_{fl})$ about π_{mfl} is obtained as follows:

$$H\left(q_{fl},\lambda_{fl}\right) = \begin{pmatrix} \dfrac{\partial^2 \pi_{fl}}{\partial q^2_{fl}} & \dfrac{\partial^2 \pi_{fl}}{\partial q_{fl}\partial \lambda_{fl}} \\ \dfrac{\partial^2 \pi_{fl}}{\partial q_{fl}\partial \lambda_{fl}} & \dfrac{\partial^2 \pi_{fl}}{\partial \lambda^2_{fl}} \end{pmatrix} = 4\varepsilon\eta - (kE + p_c E)^2$$

Specify that $4\varepsilon\eta > (kE + p_c E)^2$, It can be seen that the Hesse matrix is a semi-negative definite matrix, and the low-carbon service provider has the maximum profit at this time, and the simultaneous equation is:

$$\partial \pi_{mfl} / \partial q_{fl} = 0$$
$$\partial \pi_{mfl} / \partial \lambda_{fl} = 0$$

Find the optimal solution q^*_{cl}, λ^*_{cl} is:

$$q^*_{cl} = \frac{2\varepsilon(A - p_c E_0 - c_e)}{4\varepsilon\eta - (kE + p_c E)^2} \quad (40)$$

$$\lambda^*_{cl} = \frac{E\left(K + p_c\right)(A - p_c E_0 - c_e)}{4\varepsilon\eta - (kE + p_c E)^2} \quad (41)$$

The profit maximization model of low-carbon service providers is:

$$\max_{v_{fl}} \pi_{bfl} = q_{fl}(v_{fl} - c_e) = q_{fl}v_{fl} - q_{fl}c_e \quad (42)$$

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Substituting (40) and (41) into (42), we can get the profit maximization model of the service provider when the manufacturer makes decentralized decisions under complete rationality:

$$\max_{v_{fl}} \pi_{bfl} = \frac{2\varepsilon(v-c_e)(A-p_cE_0-v)}{4\varepsilon\eta-(kE+p_cE)^2} \tag{43}$$

Find the second derivative of π_{bfl} to v_{fl} as follows:

$$\frac{\partial^2\pi_{bfl}}{\partial v_{fl}^2} = -\frac{4\varepsilon}{4\varepsilon\eta-(kE+p_cE)^2} < 0 \tag{44}$$

It can be judged that this function is convex and the service provider has the maximum profit. The first derivative of service provider's profit about reward is:

$$\frac{\partial\pi_{bfl}}{\partial v_{fl}} = \frac{2\varepsilon(A+c_e-p_cE_0-2v)}{4\varepsilon\eta-(kE+p_cE)^2} \tag{45}$$

Specify that $\frac{\partial\pi_{bfl}}{\partial v_{fl}} = 0$, Find the optimal solution v_{fl}^* is:

$$v_{fl}^* = \frac{A-p_cE_0+c_e}{2} \tag{46}$$

Substitute (46) into (40) and (41), Find the optimal solution q^*_{cl}, λ^*_{cl} is:

$$q_{fl}^* = \frac{\varepsilon(A-p_cE_0-c_e)}{4\varepsilon\eta-(kE+p_cE)^2} \tag{47}$$

$$\lambda_{fl}^* = \frac{(kE+p_cE)(A-p_cE_0-c_e)}{2[4\varepsilon\eta-(kE+p_cE)^2]} \tag{48}$$

Substituting (46)(47)(48) into (37)(42), we get:
The manufacturer's optimal profit is:

$$\pi_{mfl}^* = \frac{\varepsilon(A-p_cE_0-c_e)^2}{4[4\varepsilon\eta-(kE+p_cE)^2]} + p_cE_g \tag{49}$$

The optimal profit of the service provider is:

$$\pi_{bfl}^* = \frac{\varepsilon(A-p_cE_0-c_e)^2}{2[4\varepsilon\eta-(kE+p_cE)^2]} \tag{50}$$

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The overall optimal profit of the supply chain is:

$$\pi_{sfl}^{*}=\frac{3\varepsilon(A-p_cE_0-c_e)^2}{4[4\varepsilon\eta-(kE+p_cE)^2]}+p_cE_g \tag{51}$$

4) Proposition 1 proves that:

$$\frac{\partial q_{cl}^{*}}{\partial k}=\frac{4\varepsilon E\left(A-p_cE_0-c_e\right)\left(kE+p_cE\right)}{\left[4\varepsilon\eta-\left(kE+p_cE\right)^2\right]^2}$$

$$\frac{\partial q_{fl}^{*}}{\partial k}=\frac{2\varepsilon E\left(A-p_cE_0-c_e\right)\left(kE+p_cE\right)}{\left[4\varepsilon\eta-\left(kE+p_cE\right)^2\right]^2}$$

Among them,

$$\varepsilon E>0,\ A-p_cE_0-c_e>0,\ kE+p_cE>0,\left[4\varepsilon\eta-\left(kE+p_cE\right)^2\right]^2>0 \tag{52}$$

Therefore,

$$\frac{\partial q_{cl}^{*}}{\partial k}=\frac{4\varepsilon E\left(A-p_cE_0-c_e\right)\left(kE+p_cE\right)}{\left[4\varepsilon\eta-\left(kE+p_cE\right)^2\right]^2}>0 \tag{53}$$

$$\frac{\partial q_{fl}^{*}}{\partial k}=\frac{2\varepsilon E\left(A-p_cE_0-c_e\right)\left(kE+p_cE\right)}{\left[4\varepsilon\eta-\left(kE+p_cE\right)^2\right]^2}>0 \tag{54}$$

$$\frac{\partial \lambda_{cl}^{*}}{\partial k}=\frac{2E\left(A-p_cE_0-c_e\right)\left(KE+p_cE\right)^2}{\left[4\varepsilon\eta-\left(kE+p_cE\right)^2\right]^2}$$

$$\frac{\partial \lambda_{fl}^{*}}{\partial k}=\frac{E\left(A-p_cE_0-c_e\right)\left[4\varepsilon\eta+\left(kE+p_cE\right)^2\right]}{2\left[4\varepsilon\eta-\left(kE+p_cE\right)^2\right]^2}$$

Among them,

$$\begin{aligned}&E>0,A-p_cE_0-c_e>0,\left(KE+p_cE\right)^2>0\\&\left[4\varepsilon\eta-\left(kE+p_cE\right)^2\right]^2>0,4\varepsilon\eta+\left(kE+p_cE\right)^2>0\end{aligned} \tag{55}$$

Therefore,

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$$\frac{\partial\lambda_{cl}^{*}}{\partial k}=\frac{2E\left(A-p_{c}E_{0}-c_{e}\right)\left(KE+p_{c}E\right)^{2}}{\left[4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}\right]^{2}}>0 \tag{56}$$

$$\frac{\partial\lambda_{fl}^{*}}{\partial k}=\frac{E\left(A-p_{c}E_{0}-c_{e}\right)\left[4\varepsilon\eta+\left(kE+p_{c}E\right)^{2}\right]}{2\left[4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}\right]^{2}}>0 \tag{57}$$

5)0 Proposition 2 proves that:

$$\frac{\partial\pi_{mfl}^{*}}{\partial k}=\frac{\varepsilon E^{2}\left(k+p_{c}\right)\left(A-p_{c}E_{0}-c_{e}\right)^{2}}{2\left[4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}\right]^{2}}>0 \tag{58}$$

$$\frac{\partial\pi_{bfl}^{*}}{\partial k}=\frac{\varepsilon E^{2}\left(k+p_{c}\right)\left(A-p_{c}E_{0}-c_{e}\right)^{2}}{\left[4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}\right]^{2}}>0 \tag{59}$$

$$\frac{\partial\pi_{scl}^{*}}{\partial k}=\frac{2\varepsilon E\left(kE+p_{c}E\right)\left(A-p_{c}E_{0}-c_{e}\right)^{2}}{\left[4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}\right]^{2}}>0 \tag{60}$$

6) Decentralized decision-making of manufacturers under overconfidence:The solution process is the same as 3.

7) Proposition 3 proves that:

$$\frac{\partial q_{fr}^{*}}{\partial r}=\frac{2\varepsilon kE\left(A-p_{c}E_{0}-c_{e}\right)\left[\left(1+r\right)kE+p_{c}E\right]}{\left(4\varepsilon\eta-\left[\left(1+r\right)kE+p_{c}E\right]^{2}\right)^{2}}>0 \tag{61}$$

$$\partial\lambda_{fr}^{*}/\partial r=\frac{\left(A-p_{c}E_{0}-c_{e}\right)\left[\left(1+r\right)kE+p_{c}E\right]}{2\left(4\varepsilon\eta-\left[\left(1+r\right)kE+p_{c}E\right]^{2}\right)}>0 \tag{62}$$

8) Proposition 4 proves that:

$$\frac{\partial\pi_{mfr}^{*}}{\partial r}=\frac{\varepsilon Ek\left(A-p_{c}E_{0}-c_{e}\right)^{2}\begin{pmatrix}4\varepsilon\eta+E^{2}\left(k+p_{c}\right)\left[\left(1+r\right)k+p_{c}\right]\\-\varepsilon\eta E\left[\left(20r+16\right)k+16p_{c}\right]\end{pmatrix}}{2\left(4\varepsilon\eta-\left[\left(1+r\right)kE+p_{c}E\right]\right)^{3}}>0 \tag{63}$$

$$\frac{\partial\pi_{bfr}^{*}}{\partial r}=\frac{2\varepsilon kE\left(A-p_{c}E_{0}-c_{e}\right)^{2}}{4\left(4\varepsilon\eta-\left[\left(1+r\right)kE+p_{c}E\right]\right)^{2}}>0 \tag{64}$$

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9) Proposition 5 proves that:

$$\pi_{mfr}^{*}-\pi_{mfl}^{*}=-\frac{\varepsilon r^{2}k^{2}E^{2}\left(A-p_{c}E_{0}-c_{e}\right)^{2}\left(4\varepsilon\eta+\left[(r+3)k+3p_{c}\right]\left[(1+r)k+p_{c}\right]E^{2}\right)}{4\left[4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}\right]\left(4\varepsilon\eta-[(1+r)kE+p_{c}E]^{2}\right)^{2}} \tag{65}$$

Among them,

$$\begin{aligned}&\varepsilon r^{2}k^{2}E^{2}>0,\left(A-p_{c}E_{0}-c_{e}\right)^{2}>0,4\varepsilon\eta+\left[(r+3)k+3p_{c}\right]>0,(1+r)k+p_{c}>0,\\&E^{2}>0,4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}>0,\left(4\varepsilon\eta-[(1+r)kE+p_{c}E]^{2}\right)^{2}>0\end{aligned} \tag{66}$$

Therefore,

$$\pi_{mfr}^{*}-\pi_{mfl}^{*}=-\frac{\varepsilon r^{2}k^{2}E^{2}\left(A-p_{c}E_{0}-c_{e}\right)^{2}\left(4\varepsilon\eta+\left[(r+3)k+3p_{c}\right]\left[(1+r)k+p_{c}\right]E^{2}\right)}{4\left[4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}\right]\left(4\varepsilon\eta-[(1+r)kE+p_{c}E]^{2}\right)^{2}}<0 \tag{67}$$

$$\pi_{sfr}^{*}-\pi_{sfl}^{*}=\frac{\varepsilon rkE^{2}\left(A-p_{c}E_{0}-c_{e}\right)^{2}\left(2\left[(r+2)k+2p_{c}\right]-rk\begin{pmatrix}4\varepsilon\eta+\left[(3+r)k+3p_{c}\right]\\\left[(1+r)k+p_{c}\right]E^{2}\end{pmatrix}\right)}{4\left[4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}\right]\left(4\varepsilon\eta-[(1+r)kE+p_{c}E]^{2}\right)^{2}}<0 \tag{68}$$

10) Proposition 6 proves that:

$$\pi_{bfr}^{*}-\pi_{bfl}^{*}=\frac{E^{2}\varepsilon rk\left(A-p_{c}E_{0}-c_{e}\right)^{2}\left[(r+2)k+2p_{c}\right]}{2\left[4\varepsilon\eta-\left(kE+p_{c}E\right)^{2}\right]\left(4\varepsilon\eta-\left[(1+r)kE+p_{c}E\right]^{2}\right)}>0 \tag{69}$$