Decision and coordination of low-carbon supply chain under the trend of new retailing

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Abstract

Considering the supply chains consisting of a single manufacturer, a single new retailer and a traditional retailer and assuming that demands were affected by the manufacturer’s reduction of carbon emission, the new retailer’s service and the traditional retailer’s promotion, new retailing channel preference coefficient is defined and the supply chain decision models under different contract mechanisms are developed. The inference of how the manufacturer improves reduction of carbon emission, how the new retailer improves service and how the traditional retailer improves promotion through effective coordination mechanism is analyzed. The research results show that the cost sharing will make supply chain have a Pareto improvement to a considerable degree. The greater the marginal profit of the supplier is, the worse the coordination effect of the cooperative emission reduction mode will be. The comparative advantage of the cooperative service coordination and cooperative promotion coordination depends on the influence of service and promotion on channel demand. The greater the impact of reduction of carbon emission on channel demand is, the higher its rate should be shared by the channel retailer. The profit of supply chain is positively related to a new retailing channel preference; this indicates that opening up the ‘new retailing’ is beneficial for improving supply chain profits.

Keywords: new retailing; low-carbon supply chain; contract mechanism; supply chain coordination

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1. INTRODUCTION

With the development of China’s economy and the increasing consumption level of residents, the demand for diversified retail mode is increasing. It has become a trend that improving the circulation efficiency of products through the deep integration of business mode and big data. Under this background, the ‘new retailing’ mode arises from the historic moment, the new retailing enterprise consists of online and offline dual channel, it inherited the characteristics of the O2O mode and ‘new retailing’ mode presents new requirements of multi-channel collaboration with supply chain management and emphasizes the quality of logistics service, so the ‘new retailing’ mode fundamentally provides consumers with higher level of service. At the same time, environmental pollution and resources shortage problems appeared gradually; in order to achieve the coordinated development between economy and environment, our country formulates a series of emissions reduction plan and promotes consumer environmental awareness.

Compared with traditional retail, experiential consumption is the core of the ‘new retailing’; the introduction to the new retail mode makes traditional retail faced intense competition, and traditional retailers guarantee their market share by offering discounts, thereby reducing channel conflict and enhancing its competitiveness. In the context of traditional retail and new retail competition, we look for the contract that can be better coordination of channel competition and maximize profits of the supply chain. It has become a new topic of theory research and practice of supply chain management.

Supply chain emission reduction is a current research hotspot. Researches were carried out from two directions: emission reduction strategy and low-carbon supply chain contract design. Rao et al. (2005) investigated East Asian companies and proved that the implementation of emission reduction strategies can increase product sales and market share. Govindan et al. (2014) believe that low-carbon production enables sustainable development of the supply chain and corporate carbon emission reduction behavior is a manifestation of fulfilling social responsibility. Liu et al. (2012)
focused on the impact of competition and consumer environmental awareness on the supply chain. Member competition includes competition between manufacturers as well as competition between manufacturers and retailers. Luo et al. (2016) considered that demand is affected by price and carbon emission reduction level under the carbon quota mechanism and studied the price and carbon emission reduction decisions of two manufacturers (with different emission reduction efficiencies) under perfect competition and cooperative competition. Zhou et al. (2016) did research on the optimization of low-carbon supply chain management decision-making and analyzed the influence of different contract mechanisms on the optimal decision-making and coordination of low-carbon supply chain. Giannoccaro et al. (2004) designed a revenue-sharing contract to coordinate a three-level supply chain, which can increase the profits of all members of the supply chain. Zissis et al. (2015) considered a secondary supply chain composed of a manufacturer and a retailer. When the retailer has private information, the quantity discount contract can coordinate the supply chain under asymmetric information. Wang et al. (2019a,b) established a fair and effective coal power supply chain carbon emission allowance allocation model. Liu et al. (2018a,b) analyzed the issue of carbon technology selection in low-carbon supply chain based on carbon trading and consumer preference.

Promotion and service are important factors that affect consumers’ purchasing behavior, and some scholars have also conducted related research on these two factors. Kumar et al. (2006) constructed a dual-channel supply chain consisting of one manufacturer and one retailer and considered the impact of retail channel service efforts on the dual-channel supply chain. Mukhopadhyay et al. (2008) studied the way of the supply chain information sharing between the upstream and downstream in the case of asymmetric service information in a multi-channel supply chain, where manufacturers dominate. Krishnan et al. (2010) proved that the implementation of rapid response in the supply chain has a negative impact on the retailer's promotion efforts and proved that the minimum acceptance contract, pre-purchase contract or exclusive transaction and the rapid response of the supply chain can eliminate the rapid response of the supply chain to retailers. Studied the supply chain optimization problem of the retailer’s decision-making promotion effort and the supplier's decision-making product quality. Wang et al. (2014) constructed a differential game model based on the assumption that demand is affected by the supplier’s low-carbon reputation and retailer’s promotion efforts and analyzed the impact of several cooperation contracts on the supply chain.

The concept of 'new retail' has not been put forward for a long time, and most of the related researches focus on the definition and development trend of 'new retail'. There are almost no theoretical studies based on mathematical models. Considering that the 'new retail' is developed by improving and innovating the O2O model and the theoretical exploration of the O2O model is relatively mature, we can learn from the research results in the O2O field to explore the 'new retail' supply chain. Research in this field focuses on two aspects: empirical research with management indicators as the core and the use of mathematical models to study supply chain decision-making. Dumrongsi et al. (2008) showed that retail employees' response speed and employee working hours can affect the profits of dual-channel supply chain; these two indicators and profits of dual-channel supply chain are positively correlated. Yan et al. (2009) analyzed the impact of retail employees' service attitudes on supply chain profits. Cai et al. (2009) designed a reasonable contract mechanism and studied the impact of the contract on the profit of O2O supply chain.

To sum up, most of the existing supply chain research literature does not combine product emission reduction, product service and product promotion in the context of ‘new retail’. Therefore, this article considers a supply chain composed of an emission reduction supplier, a new retailer focusing on providing experiential consumer services and a traditional retailer with promotional activities. Under decentralized decision-making, each member of the supply chain is an economically independent individual, making supply chain decisions with the goal of maximizing their profits. However, independent decision-making will reduce the efficiency of the supply chain. To this end, each member of the supply chain should coordinate the supply chain through effective contracts. This paper studies the model of cooperative emission reduction, cooperative promotion and cooperative service decision-making among suppliers, retailers and new retailers and provides an effective cost-sharing contract as supply chain members looking for a contract mechanism that can maximize Pareto improvement, optimize cooperation among supply chain members and solve supply chain inefficiencies. This is of great significance to the development of low-carbon supply chains under the ‘new retail’ trend.

2. PROBLEM DESCRIPTION AND ASSUMPTIONS

2.1. Problem description

This paper considers a low-carbon supply chain consisting of a supplier, a new retailer and a traditional retailer, as shown in Figure 1. The reduction of carbon emission is decided by suppliers. New retailers provide experiential consumption to consumers. (The new retailers make the decision of the new retailer’s service.) Traditional retailers are trying to promote their products in order to keep their market share, then they decide the traditional retailer’s promotion.

![Figure 1. Schematic diagram.](https://academic.oup.com/ijlct/advance-article-doi/10.1093/ijlct/ctab035/6278939)
2.2. Assumptions
Combining with the actual situation, we simplify the complex conditions and make following assumptions about the model:

Assumption 1. Supply chain members are risk neutral and completely rational, and suppliers have the capacity to meet market demand.

Assumption 2. This study does not consider the impact of price on demand, and the marginal revenue of suppliers, new retailers and traditional retailers is constant value \( w, I_n, I_r \).

Assumption 3. Referencing to Xie et al. (2017), the cost of carbon reduction is an increasing and convex function with the emission reduction. In this paper, we consider that the cost of carbon emission reduction can be expressed as a quadratic function with the carbon emission reduction. In the same way, the cost function of new retailer’s service and traditional retailer’s promotion are expressed as follows:

\[
C(e) = \frac{1}{2} k_1 e^2; \\
C(s) = \frac{1}{2} k_2 s^2; \\
C(A) = \frac{1}{2} k_3 A^2.
\]

Where the coefficients \( k_1, k_2, k_3 \), respectively, represent the carbon emission reduction coefficient, service effort coefficient and promotion effort coefficient. To simplify the calculation, we let \( k_1 = k_2 = k_3 = 1 \). Moreover, \( e, s, A \), respectively, represent the level of emission reduction, service efforts and promotion efforts.

Assumption 4. The market demand function of the new retailer is the following: \( D_n = \alpha e + \delta + \mu s \). Referencing to Chiang et al. (2003), to be convenient for computation and analysis, let the coefficient \( \delta \in (0, 1) \) denote the consumers’ propensity to buy from the new retail channel, in which \( \delta \to 0 \) means that the new retail channel is totally unacceptable and \( \delta \to 1 \) represents that no consumer chooses the traditional retail channel. The market demand function of the new retailer is the following: \( D_n = \alpha e + \delta + \mu s \). \( \alpha \) represents the impact of carbon emission on demand of new retail channel, as well as \( \mu s \) stands for the impact of service efforts on demand of new retail channel. The demand function of traditional retail channel is as follows: \( D_r = 1 - \delta + \beta e + \rho A \). \( \beta \) represents the impact of carbon emission on demand of traditional retail channel, and \( \rho \) stands for the impact of promotion efforts on demand of traditional retail channel.

3. BASIC MODEL WITH NON-COOPERATIVE GAME

In this section, we establish two models of different supply chain structures: the decentralized scenario and centralized scenario, where the optimal reduction of carbon emissions, service and promotion is obtained.

3.1. Decentralized supply chain scenario
In the decentralized scenario, the manufacturer, the new retailer and the traditional retailer maximize their own profits in the decision-making process. At this time, the profit functions of the manufacturer, the new retailer and the traditional retailer are

\[
\pi_m = -\frac{e^2}{2} + w (1 + c (\alpha + \beta) + s \mu + A \rho); \\
\pi_n = -\frac{s^2}{2} + (c \alpha + \delta + s \mu) I_n; \\
\pi_r = -\frac{A^2}{2} + (1 + e \beta - \delta + A \rho) I_r.
\]

Proposition 1. The optimal decision maximizing profit of members is obtained \( e^{D_s}, s^{D_s}, A^{D_s} \). The optimal profits of members are \( \pi_m^{D_s}, \pi_n^{D_s}, \pi_r^{D_s} \), and the optimal supply chain profit is \( \pi_{sc}^{D_s} \). Proof. The second derivative of \( e \) with respect to Equation (4): \( \frac{\partial^2 \pi_m}{\partial e^2} = -1 < 0 \), then the profit of the manufacturer is a strictly concave function with respect to the carbon reduction. Therefore, the only optimal carbon emission level can make the supplier profit maximized. Similarly, the profit of the new retailer and the traditional retailer is maximized by the only optimal service and the optimal promotion. The profit function takes the first derivative of its decision variable and equates it to zero; the optimal decision is

\[
e^{D_s} = w (\alpha + \beta) s^{D_s} = \mu I_n A^{D_s} = \rho I_r.
\]

Substituting \( e^{D_s}, s^{D_s}, A^{D_s} \) to (4), (5) and (6), we can obtain the optimal profits of members and the supply chain as follows:

\[
\pi_m^{D_s} = \frac{1}{2} w (2 + w \alpha^2 + 2 w \alpha \beta + w \beta^2 + 2 \mu^2 I_n + 2 \rho^2 I_r); \\
\pi_n^{D_s} = \frac{1}{2} I_n (2 (w \alpha (\alpha + \beta) + \delta) + \mu^2 I_n); \\
\pi_r^{D_s} = \frac{1}{2} I_r (2 + 2 w \beta (\alpha + \beta) - 2 \delta + \rho^2 I_r); \\
\pi_{sc}^{D_s} = \frac{1}{2} \left( w (2 + w (\alpha + \beta))^2 + 2 (\delta + w (\alpha^2 + \alpha \beta + \mu^2)) I_n + \mu^2 I_n^2 + 2 (1 - \delta + w (\alpha \beta + \beta^2 + \rho^2)) I_r + \rho^2 I_r^2 \right)
\]

3.2. Centralized supply chain scenario
In the centralized scenario, the manufacturer and retailer maximize the entire system in the decision-making process. At this
time, the profit function of entire supply chain is
\[ \pi_{sc} = -\frac{e^2}{2} + w (1 + e (\alpha + \beta) + S\mu + A\rho) \]
\[ - \frac{S^2}{2} + (\varepsilon\alpha + \delta + S\mu) I_n - \frac{A^2}{2} + (1 + e\beta - \delta + A\rho) I_r \]  \hfill (7)

Proposition 2. In the centralized scenario, the optimal decision maximizing profit of members is obtained \((e^c,s^c,A^c)\) and the optimal supply chain profit is \(\pi_{sc}^{c}\).

Proof. The profit function of supply chain system is joint concavity with respect to above decision variable (more details in Appendix A). \(\pi_{sc}\) takes the first derivative of the decision variable and equates it to zero; the optimal decision is
\[ e^c = w (\alpha + \beta) + \alpha I_n + \beta I_r \quad s^c = \mu (w + I_n) \quad A^c = \rho (w + I_r) . \]

Substituting \(e^c,s^c,A^c\) to (7), we can obtain the optimal profits of the supply chain as follows:
\[ \pi_{sc}^{c} = \frac{1}{2} \left[ w \left( 2 + w \left( \alpha^2 + 2\alpha\beta + \beta^2 + \mu^2 + \rho^2 \right) \right) + (\alpha^2 + \mu^2) I_n^2 + (\beta^2 + \rho^2) I_r^2 \right] + 2 \left( 1 - \delta + w (\alpha\beta + \beta^2 + \rho^2) \right) I_r + 2I_n \left( \delta + w (\alpha^2 + \alpha\beta + \mu^2 + \alpha\beta I_r) \right) . \]

Proposition 3. The optimal decisions in the decentralized scenario are in the following order in comparison to that in the decentralized scenario: \(e^D < e^c, s^D < s^c, A^D < A^c, \pi_{sc}^{D} < \pi_{sc}^{c}\).

Proof. By algebraic comparison, we can obtain as follows:
\[ e^c - e^D = \alpha I_n + \beta I_r > 0; \]
\[ s^c - s^D = \mu w > 0; \]
\[ A^c - A^D = \rho w > 0; \]
\[ \pi_{sc}^{c} - \pi_{sc}^{D} = \frac{1}{2} \left( w^2 \left( \mu^2 + \rho^2 \right) + \alpha^2 I_n^2 + 2 \alpha\beta I_n I_r + \beta^2 I_r^2 \right) > 0 . \]

Since the members of the supply chain are independent and rational individual, each individual wants to achieve the optimal effect under the centralized situation. Effective contract coordination is required to eliminate the motivation of both parties to deviate from the optimal effect. This paper designs cost-sharing contracts of different models to improve the overall performance of the supply chain by incentivizing suppliers' emission reduction levels, new retailers' service levels and traditional retailers' promotion levels. Consider the four cooperation modes to coordinate low-carbon supply chains: new retailers and traditional retailers to share suppliers' emission reduction costs (SER model), suppliers sharing the service costs of new retailers (SSC model), suppliers sharing the promotion costs of traditional retailers (SPC model) and cost sharing among members (CSA model).

4. COORDINATING LOW-CARBON SUPPLY CHAIN CONTRACT

4.1. SER model

The supplier enhances reduction of carbon emissions to increase channel sales. We consider that the new retailer and traditional retailer share the supplier emission reduction costs; a cooperative emission reduction model is developed (SER model). We denote the contract as \((\varphi_1,\varphi_2)\), where \(\varphi_1 (0 < \varphi_1 < 1)\) is the cost fraction that the new retailer shares and \(\varphi_2 (0 < \varphi_2 < 1)\) is the cost fraction that the traditional retailer shares. In the SER model, the profits of members are as follows:
\[ \pi_m = - (1 - \varphi_1 - \varphi_2) \frac{e^2}{2} + w (1 + e (\alpha + \beta) + s\mu + A\rho) ; \hfill (8) \]
\[ \pi_n = - \frac{\varepsilon^2}{2} - \varphi_1^2 + (\varepsilon\alpha + \delta + s\mu) I_n; \hfill (9) \]
\[ \pi_r = - \frac{A^2}{2} - \varphi_2^2 + (1 + e\beta - \delta + A\rho) I_r . \hfill (10) \]

Proposition 4. If \(w < I_n,w < I_r\), the optimal decision maximizing profit of members is obtained \((e^c_s,s^c_s,A^c_s,\varphi_1^*,\varphi_2^*)\). The optimal profits of members are \(\pi_{m}^{c_s},\pi_{n}^{c_s},\pi_{r}^{c_s}\), and the optimal supply chain profit is \(\pi_{sc}^{c_s}\).

Proof. If \(w < I_n,w < I_r\), there exists optimal solution (more details in Appendix A), we can obtain optimal decision variables as follows:
\[ e^{c_s} = \alpha I_n + \beta I_r \quad s^{c_s} = \mu I_n \quad A^{c_s} = \rho I_r \]
\[ \varphi_1^* = - \frac{w (\alpha + \beta) + 2\alpha I_n}{2 (\alpha I_n + \beta I_r)} \quad \varphi_2^* = - \frac{w (\alpha + \beta) + 2\beta I_r}{2 (\alpha I_n + \beta I_r)} . \]

Substituting above values to (8), (9) and (10), we can obtain the optimal profits of members and the supply chain as follows:
\[ \pi_{m}^{c_s} = \frac{1}{2} w \left( 2 + \left( \alpha^2 + 2\alpha\beta + 2\mu^2 \right) I_n + \left( \alpha\beta + \beta^2 + 2\rho^2 \right) I_r \right) ; \]
\[ \pi_{n}^{c_s} = \frac{1}{4} \left( 2 \left( \alpha^2 + \mu^2 \right) I_n + w\beta (\alpha + \beta) I_r + I_n \left( \omega (\alpha + \beta) + 4\delta + 2\alpha\beta I_r \right) \right) ; \]
\[ \pi_{r}^{c_s} = \frac{1}{4} \left( I_r \left( 4 + w\beta (\alpha + \beta) - 4\delta + 2 \left( \beta^2 + \rho^2 \right) I_r \right) + \alpha I_n \left( \omega (\alpha + \beta) + 2\beta I_r \right) \right) ; \]
\[ \pi_{sc}^{c_s} = \left( 1 - \delta + w (\alpha\beta + \beta^2 + \rho^2) \right) I_r + \frac{1}{2} \left( \beta^2 + \rho^2 \right) I_r^2 + I_n \left( \delta + w (\alpha^2 + \alpha\beta + \mu^2 + \alpha\beta I_r) + w + \frac{1}{2} (\alpha^2 + \mu^2) I_n^2 . \right) \]
Proposition 5. If \( w < I_n , w < I_r \) and \( 3\beta / \alpha > I_n / I_r > \beta / \alpha \), the optimal reduction of carbon emissions, the profits of supply chain members and the supply chain profits in the SER model are higher than that in the decentralized scenario. The optimal service and promotion effort in the NTS model are equal to that in the decentralized scenario with non-cooperative game. Namely, \( e^s > e^D_s \), \( r^s = A^D_s \), \( \pi^m = \pi^D_m \), \( \pi^n = \pi^D_n \), and \( \pi^r = \pi^D_r \).

**Proof.** By algebraic comparison, we can obtain as follows:

\[
\begin{align*}
\pi^m - \pi^D_m &= \frac{1}{2} (w (\alpha + \beta) (\alpha I_n + \beta I_r - w (\alpha + \beta)) > 0, \\
\pi^n - \pi^D_n &= \frac{1}{2} (-w^2 (\alpha + \beta)^2 + (2\alpha^2 I_n^2 + 2\alpha\beta I_n I_r + \beta I_r^2) > 0, \\
\pi^r - \pi^D_r &= \frac{1}{2} (w (\alpha + \beta) (\alpha I_n + \beta I_r - w (\alpha + \beta)) > 0.
\end{align*}
\]

From the Proposition 5, under the condition \( w < I_n , w < I_r \) and \( 3\beta / \alpha > I_n / I_r > \beta / \alpha \), the new retailer and the traditional retailer will cooperate with the supplier to reduce carbon emissions, but they will not improve their service and promotion effort. The supplier enhances reduction of carbon emissions to increase channel sales, so that each member of supply chain gets Pareto improvement. The performance of supply chain is improved effectively.

### 4.2. SSC model

The new retailer enhances service level to increase channel sales. We consider that the supplier shares the new retailer service costs; a cooperative service model is developed. We denote the contract as \( (\varepsilon) \), where \( \varepsilon \) is the cost fraction that the supplier shares. In the SSC model, the profits of members are as follows:

\[
\begin{align*}
\pi^m &= -\frac{\varepsilon^2}{2} - \frac{s^2}{2} + w (1 + e (\alpha + \beta) + s \mu + A \rho); \\
\pi^n &= -(1 - e) \frac{s^2}{2} + (\alpha \varepsilon + \delta + s \mu) I_n; \\
\pi^r &= -\frac{A^2}{2} + (1 + e \beta - \delta + A \rho) I_r.
\end{align*}
\]

Proposition 6. If \( w < I_n \), the optimal decision maximizing profit of members is obtained \((e^s, s^s, A^s, \varepsilon^s)\). The optimal profits of members are \( \pi^m > \pi^D_m \), \( \pi^n > \pi^D_n \), and \( \pi^r > \pi^D_r \).

**Proof.** If \( w < I_n \), there exists optimal solution (more details in Appendix A), we can obtain optimal decision variables as follows:

\[
\begin{align*}
e^s &= w (\alpha + \beta) - \frac{1}{2} \mu (2w + I_n) \\
s^s &= \frac{1}{2} \mu (2w + I_n) \\
A^s &= \rho I_r \varepsilon^s = \frac{2w - I_n}{2w + I_n}.
\end{align*}
\]

Substituting above values to (11), (12) and (13), we can obtain the optimal profits of members and the supply chain as follows:

\[
\begin{align*}
\pi^m &= \frac{1}{2} w \left( 2 + w (\alpha^2 + 2\alpha\beta + \beta^2 + \mu^2) + 2\rho \beta I_n + 4w\rho \mu I_n + \mu^2 I_n^2 \right) \\
\pi^n &= \frac{1}{4} I_n (4\delta + 2w (\alpha^2 + 2\alpha\beta + \mu^2) + \mu^2 I_n) \\
\pi^r &= \frac{1}{2} I_r (2w (\alpha + \beta) - 2\delta + \rho^2 I_r) \\
\pi_{sc} &= \left( \delta + w (\alpha^2 + 2\alpha\beta + \mu^2) \right) I_n + \frac{3}{8} \mu^2 I_n^2 + \frac{1}{2} \left( w (2w (\alpha^2 + 2\alpha\beta + \beta^2 + \mu^2) + 2 (1 - \delta + w (\alpha\beta + \beta^2 + \rho^2) I_r + \rho^2 I_r^2) \right).
\end{align*}
\]

Proposition 7. If \( w < I_n < 2w \), the optimal service level, the profits of supply chain members and the supply chain profits in the SSC model are higher than that in the decentralized scenario. The optimal service and promotion effort in the SER model are equal to that in the decentralized scenario with non-cooperative game. Namely, \( e^s > e^D_s \), \( s^s = s^D_s \), \( A^s = A^D_s \), \( \pi^m > \pi^D_m \), \( \pi^n > \pi^D_n \), and \( \pi^r > \pi^D_r \).

**Proof.** By algebraic comparison, we can obtain as follows:

\[
\begin{align*}
e^s - e^D &= 0 \\
s^s - s^D &= \mu w - \frac{1}{2} I_n > 0 \\
A^s - A^D &= 0.
\end{align*}
\]

\[
\begin{align*}
\pi^m &= \frac{1}{6} \mu^2 (I_n - 2w) > 0 \\
\pi^n &= \frac{1}{4} \mu^2 (2w - I_n) I_n > 0 \\
\pi^r &= \frac{1}{8} \mu^2 (4w^2 - I_n^2) > 0
\end{align*}
\]

Proposition 7 shows that when the marginal revenue of the new retailer is slightly larger than the marginal profit of the supplier, that is, \( w < I_n < 2w \), the supplier will choose the service cooperation method to cooperate with the new retailer, but the supplier will not increase the level of carbon emission reduction. Since traditional retailers bear the promotion costs alone, the service cooperation between new retailers and suppliers will not affect the
traditional retailers' promotion efforts. After the suppliers share the cost of the new retailers' service efforts, the new retailers will improve service levels and expand market demand, which will increase the profits of suppliers, new retailers and supply chains.

4.3. SPC model

To improve traditional retailers’ promotion level to increase channel demand, suppliers consider sharing the promotion costs of traditional retailers. Suppliers take the lead in determining the proportion of promotion cost sharing, and then traditional retailers determine promotion efforts while new retailers determine service efforts. Assuming that the sharing ratio is \( \theta (0 < \theta < 1) \), the supplier shares the cost of the traditional retailer's promotional efforts, the cost of emission reduction is borne by the supplier and the new retailer alone bears the service cost. In the SPC model, the profits of members are as follows:

\[
\pi_m = \frac{c^2}{2} - \theta \frac{A^2}{2} + w(1 + c(\alpha + \beta) + s\mu + A\rho)
\]

\[
\pi_n = -\frac{s^2}{2} + (\alpha\alpha + \delta + s\mu)In
\]

\[
\pi_r = -(1 - \theta) \frac{A^2}{2} + (1 + e\beta - \delta + A\rho)Ir
\]

**Proposition 8.** If \( w < Ir \), the optimal decision maximizing profit of members is obtained \((e^p, s^p, A^p, \theta^p)\). The optimal profits of members are \(\pi_m^{p}, \pi_n^{p}, \pi_r^{p}\), and the optimal supply chain profit is \(\pi_{sc}^{p}\).

**Proof.** If \( w < Ir \), there exists optimal solution (more details in Appendix A), we can obtain optimal decision variables as follows:

\[
e^p = w(\alpha + \beta) \quad s^p = \mu In \quad A^p = \frac{1}{2} \rho (2w + Ir) \quad \theta^p = \frac{2w - Ir}{2w + Ir}.
\]

Substituting above values to (14), (15) and (16), we can obtain the optimal profits of members and the supply chain as follows:

\[
\pi_m^{p} = \frac{1}{8} \left( 4w(2 + w(\alpha^2 + 2\alpha\beta + \beta^2 + \rho^2)) + 8w\mu^2 In \right. + 4w\rho^2 Ir + \rho^2 I_r^2 \right)
\]

\[
\pi_n^{p} = \frac{1}{2} Ir \left( 2w(\alpha + \beta) + \delta + \mu^2 I_r \right)
\]

\[
\pi_r^{p} = \frac{1}{4} Ir \left( 4w - 45w(2\alpha\beta + 2\beta^2 + \rho^2) + \rho^2 Ir \right)
\]

\[
\pi_{sc}^{p} = \frac{1}{8} \left( 4w(2 + w(\alpha^2 + 2\alpha\beta + \beta^2 + \rho^2)) + 8(\delta + w(\alpha^2 + \alpha\beta + \mu^2)) In + 4w\rho^2 I_r + 8(1 - \delta + w(\alpha\beta + \beta^2 + \rho^2) Ir + 3\rho^2 I_r^2 \right)
\]

**Proposition 9.** If \( w < Ir < 2w \), the optimal promotion level of traditional retailer, the profits of supply chain members and the supply chain profits in the SPC model are higher than that in the decentralized scenario. The optimal service and reduction of carbon emissions effort in the SPC model are equal to that in the decentralized scenario with non-cooperative game. Namely, \( e^p = e^D, s^p = s^D, A^p > A^D, \pi_m^{p} > \pi_m^{D}, \pi_n^{p} > \pi_n^{D}, \pi_r^{p} > \pi_r^{D}, \pi_{sc}^{p} > \pi_{sc}^{D} \).

**Proof.** By algebraic comparison, we can obtain as follows:

\[
e^p - e^D = 0
\]

\[
s^p - s^D = 0
\]

\[
A^p - A^D = \rho w - 0.5\rho Ir > 0
\]

\[
\pi_n^{p} - \pi_n^{D} = 0
\]

\[
\pi_m^{p} - \pi_m^{D} = \frac{1}{8} \rho^2(-2w + Ir)^2 > 0
\]

\[
\pi_r^{p} - \pi_r^{D} = \frac{1}{4} \rho^2 (2w - Ir) Ir > 0
\]

\[
\pi_{sc}^{p} - \pi_{sc}^{D} = \frac{1}{8} \rho^2 (4w^2 - I_r^2) > 0
\]

**Proposition 9** shows that when the marginal revenue of the new retailer is slightly larger than the marginal profit of the supplier, that is, \( w < Ir < 2w \), the supplier will choose the service cooperation method to cooperate with the new retailer, but the supplier will not increase the level of carbon emission reduction. Since traditional retailers bear the promotion costs alone, the service cooperation between new retailers and suppliers will not affect the traditional retailers' promotion efforts. After the suppliers share the cost of the new retailers' service efforts, the new retailers will improve service levels and expand market demand, which will increase the profits of suppliers, new retailers and supply chains.

It can be seen from **Proposition 9** that when the marginal revenue of the traditional retailer is slightly larger than the marginal profit of the supplier, that is, \( w < Ir < 2w \), the supplier chooses the promotion cooperation mode, but the supplier will not increase the level of emission reduction under this mode. The new retailer alone bears the service cost. Therefore, the promotion cooperation between the traditional retailer and the supplier does not affect the service level of the new retailer. After the supplier shares the promotion cost of the traditional retailer, the traditional retailer will increase the promotion level and expand the market demand, which will increase the profits of suppliers, new retailers and supply chains.

4.4. CSA model

Each member of the supply chain shares the effort cost with each other. Traditional retailers consider sharing the supplier's emission reduction investment cost. We denote the contract as \((\varphi_1, \varphi_2, \theta, \varepsilon)\), where \( \varphi_1 (0 < \varphi_1 < 1) \) is the cost fraction that the new retailer shares, and \( \varphi_2 (0 < \varphi_2 < 1) \) is the cost fraction that the traditional retailer shares, where \( 0 < \theta < 1 \) is the promotion cost fraction that the supplier shares and where
\(0 < \varepsilon < 1\) is the service cost fraction that the supplier shares. In the CSA model, the profits of members are as follows:

\[
\pi_m = -\varepsilon s^2 + w (1 + \varepsilon (\alpha + \beta) + \mu + A \rho) - (1 - \varphi_1 - \varphi_2) \frac{e^2}{2} - \theta \frac{A^2}{2}
\]

\(\pi_n = - (1 - \varepsilon) s^2 - \varphi_1 \frac{e^2}{2} + (\alpha \eta + \delta + \mu) I_n\)

\(\pi_r = - (1 - \theta) A^2 \frac{2}{2} - \varphi_2 \frac{e^2}{2} + (1 + e \beta - \delta + A \rho) I_r\)  \(\hspace{1cm} (17)\)

Proposition 10. If \(I_r < 2w, w < I_n < 2w\), the optimal decision maximizing profit of members is obtained \((e^*, r^*, \sigma^*, \varphi_1^*, \varphi_2^*, \theta^*, \varepsilon^*)\). The optimal profits of members are \(\pi_{m^*}^r, \pi_{n^*}^r, \pi_{r^*}^r\), and the optimal supply chain profit is \(\pi_{s^*}\).

Proof. If \(w < I_r < 2w, w < I_n < 2w\), there exists optimal solution (more details in Appendix A), we can obtain optimal decision variables as follows:

\[
\theta^* = \frac{2w - I_r}{2w + I_r}, \quad \varepsilon^* = \frac{2w - I_n}{2w + I_n}
\]

\[
\varphi_1^* = - \frac{w (\alpha + \beta)}{2 (\alpha I_n + \beta I_r)} + 2 \alpha I_n, \quad \varphi_2^* = \frac{-w (\alpha + \beta) + 2 \beta I_r}{2 (\alpha I_n + \beta I_r)}
\]

\[
e^* = \alpha I_n + \beta I_r, \quad s^* = \frac{1}{2} \mu (2w + I_n) A^r = \frac{1}{2} \rho (2w + I_r).
\]

Substituting above values to (17), (18) and (19), we can obtain the optimal profits of members and the supply chain profit as follows:

\[
\pi_{m^*}^r = \frac{1}{8} \left( 4w (2 + w (\mu^2 + \rho^2)) + 4w (\alpha^2 + \alpha \beta + \mu^2) I_n + \mu^2 I_n^2 + 4w (\alpha \beta + \beta^2 + \rho^2) I_r + \rho^2 I_r^2 \right)
\]

\[
\pi_{n^*}^r = \frac{1}{4} \left( I_n (4 \delta + w (\alpha^2 + \alpha \beta + 2 \mu^2) + 2 \alpha I_n I_r) + \frac{w \beta (\alpha + \beta) I_r}{2 (\beta^2 + \mu^2)} I_r^2 \right)
\]

\[
\pi_{r^*}^r = \frac{1}{4} \left( I_r (4 - 4 \delta + w (\alpha \beta + \beta^2 + 2 \rho^2) + (2 \beta^2 + \rho^2) I_r) + \alpha I_n (w (\alpha + \beta) + 2 \beta I_r) \right)
\]

\[
\pi_{s^*}^r = \frac{1}{8} \left( 4w (2 + w (\mu^2 + \rho^2)) + (4 \alpha^2 + 3 \mu^2) I_n^2 + 8 (1 - w (\alpha \beta + \beta^2 + \rho^2) I_r) + (4 \alpha \beta + 3 \rho^2) I_r^2 + 8 I_n (\delta + w (\alpha^2 + \alpha \beta + \mu^2) + \alpha I_n I_r) \right)
\]

Proposition 11. If \(w < I_r < 2w, w < I_n < 2w, w (\alpha + \beta) < G_1, w (\alpha + \beta) < G_2\), the optimal promotion level of traditional retailer, service, reduction of carbon emissions effort the profits of supply chain members and the supply chain profits in the CSA model are higher than that in the decentralized scenario. Namely, \(e^** > e^{DS}, s^* > s^{DS}, A^* > A^{DS}, \pi_{m^*}^r > \pi_{m^{DS}}^r, \pi_{n^*}^r > \pi_{n^{DS}}^r, \pi_{r^*}^r > \pi_{r^{DS}}^r, \pi_{s^*}^r > \pi_{s^{DS}}^r\).

Proof. By algebraic comparison, we can obtain as follows:

\[e^* - e^{DS} = \alpha I_n + \beta I_r - w (\alpha + \beta) > 0\]

\[s^* - s^{DS} = \mu w - \frac{1}{2} \mu I_n > 0\]

\[A^* - A^{DS} = \rho w - \frac{1}{2} \rho I_r > 0\]

\[\pi_{m^*}^r > \pi_{m^{DS}}^r, \pi_{n^*}^r > \pi_{n^{DS}}^r, \pi_{r^*}^r > \pi_{r^{DS}}^r, \pi_{s^*}^r > \pi_{s^{DS}}^r\]

It can be seen from Proposition 11 that when the marginal revenue of traditional retailers and the marginal revenue of suppliers meet certain conditions, suppliers will choose service cooperation and promotion cooperation to cooperate with new retailers and traditional retailers. The carbon emission reduction cooperation between retailers and suppliers has allowed suppliers to increase their carbon emission reduction levels. Traditional retailers increase their own promotional efforts, while new retailers improve their service levels and strive to expand market demand, thereby achieving Pareto improvement to improve the performance of the supply chain.

Proposition 12. The relationship between supply chain profits under the four models are as follows:

\[
\pi_{sc}^e < \pi_{sc}^{e*} < \pi_{sc}^{Dp} < \pi_{sc}^{rs}, \quad \text{if } w > \frac{\beta (4 \alpha + \beta) + \alpha (2 \alpha + \beta)}{4 \alpha (4 \alpha + \beta)}, \quad \mu < \rho
\]

\[
\pi_{sc}^{Dp} < \pi_{sc}^{rs} < \pi_{sc}^{e*} < \pi_{sc}^e, \quad \text{if } w > \frac{\beta (4 \alpha + \beta) + \alpha (2 \alpha + \beta)}{4 \alpha (4 \alpha + \beta)}, \quad \mu \geq \rho
\]

\[
\pi_{sc}^{rs} < \pi_{sc}^{e*} < \pi_{sc}^{rs}, \quad \text{if } w < \min \left \{ \frac{\beta (4 \alpha + \beta) + \alpha (2 \alpha + \beta)}{4 \alpha (4 \alpha + \beta)}, \frac{\beta (4 \alpha + \beta) + \alpha (2 \alpha + \beta)}{4 \alpha (4 \alpha + \beta)} \right \}, \quad \mu < \rho
\]

\[
\pi_{sc}^{rs} < \pi_{sc}^{e*} < \pi_{sc}^{rs}, \quad \text{if } w < \min \left \{ \frac{\beta (4 \alpha + \beta) + \alpha (2 \alpha + \beta)}{4 \alpha (4 \alpha + \beta)}, \frac{\beta (4 \alpha + \beta) + \alpha (2 \alpha + \beta)}{4 \alpha (4 \alpha + \beta)} \right \}, \quad \mu \geq \rho
\]

Proof. More details in Appendix A.

It can be seen from Proposition 12 that the supply chain has the greatest profit under CSA model. Under this model, each member of the supply chain bears the cost of each other's efforts, thereby increasing the level of emission reduction, service effort and promotion effort; increasing demand; and increasing the profits of each member and whole supply chain. When the supplier's marginal revenue is greater than the threshold, the cooperative service and cooperative promotion model are better than the cooperative emission reduction model. The supply chain profit is the smallest under the cooperative emission reduction model. On the contrary, the cooperative emission reduction model is the second only to the mutual burden model. The relationship between \(\mu\) and \(\rho\) determines the relationship between the supply chain profit under the cooperative service mode and the cooperative promotion mode. Obviously, the influence of the service level on the demand of the new retail channel is greater than the influence of the promotion level on the demand of the traditional retail channel. Compared with sharing the service cost of the new retailer and the promotion cost of the traditional retailer, the coordination effect of the former is better than that of the latter and vice versa.
5. NUMERICAL EXAMPLE

5.1. Pareto improvement of supply chain under different models

In order to further analyze and compare the effectiveness of the four coordination mechanisms, and to more intuitively reflect the changes in the profits of suppliers, new retailers, traditional retailers and supply chain under different situations, the basic parameters are as follows: \( \alpha = 1, \beta = 0.8, \mu = 0.5, \rho = 0.7, w = 1.7, I_r = 2.7, I_a = 3.3; \) this parameter setting guarantees that four different models have optimal solutions.

Under the SER model, from Proposition 1, the optimal supply chain strategy under decentralized decision-making can be obtained \((e^{Ds^*}, s^{Ds^*}, A^{Ds^*}) = (3.06, 1.65, 1.89)\). From Proposition 4, we can obtain the optimal supply chain strategy under the cooperative emission reduction mode \((e^{es^*}, s^{es^*}, A^{es^*}, \psi_1^*, \psi_2^*) = (5.46, 1.65, 1.89, 0.32, 0.12)\). Obviously, there is a relationship between decision variables in this mode and decision variables in decentralized decision-making as described in Proposition 5: \( e^{es^*} > e^{Ds^*}, s^{es^*} = s^{Ds^*}, A^{es^*} = A^{Ds^*} \). The optimal profit of suppliers, new retailers, traditional retailers and supply chains varies with \( \delta \) (consumers' preference coefficient for new retail channels), as shown in Figures 2 and 3.

It can be seen from Figures 2 and 3 that no matter how the coefficient \( \delta \) changes, the optimal profits of suppliers, new retailers, traditional retailers and the supply chain under the cooperative emission reduction model are greater than the optimal profits under the decentralized model. Retailers share the supplier's emission reduction costs, leading to an increase in suppliers' emission reduction levels and increasing the supply chain and members' profits.

In the SSC model, the optimal strategy of the supply chain under decentralized decision-making is \((e^{Ds^*}, s^{Ds^*}, A^{Ds^*}) = (3.06, 1.65, 1.89)\), from Proposition 6, cooperation. The optimal strategy combination of the supply chain under the SSC model is \((e^{Ds^*}, s^{Ds^*}, A^{Ds^*}, e^*) = (3.06, 1.68, 1.89, 0.02)\). Obviously, the relationship between decision variables under the model and the decision variables under decentralized decision-making is as described in Proposition 7: \( e^{es^*} = e^{Ds^*}, s^{es^*} > s^{Ds^*}, A^{es^*} = A^{Ds^*} \). The optimal profit of suppliers, new retailers, traditional retailers and supply chains varies with consumers' preference coefficient \( \delta \) for new retail channels as shown in Figures 4 and 5.

It can be seen from Figures 4 and 5 that no matter how the coefficient \( \delta \) changes, the optimal profit of the supplier, the new retailer and the supply chain in the cooperative service mode is greater than the optimal value in the decentralized mode because the new retailer and the supplier. Service cooperation enables new retailers to improve their service efforts, thereby increasing the demand for new retail channels and making the profits of suppliers and new retailers higher than the profits of suppliers and new retailers under decentralized decision-making; traditional retailers alone bear the cost of promotion efforts and promotion efforts. Compared with the decentralized decision-making situation under the service cooperation model, the level has not improved. The retail channel demand remains unchanged, so the profit of traditional retailers remains unchanged, so \( \pi^*_s, \pi^*_r \) completely coincide.

In the SPC model, the optimal strategy of the supply chain under decentralized decision-making is \((e^{Ds^*}, s^{Ds^*}, A^{Ds^*}) = (3.06, 1.65, 1.89)\), from Proposition 8. The optimal strategy combination of the supply chain under the SPC model is \((e^{ps^*}, \phi^{ps^*}, A^{ps^*}, \theta^*) = (3.06, 1.65, 2.14, 0.12)\), supplier. The optimal profit of new retailers, traditional retailers and the supply chain varies with consumers' preference coefficient \( \delta \) for new retail channels as shown in Figures 6 and 7.

It can be seen from Figures 6 and 7 that no matter how the coefficient \( \delta \) changes, the optimal profit of suppliers, traditional retailers and the supply chain in the cooperative promotion mode is greater than the optimal profit in the decentralized mode. Promotional cooperation enables traditional retailers to improve their promotion level, thereby increasing the demand for traditional retail channels and making the profits of suppliers and traditional retailers higher than those of suppliers and traditional retailers under decentralized decision-making; new retailers alone bear the cost of service effort, and the level of service effort is compared with scattered under the promotion cooperation model.
The decision-making situation has not improved, and the demand for new retail channels remains unchanged, so the profits of new retailers remain unchanged, \( \pi^c, \pi^p \) completely coincide.

Under the CSA model, the optimal supply chain strategy under decentralized decision-making is \((e^D, s^D, A^D) = (3.06, 1.65, 1.89)\), by Proposition 10, mutual responsibility. The optimal strategy combination of the supply chain under the model is \((e^*, s^*, A^*, \varphi_1^{**}, \varphi_2^{**}, \theta^{**}, \epsilon^{**}) = (5.46, 1.68, 2.14, 0.32, 0.12, 0.12, 0.02)\). Obviously, the decision variables in this mode and the decision variables in decentralized decision-making have the same as described in Proposition 11: \( e^* > e^D, s^* > s^D, A^* > A^D \). The optimal profit of suppliers, new retailers, traditional retailers and supply chains varies with consumers’ preference coefficient \( \delta \) for new retail channels, as shown in Figures 8 and 9.

It can be seen from Figures 8 and 9 that no matter how the coefficient \( \delta \) changes, the optimal profit of suppliers, new retailers, traditional retailers and supply chain under the mutual CSA model is greater than the optimal profit of the decentralized model, traditional retailers and new retailers. Sharing the cost of reducing emissions from suppliers, the cost of new retailers’ services by suppliers and the cost of traditional retailers’ promotion has led to an increase in suppliers’ emission reduction, service efforts and promotion efforts. Increased efforts have led to an increase in demand, thus increasing supply chain and profit of each member.

As can be seen from Figures 2, 4, 6 and 8, under the four models, the profit of new retailers is positively correlated with the coefficient of consumer preference for new channels, while the profit of traditional retailers decreases as the coefficient of consumer preference for new channels increases. Since traditional retailers have obtained a certain market through promotional efforts, when the consumer preference coefficient for new channels is equal to 1, the profits of traditional retailers are not equal to zero; as can be seen from Figures 3, 5, 7 and 9, the supply chain profits vary with consumers’ preference for new channels increases, and opening up new retail channel can increase supply chain profits.

5.2. Comparison of supply chain profits under different models

When \( \omega \) satisfies different relationships with \( I_n, I_M, \mu \) and \( \rho \), there are different supply chain profits in the four models. Since Proposition 12 has given a detailed proof, the calculation example discusses one relationship, so refer to the same as above.
Figure 10 reflects the supply chain profits of the four coordination models. The order of supply chain profits in the four models from large to small is as follows: CSA model, SER model, SPC model and SSC model. The supply chain profits under the four cooperation models are all greater than the supply chain profits under the decentralized decision-making. Under this condition, the cooperative service model and the cooperative promotion model are available. The coordination effect of the cooperative service mode and the cooperative promotion model is average. After the two modes are coordinated, the increase in the supply chain profit is not significant. The coordination effect of the emission reduction model is close to the mutual burden model. Therefore, when the profitability of suppliers is low, traditional retailers and new retailers should actively share the cost of carbon emission reduction from suppliers, thereby incentivizing suppliers to reduce emission levels and significantly increasing supply chain profits.

5.3. Changes in the sharing fraction under the CSA model

According to the model in this paper, the change trend of coordination ratio and related parameters in the CSA model are shown in Figure 11.

\[ \alpha > \beta \]

\[ \alpha < \beta \]

It can be seen from Figure 11 that the carbon emission reduction cost sharing ratio of new retailers and the impact factor \( \alpha \) of carbon emission reduction on the demand for new retail channels changes positively, while the carbon emission reduction cost sharing ratio of traditional retailers and \( \alpha \) change negatively. The carbon emission reduction cost sharing ratio and the impact
factor $\beta$ of carbon emission reduction on retail channel demand change positively, and the carbon emission reduction cost sharing ratio of new retailers and $\beta$ change negatively. When the impact factor of carbon emission reduction on the demand for new retail channels is greater than the impact factor of carbon emission reduction on the demand for retail channels, the proportion of carbon emission reduction costs shared by new retailers is greater than that of traditional retailers and vice versa. Therefore, the impact factor of carbon emission reduction on channel demand directly affects the channel retailer's carbon emission reduction cost-sharing ratio. The channel retailer with the larger impact factor shares the higher supplier emission reduction cost to incentivize the supplier's emission reduction level. Stimulate channel factors share the higher carbon emission reduction cost to incentivize the supplier's emission reduction level. Stimulate channel factors share the higher supplier emission reduction cost to incentivize the supplier's emission reduction level. Stimulate channel factors share the higher supplier emission reduction cost to incentivize the supplier's emission reduction level. Stimulate channel factors share the higher supplier emission reduction cost to incentivize the supplier's emission reduction level. Stimulate channel factors share the higher supplier emission reduction cost to incentivize the supplier's emission reduction level. Stimulate channel factors share the higher supplier emission reduction cost to incentivize the supplier's emission reduction level. Stimulate channel factors share the higher supplier emission reduction cost to incentivize the supplier's emission reduction level. Stimulate channel factors share the higher supplier emission reduction cost to incentivize the supplier's emission reduction level. 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A.1. $\pi_{SC}$ IS THE JOINT CONCAVE FUNCTION OF $E\ Hernandezia, S$, $A$

Proof. From Equation (7), we can see that the Hessian matrix of $\pi_{SC}$ is

$$H(e, s, A) = \begin{bmatrix}
\frac{\partial^2 \pi_{SC}}{\partial e^2} & \frac{\partial^2 \pi_{SC}}{\partial e \partial s} & \frac{\partial^2 \pi_{SC}}{\partial e \partial A} \\
\frac{\partial^2 \pi_{SC}}{\partial e \partial s} & \frac{\partial^2 \pi_{SC}}{\partial s^2} & \frac{\partial^2 \pi_{SC}}{\partial s \partial A} \\
\frac{\partial^2 \pi_{SC}}{\partial e \partial A} & \frac{\partial^2 \pi_{SC}}{\partial s \partial A} & \frac{\partial^2 \pi_{SC}}{\partial A^2}
\end{bmatrix} = \begin{bmatrix}
-1 & 0 & 0 \\
0 & -1 & 0 \\
0 & 0 & -1
\end{bmatrix}$$

Because of $\frac{\partial^2 \pi_{SC}}{\partial e^2} < 0$, there exists a second-order determinant greater than zero and $|H| > 0$, we know that the Hessian matrix is negative definite, and $\pi_{SC}$ is the joint concave function of $e, s, A$. There exists an optimal supply chain profit.

A.2. THE EXISTENCE OF THE OPTIMAL SOLUTION UNDER THE SER MODEL

Proof. The new retailer and the traditional retailer determine the sharing ratio and the supplier determines the emission reduction effort and solves it according to the reverse induction method. $1 - \varphi_1 - \varphi_2$ is the proportion of the emission reduction cost borne by the supplier, so $1 - \varphi_1 - \varphi_2 > 0$. The second derivative of Equation (8) with respect to $e$ obtained as $\frac{\partial^2 \pi_n}{\partial e^2} = -(1 - \varphi_1 - \varphi_2) < 0$, to find the first-order partial derivative of $e$ in Equation (8) and let it equals zero, we get $e = -\frac{w(\alpha + \beta)}{1 - \varphi_1 - \varphi_2}$, substituting into Equations (9) and (10), we get

$$\pi_n = -\frac{S^2}{2} - \frac{w^2(\alpha + \beta)^2 \varphi_1}{2(1 - \varphi_1 - \varphi_2)^2} + I_r \left(\delta + \mu - \frac{w(\alpha + \beta)}{1 - \varphi_1 - \varphi_2}\right)$$

$$\pi_r = -\frac{A^2}{2} - \frac{w^2(\alpha + \beta)^2 \varphi_2}{2(1 - \varphi_1 - \varphi_2)^2} + I_r \left(1 - \delta + A\mu - \frac{w(\alpha + \beta)}{1 - \varphi_1 - \varphi_2}\right)$$

The Hessian matrix of $\pi_n$ can be calculated by the following:

$$H(s, \varphi_1) = \begin{bmatrix}
\frac{\partial^2 \pi_n}{\partial s^2} & \frac{\partial^2 \pi_n}{\partial s \partial \varphi_1} \\
\frac{\partial^2 \pi_n}{\partial s \partial \varphi_1} & \frac{\partial^2 \pi_n}{\partial \varphi_1^2}
\end{bmatrix} = \begin{bmatrix}
-1 & 0 \\
0 & \frac{w(\alpha + \beta)(w(\alpha + \beta)(2 + \varphi_1 - 2\varphi_2) + 2I_r(1 - \varphi_1 + \varphi_2))}{(1 - \varphi_1 + \varphi_2)^4}
\end{bmatrix}$$

$H(s, \varphi_1)$ is a negative definite, and strictly joint concave in $s$ and $\varphi_1$, when the condition of $|H(s, \varphi_1)| = \frac{w(\alpha + \beta)(w(\alpha + \beta)(2 + \varphi_1 - 2\varphi_2) + 2I_r(1 - \varphi_1 + \varphi_2))}{(1 - \varphi_1 + \varphi_2)^4} > 0$ is satisfied. We can get $\frac{\partial^2 \pi_n}{\partial s \partial \varphi_1} > 0 \iff \varphi_1 > I_r$, $\pi_n$ is the joint concave function of $\varphi_2$. The hessian matrix of $\pi_r$ can be calculated by the following:

$$H(A, \varphi_2) = \begin{bmatrix}
\frac{\partial^2 \pi_r}{\partial A^2} & \frac{\partial^2 \pi_r}{\partial A \partial \varphi_2} \\
\frac{\partial^2 \pi_r}{\partial A \partial \varphi_2} & \frac{\partial^2 \pi_r}{\partial \varphi_2^2}
\end{bmatrix} = \begin{bmatrix}
-1 & 0 \\
0 & \frac{w(\alpha + \beta)(w(\alpha + \beta)(-2 + 2\varphi_1 - \varphi_2) - 2I_r(1 - \varphi_1 + \varphi_2))}{(1 - \varphi_1 + \varphi_2)^4}
\end{bmatrix}$$

$H(A, \varphi_2)$ is a negative definite, and strictly joint concave in $A$ and $\varphi_2$, when the condition of $|H(A, \varphi_2)| = \frac{w(\alpha + \beta)(w(\alpha + \beta)(-2 + 2\varphi_1 - \varphi_2) - 2I_r(1 - \varphi_1 + \varphi_2))}{(1 - \varphi_1 + \varphi_2)^4} > 0$ is satisfied. We can get $\frac{\partial^2 \pi_r}{\partial A \partial \varphi_2} > 0 \iff \varphi_2 > I_r$, $\pi_n$ is the joint concave function of $\varphi_2$. There exists an optimal solution for traditional retailer profits.

2.2 When satisfied the condition of $w < I_r$, $w < I_r$ and $3\beta/\alpha > I_r/I_r > \beta/3\alpha$, we can get the relationship $\pi_n^{es} > \pi_n^{Ds}$, $\pi_r^{es} > \pi_r^{Ds}$.

Proof.

$$\pi_n^{es} - \pi_n^{Ds} = \frac{1}{4} \left(2\alpha^2 I_r^2 + 2\alpha I_r \beta I_r + \beta I_r w(\alpha + \beta) - 3\alpha I_r w(\alpha + \beta)\right) > 0$$
Assuming that the marginal revenue meets: \(3\beta I_r > \alpha I_n + \frac{1}{3} (3\alpha I_n \beta I_r - \alpha^2 I_r^2) > 0\), then \(\pi_n e > \pi_n D_s\).

\[\pi_r e - \pi_r D_s = \frac{1}{4} (2\beta^2 I_r^2 + 2\alpha I_n \beta I_r + \alpha I_n w(\alpha + \beta)) - 3\beta I_r w(\alpha + \beta) > \frac{1}{4} (3\alpha I_n \beta I_r - \beta^2 I_r^2)\]

Assuming that the marginal revenue meets: \(3\alpha I_n > \beta I_r, \frac{1}{4} (3\alpha I_n \beta I_r - \beta^2 I_r^2) > 0\), then \(\pi_r e > \pi_r D_s\).

### A.3. The Existence of the Optimal Solution Under the SSC Model

**Proof.** We solve the model according to the backward method. The second derivative of Equation (12) with respect to \(s\) is obtained as follows: \(\frac{\partial^2 \pi_n}{\partial s^2} = -(1 - \theta) < 0\). The second derivative of Equation (13) with respect to \(A\) is obtained as:

\[H_m = -\frac{\partial^2 \pi_n}{\partial s \partial A} = \frac{\partial^2 \pi_n}{\partial s \partial A} = \left[ \begin{array}{c} -1 - \frac{\rho^2 I_r^2}{2(1-\theta)} \\ 0 \end{array} \right] \]

\(H(e, \theta) = \left[ \begin{array}{cc} \frac{\partial^2 \pi_n}{\partial e \partial e} & \frac{\partial^2 \pi_n}{\partial e \partial \theta} \\ \frac{\partial^2 \pi_n}{\partial s \partial e} & \frac{\partial^2 \pi_n}{\partial s \partial \theta} \end{array} \right] = \left[ \begin{array}{cc} -1 & 0 \\ 0 & -\frac{\rho^2 I_r (2w(-1+\theta)+(2+\theta)I_n)}{(-1+\theta)^3} \end{array} \right]\]

\(H(e, \theta)\) is a negative definite, and strictly joint concave in \(e\) and \(\theta\), when the condition of \(|H(e, \theta)| = \rho^2 I_r (2w(-1+\theta)+(2+\theta)I_n) > 0\) is satisfied. We can get \(\frac{2\theta}{1-\theta} > \frac{2w}{I_n}\). Let \(f_\theta(e) = \frac{2\theta}{1-\theta}\). It is easy to prove that \(f_\theta(e)\) is monotonically increasing during \([0, 1]\). Thus, if \(w < I_n, \pi_m\) is the joint concave function of \(e, \theta\). There exists the optimal solution under the SPC model.

### A.4. The Existence of the Optimal Solution Under the SPC Model

**Proof.** We solve the model according to the backward method. The second derivative of Equation (16) with respect to \(A\) is obtained as follows: \(\frac{\partial^2 \pi_r}{\partial A^2} = -(1 - \theta) < 0\). The second derivative of Equation (13) with respect to \(s\) is obtained as follows: \(\frac{\partial^2 \pi_n}{\partial s^2} = -1 < 0\), optimal profits exist for both new and traditional retailers, for Equations (15) and (16), respectively, the first-order partial derivative of \(A\) and \(s\), we let it to zero, we can get

\[\pi_m = -\frac{e^2}{2} + \frac{\theta e^2 I_r^2}{2(1-\theta)^2} + w(1 + e(\alpha + \beta) + \mu^2 I_n - \frac{\rho^2 I_r}{1-\theta})\]

The hessian matrix of \(\pi_m\) can be calculated by the following:

\[H(\epsilon, \theta) = \left[ \begin{array}{cc} \frac{\partial^2 \pi_m}{\partial \epsilon^2} & \frac{\partial^2 \pi_m}{\partial \epsilon \partial \theta} \\ \frac{\partial^2 \pi_m}{\partial s \partial \epsilon} & \frac{\partial^2 \pi_m}{\partial s \partial \theta} \end{array} \right] = \left[ \begin{array}{cc} -1 & 0 \\ 0 & -\frac{\rho^2 I_r (2w(-1+\theta)+(2+\theta)I_n)}{(-1+\theta)^3} \end{array} \right]\]

\(H(\epsilon, \theta)\) satisfies the condition \(w < I_r, w < I_n\) is negative definite, then \(\pi_m\) is the joint concave function of \(\epsilon, \theta, \phi_1\). The hessian matrix of \(\pi_n\) can be calculated by the following:

\[H(s, \phi_1) = \left[ \begin{array}{cc} \frac{\partial^2 \pi_n}{\partial s^2} & \frac{\partial^2 \pi_n}{\partial s \partial \phi_1} \\ \frac{\partial^2 \pi_n}{\partial s \partial s} & \frac{\partial^2 \pi_n}{\partial s \partial \phi_1} \end{array} \right] = \left[ \begin{array}{cc} -1 + e & 0 \\ 0 & -\frac{w(\alpha + \beta)(\alpha + \beta)(2\phi_1 - \phi_2) + 2w I_r (\phi_1 - \phi_2)}{(-1+\phi_1+\phi_2)^4} \end{array} \right]\]

\(H(s, \phi_1)\) satisfies the condition \(w < I_n\) is negative definite, then \(\pi_n\) is the joint concave function of \(s, \phi_1\).
The hessian matrix of \( \pi_r \) can be calculated by the following:

\[
H(A, \varphi_2) = \begin{bmatrix}
\frac{\partial^2 \pi_r}{\partial A^2} & \frac{\partial^2 \pi_r}{\partial A \varphi_2} \\
\frac{\partial^2 \pi_r}{\partial \varphi_2 A} & \frac{\partial^2 \pi_r}{\partial \varphi_2^2}
\end{bmatrix}
\]

\[
= \begin{bmatrix}
-1 + \theta & 0 \\
\frac{w(\alpha + \beta)w(\alpha \beta)}{w(\alpha + \beta)(-2 + 2\alpha \varphi_2 - 3\alpha \varphi_2 - 2\beta \varphi_2 - (1 + \varphi_2))} & 0
\end{bmatrix}
\]

\( H(A, \varphi_2) \) satisfies the condition \( w < \alpha_1 \) is negative definite, then \( \pi_r \) is the joint concave function of \( A, \varphi_2 \).

### A.6. COMPARISON OF SUPPLY CHAIN PROFITS UNDER FOUR COORDINATION MODELS

To compare the supply chain profits under the above four coordination models, first compare the supply chain profits under the CSA model with the supply chain profits under the other three models:

\[
\pi_{sc}^{r*} - \pi_{sc}^{e*} = \frac{1}{8} \mu^2 (4w^2 - I_n^2) + \rho^2 (4w^2 - \rho^2 I_n^2)
\]

Then \( \pi_{sc}^{r*} > \pi_{sc}^{e*} \), \( \pi_{sc}^{e*} > \pi_{sc}^{e*} \), \( \pi_{sc}^{e*} > \pi_{sc}^{e*} \), \( \pi_{sc}^{e*} > \pi_{sc}^{e*} \).

Second, we compare the supply chain profit in two cooperation scenarios: SSC model and SPC model:

\[
\pi_{sc}^{p*} - \pi_{sc}^{e*} = \frac{1}{8} (\rho^2 - \mu^2)(4w^2 - I_n^2)
\]

\[
\pi_{sc}^{p*} - \pi_{sc}^{e*} = \frac{1}{8} (4w^2 (\alpha + \beta) + 4 \alpha I_n + \beta I_r)^2 \Rightarrow \pi_{sc}^{p*} > \pi_{sc}^{e*}
\]

At last, we compare the supply chain profit in two cooperation scenarios, SER model and SPC model:

\[
\pi_{sc}^{e*} - \pi_{sc}^{e*} = \frac{1}{8} (4w^2 (\alpha^2 + 2\alpha \beta + \beta^2 + \mu^2)
\]

\[
+ (4w^2 - \mu^2) I_n^2 - 8\alpha \beta I_n I_r - 4\beta^2 I_r^2)
\]

\[
\pi_{sc}^{e*} - \pi_{sc}^{e*} = \frac{1}{8} (4w^2 (\alpha^2 + 2\alpha \beta + \beta^2 + \mu^2)
\]

\[
- (4w^2 + \mu^2) I_n^2 - 8\alpha \beta I_n I_r - 4\beta^2 I_r^2)
\]

\[
\pi_{sc}^{e*} - \pi_{sc}^{e*} = \frac{1}{8} \sqrt{\frac{\mu^2 I_n^2 + 4(\alpha I_n + \beta I_r)^2}{4\mu^2 + 4(\alpha + \beta)^2}}
\]

\[
\pi_{sc}^{p*} - \pi_{sc}^{e*} = \frac{1}{8} \sqrt{\frac{\rho^2 I_n^2 + 4(\alpha I_n + \beta I_r)^2}{4\rho^2 + 4(\alpha + \beta)^2}}
\]
Above all, if $w \geq \sqrt{\frac{\mu^2 I_n^2 + 4(\alpha I_n + \beta L)^2}{4\mu^2 + 4(\alpha + \beta)^2}}$ and $\mu < \rho$, we can get $\pi_{sc}^{es} \leq \pi_{sc}^{ss} < \pi_{sc}^{ps} < \pi_{sc}^{rs}$ if $w < \min(\sqrt{\frac{\mu^2 I_n^2 + 4(\alpha I_n + \beta L)^2}{4\mu^2 + 4(\alpha + \beta)^2}}, \sqrt{\frac{\rho^2 I_r^2 + 4(\alpha I_r + \beta L)^2}{4\rho^2 + 4(\alpha + \beta)^2}})$ and $\mu < \rho$, we can get $\pi_{sc}^{es} \leq \pi_{sc}^{ss} < \pi_{sc}^{ps} < \pi_{sc}^{rs}$ if $w < \min(\sqrt{\frac{\mu^2 I_n^2 + 4(\alpha I_n + \beta L)^2}{4\mu^2 + 4(\alpha + \beta)^2}}, \sqrt{\frac{\rho^2 I_r^2 + 4(\alpha I_r + \beta L)^2}{4\rho^2 + 4(\alpha + \beta)^2}})$ and $\mu \geq \rho$, we can get $\pi_{sc}^{ps} \leq \pi_{sc}^{ss} < \pi_{sc}^{es} < \pi_{sc}^{rs}$. 

International Journal of Low-Carbon Technologies 2021, 00, 1–15

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