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OPERATIONS, INFORMATION & TECHNOLOGY | RESEARCH ARTICLE

Operation and coordination mechanism of closed-loop supply chain considering corporate social responsibility behavior consciousness

A. K. M. Mohsin^{1*}, Hongzhen Lei¹, Syed Far Abid Hossain², Hasanuzzaman Tushar², Mozaffar Alam Chowdhury² and Mohammad Ebrahim Hossain³

Abstract: The closed-loop supply chain (CLSC) management has become an important development strategy for many large enterprises, which reduces environmental pollution. This study is about the operation and coordination of third-party recycling CLSC considering the manufacturer's corporate social responsibility (CSR) behavior awareness and the retailer's profit donation as CSR investment. Based on the observations in industry, it is assumed that the CSR behavior of the manufacturer is to take consumer surplus as maximizing social welfare. At the same time, the retailer performs the CSR investment behavior to social welfare organizations. The CSR investment of retailers brings reputation and affects the market demand for new products. The results show that the CSR behavior awareness of manufacturers and the CSR investment of retailers have a mutual incentive effect and is conducive to expanding the market demand for new products and improving the recycling rate of waste products. The study constructs a third-party recycling closed-loop supply chain operation and coordination model. It analyzes

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PUBLIC INTEREST STATEMENT

The closed-loop supply chain (CLSC) management is a ubiquitous issue among large enterprises. Operation and coordination mechanisms of closed-loop supply chain management and corporate social responsibility behavior consciousness were not investigated together by the scholarly articles. The operation and coordination of third-party recycling CLSC considering manufacturer's CSR behavior awareness was the primary focus in this research. Based on the industry observations, it is assumed that the manufacturer's CSR behavior is to take consumer surplus as maximizing social welfare. At the same time, the retailer performs the CSR investment behavior to social welfare organizations. The CSR investment of retailers brings reputation and affects the market demand for new products. The key benefit for the society is reducing environmental pollution with the closed-loop supply chain (CLSC) management strategy that could simultaneously ensure the corporate social responsibility and sustainable social development.

both manufacturer's CSR awareness and retailer CSR investment to the closed-loop supply chain members. The findings are that both of them have a mutually stimulating effect, expanding the market demand for new products, increasing the recycling rate of waste and bringing higher social welfare.

Subjects: Sustainable Development; Production, Operations & Information Management; Operational Research / Management Science

Keywords: closed-loop supply chain; CSR investment; CSR behavior awareness; "revenue-cost sharing" contract

1. Introduction

As China vigorously advocates the development of green and circular economy, the concept of environmental protection and sustainable development has been deeply rooted in the hearts of the people. In 2013, the State Council issued the "Circular Economy Development Strategy and Short-term Action Plan", which pointed out that the development of a circular economy is a major strategic decision in China. It also requires companies to focus not only on using the forward supply chain to carry out new product procurement, production and sales activities, but also on using the reverse supply chain to implement recycling and reuse of used products, i.e. implementing closed-loop supply chain management.

Current research on the operation of closed-loop supply chains mainly focuses on the selection of recycling channels (Hong & Yeh, 2012; Jiang, 2012; Liu et al., 2017; Savaskan et al., 2004) pricing decisions (Wei et al., 2015, 2012), government rewards and punishments (Chen & Ulya, 2019), coordination mechanisms (Choi et al., 2013; Zheng et al., 2017) and other issues. However, most of the existing research assumes that the members of the closed-loop supply chain or the whole group of closed-loop supply chain pursue pure profit maximization as the decision-making goal. In recent years, more and more companies have actively performed corporate social responsibility (CSR), promoted corporate image, and gained a good social reputation, consequently winning widespread recognition from consumers. CSR requires companies to produce in operation, and we must not only pursue economic benefits but also pay attention to the contributions to its stakeholders, consumers, the environment, and society. Many well-known companies, such as Huawei, Intel, HP, IBM, Haier, and few others., have achieved massive gains by actively fulfilling CSR. At the same time, it has won high social prestige. Pino et al. (2016) explored whether or not companies' promotion of CSR has a significant impact on consumers' choices. Servaes and Tamayo (2013) find that those who actively make CSR companies distract their energies and obtain higher corporate value. Studies considering CSR in modeling forward and closed-loop supply chain optimization are now more common. Ding et al. (2011) studied the issues of supply chain pricing, collaboration, and profit-sharing considering CSR investment. Li et al. (2017) analyzed CSR operations, configuration, and cooperation in the supply chain. They pointed out that CSR investment of supply chain members has a mutual incentive effect. Cruz (2009) studied the effect of supply chain differential pricing considering member companies' CSR behavior awareness. Tate et al. (2010) explored CSR investment's role in transmitting supplier quality information and the profitability conditions for implementing CSR investment signal means. Wu et al. (2017) studied the supply chain coordination problem considering CSR investment and offered the quantity flexible contract and wholesale price incentive contract for the coordinated supply chain. Panda and Modak (2016) researched supply chain coordination and revenue distribution problems when manufacturers and retailers are aware of CSR behavior. Fan et al. (2016) showed that manufacturers' CSR behavioral awareness is mostly expressed in product responsibility and that manufacturers' CSR behavioral awareness improves product quality. In addition, Letizia and Hendrikse (2016) examined the supply chain social responsibility incentives for considering CSR investments under different channel power structures. The above studies mainly focused on analyzing the impact of CSR on positive supply chain pricing decisions and coordination strategies.

The manufacturer's awareness of CSR behavior is beneficial to increase member companies' profits and improve the recycling efficiency of waste products (Panda et al., 2017). Nagasawa et al. (2019) investigated the impact of government subsidies and CSR investment behavior of different member companies on closed-loop supply chain decision-making. Johari and Hosseini-Motlagh (2019) studied recycling channels when leading manufacturers have CSR behavior awareness. Zhu et al. (2018) examined the pricing decision and coordination issues of a closed-loop supply chain with bilateral CSR behavior awareness. Shu et al. (2018) studied the closed-loop supply chain pricing decision considering CSR behavior awareness under carbon emission constraints. The mentioned studies showed that enterprises' CSR behavior is beneficial to increase the recycling rate of waste products and reduce carbon emissions. Zhang et al. (2015) compared four different CSR investment modes in the closed-loop supply chain. Modak et al. (2019) studied the pricing decision and coordination issues of closed-loop supply chain considering CSR investment under three recycling channel structures from the perspective of philanthropic donations. Deng et al. (2014) also found CSR behavioral awareness and advertising effects on closed-loop supply chain pricing and recycling decisions. Hosseini-Motlagh et al. (2020) studied the two-stage closed-loop supply chain coordination strategy when different entities undertake CSR. The above research explored the impact of CSR on the pricing decisions of the forward supply chain. Further, it analyzed effect of CSR strategies on the recycling of waste products in the reverse supply chain.

A rigorous review of existing research shows that research on CSR is positive. Closed-loop supply chains can be broadly divided into two categories: one is considered at the macro-strategic level, which feels a firm's CSR behavior to be an awareness of its initiative to benefit its stakeholders; the other is found from the micro-investment perspective, which considers a firm's CSR behavior is an investment behavior in which a firm spends a specific cost to improve stakeholder interests while also stimulating consumption. However, first, existing studies analyzed the impact of CSR on supply chain operations from either a macro-strategic or micro-investment perspective alone, and a few studies have considered both different forms of CSR behavior simultaneously. Secondly, existing studies generally ignored the motivations of supply chain members to perform CSR that may vary depending on their position in the supply chain. The dominant player in the supply chain (assumed to be the manufacturer in this paper) usually earns more channel profits. Therefore, this review is more inclined to consider CSR at a macro-strategic level and thus achieve stable operation of the supply chain system by benefiting other members and consumers. As a channel follower (assumed to be a retailer in this paper), it tends to stimulate consumption directly through CSR investments (e.g. philanthropic donations) due to its closer proximity to consumers. In 2017, Apple and JD.com jointly conducted the "I love charity" activity, where Apple offered some discounts to JD's purchases and also provided consumers specific discounts (Apple's sale of products over 1000 minus 100 during the activity). On the other hand, JD.com promised to donate more than 100,000 RMB during the event. By donating 1 yuan for every Apple product sold during the period, Apple and JD.com performed CSR in different ways, which effectively stimulated market demand and also improved the overall performance of the supply chain.

This paper investigates the operation and coordination of the closed-loop supply chain of third-party recycling under the assumption that manufacturers are aware of CSR behaviors, and retailers make CSR investments. First, the impact of manufacturers' CSR awareness and retailers' CSR investment on closed-loop supply chain members' performance is analyzed. Second, the interactive relationship between manufacturers' CSR awareness and retailers' CSR investment is interpreted. Third, a "benefit-sharing-cost-sharing" system is designed to realize the coordination of the "closed-loop supply chain system" contract. Finally, the main conclusions of the paper and the validity of the agreement are verified by numerical analysis. The research in this paper provides a decision test for a closed-loop supply chain operation that considers CSR behavioral awareness and investments under third-party recovery.

2. Problem statement and assumptions

Suppose the closed-loop supply chain in this paper consists of a manufacturer, a retailer, and a third-party recycler (referred to as the third party) in a Stackelberg game with full information and the manufacturer as the channel leader. In a positive supply chain, the manufacturer is responsible for producing new products and the remanufacturing of used products, while the retailer is responsible for the sale of new products refer to (Jiang, 2012; Savaskan et al., 2004). It is assumed that there is no difference between new and remanufactured products. In the reverse supply chain, a third party is responsible for recycling used products (according to the White Paper on China's Waste). Therefore, this paper considers the reverse channel structure assumption based on the assumption that third parties are responsible for recycling used and end-of-life products to be more realistic. It is assumed that manufacturers have behavioral awareness to pay attention to their stakeholders (refer to Panda et al., 2017). It is argued that manufacturers' CSR behavioral awareness is concretely manifested in the fact that manufacturers use consumer surplus as part of their own goal of pursuing social welfare maximization. At the same time, it is assumed that retailers fulfill CSR through specific CSR investment behaviors. Modak et al. (2019) found that retailers donate a portion of the profits earned from the sale of their products directly to social welfare organizations. A retailer's CSR investment also brings goodwill to itself, indirectly affecting the market demand for its products. For example, in reality, some Taobao stores demonstrate CSR behavior by explaining to consumers that they will donate a certain amount of money to a charity organization for every unit of product sold, which effectively stimulates product sales. The demand function of a closed-loop supply chain is assumed to be as follows (Refer to Modak et al., 2019),

$$q = a - \beta p + \theta d \quad (1)$$

Where a is the market capacity and $a > 0$. p is the retail price of the new product and β is the consumer response to the new product price sensitivity coefficient. d refers to the social donation (i.e. CSR investment level) given by retailers to public welfare organizations or relevant departments when selling new products per unit, and θ represents the sensitivity coefficient of consumers to the CSR investment level of retailers. $\theta > \beta > 0$ and $a > \beta p$. $\theta > \beta$ indicates that consumers are more sensitive to the retailer's level of CSR investment than the price of the new product. Other symbols and variables are shown in Table 1 below.

To ensure that the maximum recovery rate in the article is limited to a given range. The profit work of each member organization is concave, and related expressions are economically feasible. As Kejing (2015) estimates, our scale parameters $k, g > 0$ are required and should be large enough. Therefore, the overall profit activity of the closed-loop supply chain can be disclosed considering the manufacturer's CSR behavior awareness and the retailer's CSR investment (Superscript "C" presents the results of various expressions and balances under the central decision model).

3. Construction and solution of the closed loop supply chain model considering CSR behavior awareness and investment

When manufacturers are conscious of CSR behavior, they make decisions intending to maximize social welfare. According to the relevant assumptions in economics, social welfare is equal to the sum of producer surplus and consumer surplus (CS). For a given market demand, CS is the difference between the highest price a consumer is willing to pay for a product and the actual market price. Thus, in this paper, CS can be expressed as,

$$CS = \int_{p_{\min}}^{p_{\max}} q dp = \int_{p_{\min}}^{p_{\max}} (a - \beta p + \theta d) dp \quad (2)$$

$$= \frac{a + \theta d - q}{\beta} = \frac{(a - \beta p + \theta d)}{2\beta}$$

Table 1. Symbol definitions and interpretation

Symbol	Definitions and interpretation
w	The retailer's unit wholesale price for new products ordered from the manufacturer
c_m	The manufacturer's fixed cost per unit of new product, $W > c_m$
c_r	The unit cost of the manufacturer's remanufactured products, to ensure that the remanufacturing is meaningful, obviously $\Delta_0 = c_m - c_r > 0$
b	The manufacturer's unit transfer payment for recycling waste products to third parties is an endogenous variable. To make remanufacturing meaningful, clearly $c_m - c_r - b > 0$
A	Unit service fee for third-party recycling of waste products. To make the recycling and disposal of waste products economically feasible, obviously $b > A$
τ	Recycling rate of waste products, $0 \leq \tau \leq 1$
$c(\tau)$	Recover effort costs. Refer to Savaskan et al. (2004); assumed that $C(\tau) = k\tau^2$, where k is the scale parameter and $K > 0$
$h(d)$	CSR investment cost to the retailer. Refer to Modak et al. (2019); assume that $h(d) = gd^2$, where g denotes the size parameter of the retailer's CSR investment and $g > 0$
r	Manufacturer's CSR behavior awareness level, $0 < r < 1$
CS	Consumer Surplus. Refer to Panda et al. (2017) and Shu et al. (2018); $CS = \int_{P_{min}}^a qdp = \frac{(a-\theta p+\theta d)^2}{2\theta}$
π_X^i	The net profit of member firm X under the i model. $i = \{D, S\}$ respectively represent decentralized decision-making and coordination models, and $X = \{m, r, t\}$ respectively represent manufacturers, retailers and third parties.
V_Y^j	Under the j model, the total profit of entity Y , $j = \{C, D, S\}$ represents the centralized decision-making, decentralized decision-making and coordination models, respectively, and $Y = \{m, s\}$ serves the manufacturer and the closed-loop supply chain system as a whole.

3.1. Optimal decision making under the centralized decision

Under the centralized decision model, the closed-loop supply chain system is an idealized “super-organization” that aims at maximizing the total profit of the system as a whole. Therefore, taking into account the manufacturer's CSR awareness and the retailer's CSR investment, the profit function of the closed-loop supply chain as a whole can be expressed as (the superscript “C” indicates the various expressions and equilibrium results under the centralized decision model):

$$V_s^C(p, d, \tau) = (p - c_m - d)q + (c_m - c_r - A)\tau q - gd^2 - k\tau^2 + r \frac{q^2}{2\beta} \quad (3)$$

Theorem 1 is a closed-loop supply chain that considers the CSR behavioral awareness of manufacturers and the CSR investment of retailers when centralization decisions are made, optimal retail price of the new product is, $p^{C*} = \frac{ag\Delta_2 + \Delta_3}{\Delta_4}$; retailer's optimal CSR investment level is, $d^{C*} = \frac{k(\theta - \beta)(a - \beta c_m)}{\Delta_4}$; optimal market demand for new products is, $q^{C*} = \frac{2kg\beta(a - \beta c_m)}{\Delta_4}$; optimal recovery of waste products is, $\tau^{C*} = \frac{g\beta(a - \beta c_m)\Delta_1}{\Delta_4}$; gross profit for the closed-loop supply chain system is $V_s^{C*} = \frac{kg(a - \beta c_m)^2}{\Delta_4}$, Where, $c_m - c_r = \Delta_1$, $2k(1 - r) - \beta\Delta_1^2 = \Delta_2$, $2kg\beta c_m + k(\theta - \beta)(a - \theta c_m) = \Delta_3$,

$g\beta(2k(2-r) - \beta\Delta_1^2) - k(\theta - \beta)^2 = \Delta_4$. Under the assumptions of correlation sign and scale parameters $k, g, \Delta_1, \Delta_2, \dots, \Delta_4 > 0$

Proof: Under the scale parameters k, g and other related assumptions, it is easy to find that the total profit function of the closed-loop supply chain system $V_s^C(p, d, \tau)$ about p, d, τ is a strictly joint concave function. According to the first-order condition, the optimal feedback function for the overall closed-loop supply chain system regarding retail prices, CSR investment levels, and recovery rates are:

$$p^C = \frac{a + (\theta + \beta)d + \beta c_m - \beta\Delta_1\tau - r(a + \theta d)}{\beta(2 - r)} \quad (4)$$

$$d^C = \frac{(r\theta - \beta)(a - \beta p) + \theta\beta(p - c_m + \Delta_1\tau)}{2\beta(\theta + g) - r\theta^2} \quad (5)$$

$$\tau^C = \frac{(a - \beta p + \theta d)\Delta_1}{2k} \quad (6)$$

Furthermore, by combining Equations (4)–(6), the optimal retail price p^{C*} , the optimal CSR investment level d^{C*} , and the optimal recovery rate τ^{C*} of the closed-loop supply chain system can be solved. Then according to (1), the optimal market demand q^{C*} can be obtained. Finally, by substituting the above equilibrium variables into Equation (3), the corresponding total profit of the closed-loop supply chain system under centralized decision-making can be obtained. The proof is complete.

3.2. Optimal decision making under the decentralized decision

Under decentralized decision-making, the manufacturer with CSR awareness takes maximizing social welfare as the decisive goal. The retailer pursues maximizing pure profit while making CSR investments. The third party also seeks to maximize pure profit while being responsible for the recycling of waste products. The Stackelberg game decision sequence of the manufacturer, retailer and third party is as follows: (1) the manufacturer, as the channel leader, determines the wholesale price and transfer payment of the new product; (2) then the retailer and third party, as the followers, make decisions simultaneously, i.e. the retailer determines the retail price and CSR investment level of the new product, while the third party determines the recycling rate of the used product. At this point, each member of the closed-loop supply chain's objective function can be expressed as (the upper corner marked "D" indicates the various expressions and equilibrium results under decentralized decision making)

$$V_m^D(w, b) = \pi_m^D(w, b) + rCS = (w - c_m)q + (c_m - c_r - b)\tau q + r\frac{q^2}{2\beta} \quad (7)$$

$$\pi_r^D(p, d) = (p - w - d)q - gd^2 \quad (8)$$

$$\pi_t^D(\tau) = (b - A)\tau q - k\tau^2 \quad (9)$$

Theorem 2 In the closed-loop supply considering the manufacturer's CSR behavior awareness and the retailer's CSR investment, when decentralized decision-making is adopted, the optimal wholesale price and retail price of the new product are respectively, $w^{D*} = \frac{ag\beta\Delta_5 + \Delta_6}{\beta\Delta_7}$, $p^{D*} = \frac{ag\beta\Delta_8 + \Delta_9}{\beta\Delta_7}$; retailer optimal CSR investment level is $d^{D*} = \frac{2k(\theta - \beta)(a - \beta c_m)}{\Delta_7}$; optimal market demand for new products is $q^{D*} = \frac{4kg\beta(a - \beta c_m)}{\Delta_7}$; optimal transfer payment from the manufacturer to the third party is $b^{D*} = \frac{\Delta_0 + A}{2}$; the optimal recovery rate of the third party is $\tau^{D*} = \frac{g\beta(a - \beta c_m)\Delta_1}{\Delta_7}$. Among them,

$$\begin{aligned} 4k(2-r) - \beta\Delta_1^2 &= \Delta_5, 8kg\beta^2c_m - 2k(a + \beta c_m)(\theta - \beta)^2 = \Delta_6, \\ g\beta(4k(4-r) - \beta\Delta_1^2) - 4k(\theta - \beta)^2 &= \Delta_7, 4k(3-r) - \beta\Delta_1^2 = \Delta_8, \\ 4kg\beta^2c_m + 2k(\theta - \beta)(2a\beta - \theta(a + \beta c_m)) &= \Delta_9, \\ g\beta(8k(2-r) - \beta\Delta_1^2) - 4k(\theta - \beta)^2 &= \Delta_{10}, 4g\beta - (\theta - \beta)^2 = \Delta_{11}, \quad g\beta(8k(6-r) - \beta\Delta_1^2) - 12k(\theta - \beta)^2 = \\ \Delta_{12}. \end{aligned}$$

Under the assumptions of related symbols and scale parameters k, g etc., $\Delta_5, \Delta_6, \dots, \Delta_{12} > 0$

Proof: based on the game order of the manufacturer-dominated two-stage closed-loop supply chain, solved by backward recursion. Under the assumption of the scale parameter k, g and other relevant parameters, it is easy to show $\pi_r^d(p, d)$ on p, d joint strictly concave function, $\pi_r^d(\tau)$ about τ is a strictly concave function. According to first-order conditions, optimal feedback function can be obtained as follows,

$$p^D = \frac{(\theta - \beta)(a - \theta w) + 2g(a + \beta w)}{4g\beta - (\theta - \beta)^2} \quad (10)$$

$$d^D = \frac{(\theta - \beta)(a - \beta w)}{4g\beta - (\theta - \beta)^2} \quad (11)$$

$$\tau^D = \frac{g\beta(a - \beta w)(b - A)}{k(4g\beta - (\theta - \beta)^2)} \quad (12)$$

Substituting the above optimal feedback function into Equation (7). It is easy to verify that the manufacturer's total profit function $V_m^D(w, b)$ about w, b is a strict joint four-function. According to the first-order conditions, the manufacturer's optimal wholesale price w^{D*} and optimal transfer payment b^{D*} can be obtained. Further, by substituting w^{D*} and b^{D*} into the expressions of p^D, d^D , and τ^D , the retailer's optimal retail price p^{D*} , the optimal CSR investment level d^{D*} and the first The three-party optimal recovery rate τ^{D*} , and then according to the formula (1), the optimal market demand q^{D*} . Finally, by substituting the above equilibrium variables into each member company's objective functions, the manufacturer's social welfare under decentralized decision-making, the maximum profit of each member of the closed-loop supply chain, and the system as a whole can be obtained, and the proof is complete.

Proposition 1 When $b^{D*} = \frac{\Delta_0 + A}{2}$, the manufacturer's social welfare V_m^{D*} achieves the maximum value at the time.

Proof: Because the manufacturer is engaged in the remanufacturing of waste products per unit, the marginal profit is always $\Delta_0 - b$, and the marginal profit of a third party involved in unit waste product recycling is always $b - A$. If the manufacturer increases the transfer payment price to a third party, its income will inevitably decrease. On the contrary, the marginal profit of the third party will necessarily decline. Therefore, to balance the minimal income of itself and the third party, combined with the conclusion of Theorem 2, the optimal transfer payment from the manufacturer to the third party is $b^{D*} = \frac{\Delta_0 + A}{2}$. In this case the manufacturer's social welfare V_m^{D*} obtain maximum proof.

The above proposition 1 also reveals that, when $b^{D*} = \frac{\Delta_0 + A}{2}$; manufacturer and the third party share equally the revenue generated from the recycling of units of used products, this is also consistent with the findings of Savaskan et al. (2004) without considering CSR.

4. Equilibrium results analysis

Property 1 $\frac{\partial \pi^{D*}}{\partial r} > 0, \frac{\partial d^{D*}}{\partial r} > 0$

Proof: according to the relevant equilibrium result in Theorem 2, it is easy to obtain the following proof.

$$\frac{\partial \tau^{D^*}}{\partial r} = \frac{4kg^2\beta^2(a - \beta c_m)\Delta_1}{\Delta_7^2} > 0,$$

$$\frac{\partial d^{D^*}}{\partial r} = \frac{8k^2g\beta(\theta - \beta)(a - \beta c_m)}{\Delta_7^2} > 0$$

Property 1 shows that an increased level of awareness of CSR behavior among manufacturers will lead to an increase in the recycling rate of used and end-of-life products by third parties, but will also lead to an increased level of CSR investment retailers. This is due to the fact that the CSR behaviors implemented by manufacturers are ultimately reflected in the recycling rate of used products, so as the awareness of manufacturers' CSR behaviors increases, the recycling rate of used products also increases; furthermore, the perception of the dominant manufacturer's active commitment to CSR behaviors implies that the manufacturer, as a channel leader, will actively share its profits to benefit its stakeholders, and retailers will also (Property 3 shows that the retailer's net profit is directly proportional to the manufacturer's level of CSR awareness), so the retailer will take the initiative to increase its own level of CSR investment in response to and incentivize the dominant manufacturer to further enhance its individual level of CSR awareness. Ni and Li (2012) also shows that the CSR behavior of supply chain members is mutually incentivizing (role, i.e. the CSR behavior of either party motivates the other party to actively engage in CSR investment).

Also, Panda et al. (2017) considered this from the level of CSR macro-awareness. They pointed out that by encouraging recyclers to recycle waste products and remanufacturing waste products by themselves, manufacturers reflect the CSR behavior of manufacturers. The research in this article further reveals that when retailers make CSR investment at the same time, the manufacturer's awareness of CSR behavior not only effectively promotes the recycling and remanufacturing of waste products, but also achieves the purpose of encouraging retailers to increase CSR investment levels.

$$\text{Property 2 } \frac{\partial w^{D^*}}{\partial r} < 0, \frac{\partial p^{D^*}}{\partial r} < 0, \frac{\partial q^{D^*}}{\partial r} > 0$$

Proof: Since the proof process of Property 2 is similar to Property 1, it is omitted here, and the proof is complete.

Property 2 indicates that as manufacturers' awareness of CSR behavior increases, the wholesale and retail prices of new products will decrease, and the market demand for new products will increase accordingly. As the manufacturer's awareness of CSR behavior increases, the manufacturer, as a leader, will actively reduce the wholesale price to achieve the purpose of benefiting stakeholders and increasing social welfare (Property 3 also indicates that the manufacturer's social welfare is maximized Target CSR behavior is proportional to the level of awareness), and at the same time, this kind of dynamic profit-making behavior will indirectly prompt retailers to reduce the retail price of new products. Furthermore, in combination with Property 1, retailers also increase their own CSR investment levels, so the market demand for new products will increase accordingly.

Property 1 and Property 2 reveal that the manufacturer's awareness of CSR behavior lowers the wholesale and retail prices of new products and effectively encourages retailers to increase CSR investment levels and encourages third parties to improve the recycling rate waste products. To reduce the production cost of new products and stimulate market demand, if the manufacturer grasps the degree of CSR, it will have more advantages than disadvantages for the manufacturer.

$$\text{Property 3 } \frac{\partial \pi_m^{D^*}}{\partial r} < 0, \frac{\partial V_m^{D^*}}{\partial r} > 0, \frac{\partial \pi_r^{D^*}}{\partial r} > 0, \frac{\partial \pi_t^{D^*}}{\partial r} > 0, \frac{\partial V_s^{D^*}}{\partial r} > 0$$

Proof: according to the relevant equilibrium result in Theorem 2, it is easy to obtain the following

$$\frac{\partial \pi_m^{D^*}}{\partial r} = \frac{-64k^3g^3\beta^2(a-\beta c_m)^2r}{\Delta_7^3} < 0,$$

$$\frac{\partial V_m^{D^*}}{\partial r} = \frac{8k^2g^2\beta(a-\beta c_m)^2}{\Delta_7^2} > 0,$$

$$\frac{\partial \pi_r^{D^*}}{\partial r} = \frac{32k^3g^2\beta(a-\beta c_m)^2\Delta_{11}}{\Delta_7^3} > 0,$$

$$\frac{\partial \pi_t^{D^*}}{\partial r} = \frac{8k^2g^3\beta^3(a-\beta c_m)^2\Delta_1^2}{\Delta_7^3} > 0,$$

$$\frac{\partial V_s^{D^*}}{\partial r} = \frac{32k^2g^2\beta(a-\beta c_m)^2\Delta_{13}}{\Delta_7^3} > 0,$$

Where, $k(g\beta(8-r) - 2(\theta-\beta)^2) = \Delta_{13}$, under the assumption of the scale parameter k, g , it is easy to know $\Delta_{13} > 0$, proof is complete.

Property 3 shows the increase in manufacturer awareness about CSR behavior. The manufacturer's net profit is declining, yet the manufacturer's social welfare, the profits of other members of the closed-loop supply chain, and the overall profitability of the system are increasing. As a team responsible for CSR, the manufacturers will pursue their own goal of maximizing social welfare in exchange for improving the overall profits of other member organizations and giving up some of its earnings. In a combination of Property 1 and Property 2, manufacturers' behavioral awareness to actively adopt CSR can effectively increase the recycling rate of waste products, achieve environmental protection and green sustainable development goals, and improve the overall efficiency of the closed-loop supply chain systems.

Property 3 reveals that a leading manufacturer's awareness of CSR is always beneficial to the stable operation of a closed-loop supply chain system. The stronger the manufacturer's awareness of CSR, the higher the sacrifice to its net profit, and the more significant the contribution to social welfare. Therefore, in actual problems, manufacturers need to realize the level of awareness about CSR behavior and close trade between their profit and overall profit, to achieve a "multi-win" situation.

Proposition 2 is a closed-loop supply chain that considers manufacturers "CSR behavioral awareness and retailers" CSR investment under decentralized decision making, when $0 < r \leq r^*$,

$$\pi_m^{D^*} \geq \pi_r^{D^*} > \pi_t^{D^*}; \text{ when } r^* < r < 1, \pi_r^{D^*} > \pi_m^{D^*} > \pi_t^{D^*}. \text{ Among them, } r^* = \frac{g\beta(8k-\beta\Delta_1^2)-2k(\theta-\beta)^2}{8kg\beta}$$

Proof: according to the relevant equilibrium result in Theorem 2, it is easy to obtain the following

$$\pi_m^{D^*} - \pi_t^{D^*} = \frac{kg(a-\beta c_m)^2\Delta_{14}}{\Delta_7^2} > 0$$

$$\pi_r^{D^*} - \pi_t^{D^*} = \frac{kg(a-\beta c_m)^2\Delta_{15}}{\Delta_7^2} > 0$$

Where, $g\beta(16k(2-r) - 3\beta\Delta_1^2) - 8k(\theta-\beta)^2 = \Delta_{14}$, $g\beta(16k - \beta\Delta_1^2) - 4k(\theta-\beta)^2 = \Delta_{15}$, under the assumption of the scale parameter k, g , it is easy to know $\Delta_{14}, \Delta_{15} > 0$, proof is complete. Let

$$f(r) = \pi_m^{D^*} - \pi_r^{D^*} = 0, \text{ can be obtained only non-negative root } r^* = \frac{g\beta(8k-\beta\Delta_1^2)-2k(\theta-\beta)^2}{8kg\beta}$$

Combined with Property 3, it is clear that $\frac{\partial f(r)}{\partial r} = \frac{\partial \pi_m^{D^*}}{\partial r} - \frac{\partial \pi_r^{D^*}}{\partial r} < 0$; i.e. $f(r)$ at $(0, 1)$ is monotonically decreasing, when $0 < r \leq r^*$, $\pi_m^{D^*} \geq \pi_r^{D^*}$; when, $r^* < r < 1$, $\pi_r^{D^*} > \pi_m^{D^*}$, proposition 1 can be proved, and the proof is complete.

Proposition 2 shows that regardless of the manufacturer's awareness of CSR behavior, third parties' net profit is always the lowest compared to manufacturers and retailers. The relationship between the manufacturer and the retailer's net profit depends on the manufacturer's awareness of CSR behavior. In particular, when the manufacturer's knowledge of CSR behavior is weak ($0 < r \leq r^*$), the manufacturer will not receive less than the retailer's channel net profit; When the manufacturer's awareness of CSR behavior is keen ($r^* < r < 1$), the manufacturer's net profit may be less than the retailer's net profit.

The findings in this paper suggest that the dominant manufacturer's net profit may be lower than the retailer's net profit. When manufacturers are more conscious of their CSR behavior, they give more concessions to their stakeholders, which in turn generates more consumer surplus, resulting in lower net profits for themselves than retailers. Still, then the manufacturers achieve their goal of maximizing social welfare, consistent with the relevant findings of Fan et al. (2016). When only manufacturers are considered to undertake CSR—combined with Property 3, as the manufacturer's CSR awareness increases, the manufacturer's net profit decreases while the retailer's and third party's net profit increases, i.e. the manufacturer's net profit and the net profit of other members of the closed-loop supply chain are in a reciprocal pattern, but the total profit of the closed-loop supply chain increases, which also reveals the impact of the manufacturer's active CSR awareness. Consumer surplus is much larger than the loss of their net profit. Panda et al. (2017) also reached a similar view, and the finding in this paper is a further extension of the relevant findings of Panda et al. when retailer CSR investments are not considered.

Proposition 3 is a closed-loop supply chain that considers manufacturers "CSR behavioral awareness and retailers" CSR investment when centralized and decentralized decision making is used, respectively (1) $\tau^{C*} > \tau^{D*}$, $d^{C*} > d^{D*}$, $p^{D*} > p^{C*}$, $q^{C*} > q^{D*}$; (2) $V_s^{C*} > V_s^{D*}$.

Proof: According to the relevant equilibrium results in Theorem 1 and Theorem 2, it is easy to obtain the following

$$\begin{aligned}\tau^{C*} - \tau^{D*} &= \frac{kg\beta(a - \beta c_m)\Delta_{16}}{\Delta_4\Delta_7} > 0, \\ d^{C*} - d^{D*} &= \frac{k(\theta - \beta)(a - \beta c_m)\Delta_{17}}{\Delta_4\Delta_7} > 0, \\ p^{D*} - p^{C*} &= \frac{(a - \beta c_m)(kg\beta\Delta_{18} + \Delta_{19})}{\beta\Delta_4\Delta_7} > 0, \\ q^{C*} - q^{D*} &= \frac{2kg\beta(a - \beta c_m)\Delta_{17}}{\Delta_4\Delta_7} > 0, \\ V_s^{C*} - V_s^{D*} &= \frac{k^2g(a - \beta c_m)^2\Delta_{20}}{\Delta_4\Delta_7^2} > 0,\end{aligned}$$

Among them, $2g\beta(6 - r) - 3(\theta - \beta)^2 = \Delta_{16}$, $2k\Delta_{11} + g\beta^2\Delta_1^2 = \Delta_{17}$,
 $4k(4g\beta - 3\theta^2) + \beta\Delta_1^2(2g\beta - \theta(\theta - \beta)) = \Delta_{18}$, $2k^2(\theta - \beta)(2g\beta^2(4\theta - \beta) + \theta(\theta - \beta)^2) = \Delta_{19}$,
 $32kg\beta(2g\beta - (\theta - \beta)^2) + g\beta^2\Delta_1^2(2g\beta(10 - r) - 5(\theta - \beta)^2) + 4k(\theta - \beta)^4 = \Delta_{20}$, Under the assumption of scale parameters k, g , it is easy to know that $\Delta_{16}, \Delta_{19}, \dots, \Delta_{20} > 0$, the proof is complete.

Proposition 3 shows that in a closed-loop supply chain that considers manufacturer CSR behavioral awareness and retailer CSR investment, the retail price of a new product is lower under centralized decision making. In contrast, the market demand for the new product, the recycling rate of used products, and the level of retailer CSR investment are higher under centralized decision-making than decentralized decision-making. Further, the closed-loop supply chain system's total profit is also higher in centralized decision-making than in decentralized decision-

making. That is, decentralized decisions lead to a “double marginal” effect in the closed-loop supply chain, which results in a loss of total profit in the closed-loop supply chain system.

5. Coordination mechanism

Proposition 3 of this paper shows that decentralized decision-making will cause the system to produce “double marginal” effects. This section will further explore the coordination of the closed-loop supply chain under decentralized decision-making. Therefore, a “benefit-sharing-cost-sharing” contract is designed for this paper based on the traditional benefit-sharing contract. First, the CSR-conscious lead manufacturer offers a lower wholesale price w^s to the retailer and a new transfer payment b^s to a third party. According to the principle of revenue sharing, the retailer shares its own sales revenue with the manufacturer in a particular proportion, assuming that the retailer’s sales revenue ratio is x , and the manufacturer’s ratio is $1 - x$, $x \in (0, 1)$; At the same time, according to the principle of cost-sharing, the leading manufacturer will also share a certain percentage of the recovery cost for the third party. Assume that the third party shares the recovery cost ratio y , and the manufacturer shares the ratio $1 - y$, $y \in (0, 1)$. Finally, to achieve perfect coordination of the closed-loop supply chain system, the retailer under this coordination contract is made to directly make CSR investments at the level of CSR investments under centralized decision making (refer to Deng et al., 2014), i.e. satisfying $d^{s*} = d^{c*}$. The objective functions of the manufacturer, the retailer and the third party under the above contract are expressed as (various expressions and equilibrium results under the Coordinated Decision Model are indicated by the superscript S).

$$V_m^S(w, b) = \pi_m^S(w) + rCS = (1 - x)pq - (1 - y)k\tau^2 + (w - c_m)q + (c_m - c_r - b)\tau q + r\frac{q^2}{2\beta} \quad (13)$$

$$\pi_r^S(p) = xpq - (w + d^{c*})q - g d^2 \quad (14)$$

$$\pi_t^S(\tau) = (b - A)\tau q - yk\tau^2 \quad (15)$$

Theorem 3 In a closed-loop supply chain that considers the manufacturer’s CSR behavioral awareness and the retailer’s CSR investment, under the “revenue sharing-cost sharing” contract, when the manufacturer’s re-established wholesale price is $w^{s*} = \frac{x\Delta_{21} - k(\theta - \beta)(a - \beta c_m)}{\Delta_4}$, transfer payment to a third party is $b^{s*} = A + y\Delta_1$, When the sales revenue sharing ratio satisfies $x \in [X^*, X^{**}]$, and the cost-sharing ratio satisfies $y \in [Y^*, 1]$, all member companies of the closed-loop supply chain can accept the coordination contract and achieve coordination. Furthermore, under the coordination contract, the total social welfare of the manufacturer, the retailer, the third party and the overall profit of the closed-loop supply chain system are respectively $V_m^{s*} = \frac{kg^2\beta(a - \beta c_m)^2\Delta_{22}}{\Delta_4^2}$, $\pi_r^{s*} = \frac{k^2g(a - \beta c_m)^2\Delta_{23}}{\Delta_4^2}$, $\pi_t^{s*} = \frac{kg^2\beta^2y(a - \beta c_m)^2\Delta_1}{\Delta_4^2}$, $V_s^{s*} = \frac{kg(a - \beta c_m)^2}{\Delta_4}$. Among them, $Y^* = \frac{\Delta_2^2}{\Delta_7^2}$, $X^* = \frac{16g\beta\Delta_2^2 + (\theta - \beta)^2(\Delta_7^2 - 4\Delta_2^2)}{4g\beta\Delta_7^2}$, $X^{**} = \frac{g^2\beta^2\Delta_{24} + (\theta - \beta)^2(2g\beta^2\Delta_1^2 - k(\theta - \beta)^2)}{2g\beta\Delta_7}$, $4kg\beta c_m - ag(2kr + \beta\Delta_1^2) + k(\theta - \beta)(a - \theta c_m) = \Delta_{21}$, $2(2k(1 - x) - \beta\Delta_1^2) - 2kr + (1 - y)\beta\Delta_1^2 = \Delta_{22}$, $4g\beta x - (\theta - \beta)^2 = \Delta_{23}$, $8k(2 - r) + \beta\Delta_1^2(10 - r) = \Delta_{24}$, Under the assumption of scale parameters k, g , it is easy to know that $\Delta_{21}, \Delta_{22}, \dots, \Delta_{24} > 0$.

Proof: Similar to the solution process in subsection 3.2, the inverse recursive method is used to solve the problem. First, according to the first-order condition, let $\frac{\partial \pi_r^{s*}}{\partial p} = 0$, $\frac{\partial \pi_t^{s*}}{\partial \tau} = 0$,

$$p^s = \frac{(ax + \beta w)\Delta_4 + k(\theta x + \beta)(\theta - \beta)(a - \beta c_m)}{2\beta x \Delta_4} \quad (16)$$

$$\tau^s = \frac{2kg\beta(a - \beta c_m)(b - A)}{2ky\Delta_4} \quad (17)$$

The total profit of the closed-loop supply chain system under the contract to reach the total-profit under the central decision is necessary to satisfy: $p^s = p^{c^*}$, $\tau^s = \tau^{c^*}$. Therefore, w^s and b^s , re-established by the manufacturer, can be resolved under the coordination agreement.

Furthermore, for all members of the closed-loop supply chain to accept the coordination contract, it is necessary to ensure that the total profit obtained by the parties participating in the coordination is not lower than the total profit under decentralized decision-making, i.e. it should be when satisfying $V_m^s \geq V_m^{D^*}$, $\pi_r^s \geq \pi_r^{D^*}$, $\pi_t^s \geq \pi_t^{D^*}$, $V_s^s = V_s^{C^*} > V_s^{D^*}$, the corresponding range of values of x, y can be obtained from this, and the proof is complete.

$$\text{Property 4 } \frac{\partial X^*}{\partial r} < 0, \frac{\partial X^{**}}{\partial r} < 0, \frac{\partial Y^*}{\partial r} < 0$$

Proof: According to the relevant equilibrium result in Theorem 3, it is easy to obtain the following

$$\begin{aligned} \frac{\partial X^*}{\partial r} &= \frac{-4k\Delta_4\Delta_{11}(\Delta_7-2\Delta_4)}{\Delta_7^3} < 0, \\ \frac{\partial X^{**}}{\partial r} &= \frac{-(4kg\beta(8k\Delta_{25}+\beta\Delta_1^2\Delta_{11})+\Delta_{26})}{2\Delta_7^2} < 0, \\ \frac{\partial Y^*}{\partial r} &= \frac{-4kg\beta\Delta_4(\Delta_7-2\Delta_4)}{\Delta_7^3} < 0, \end{aligned}$$

Among them, $2g\beta - (\theta - \beta)^2 = \Delta_{25}$, $4k^2(\theta - \beta)^4 + g^2\beta^4\Delta_1^4 = \Delta_{26}$, Under the assumption of scale parameters k, g , it is easy to know that $\Delta_{25}, \Delta_{26} > 0$, the proof is complete.

Property 4 shows that as the level of awareness of manufacturer CSR behavior increases, the upper and lower bounds of the benefit-sharing ratio become smaller, as does the lower bound of the cost-sharing ratio. It is because of the limited profitability of third parties in closed-loop supply chains. Their channel profits under decentralized decision making are always less than those of manufacturers and retailers. Hence, as manufacturers become more aware of CSR behavior, they will be more willing to give more benefits to third parties, i.e. they can bear more of the cost of recycling used products for third parties. Retailers with further CSR investment behaviors will also share more sales revenue to respond to and motivate manufacturers' awareness of CSR behavior.

Property 4 reveals that the manufacturer's awareness of CSR behavior can effectively affect the revenue sharing and cost-sharing ratio. However, the specific ratio still needs to be discussed and determined by the three parties. At the same time, the member companies of the closed-loop supply chain should be aware that coordination can not only benefit all enterprises but also help improve social welfare and improve the environment, which is hugely beneficial to the closed-loop supply chain as a whole and society.

6. Numerical simulation

In this section, the above main findings will be analyzed and verified through numerical simulation. Firstly, the numerical simulation is used to analyze the influence of the change in the manufacturers' CSR awareness on the optimal decision of the closed-loop supply chain. Secondly, the numerical simulation is used to analyze the influence of the change of consumers' sensitivity to the retailers' CSR investment level on the optimal decision of closed-loop supply chain. Finally, the validity of the contract designed in this paper is verified through numerical simulation results.

6.1. Analysis of the influence of the manufacturer's behavior consciousness on optimal decision

This section analyzes and verifies the influence of the changes in the awareness level of manufacturers' CSR behavior on the optimal decision of closed-loop supply chain. Due to the similarity between centralized and decentralized decision making, we mainly analyze the findings of decentralized decision making in this paper. Based on the numerical simulation parameters in [28], the demand function is assumed to be $q = 100 - P + 4d$, and the other settings are $C_m = 60$, $C_r = 30$,

$A = 10$, $k = 500$, $g = 90$. The precise simulation results, according to the relevant research results of this paper, will be shown in Table 2 and Figure 1.

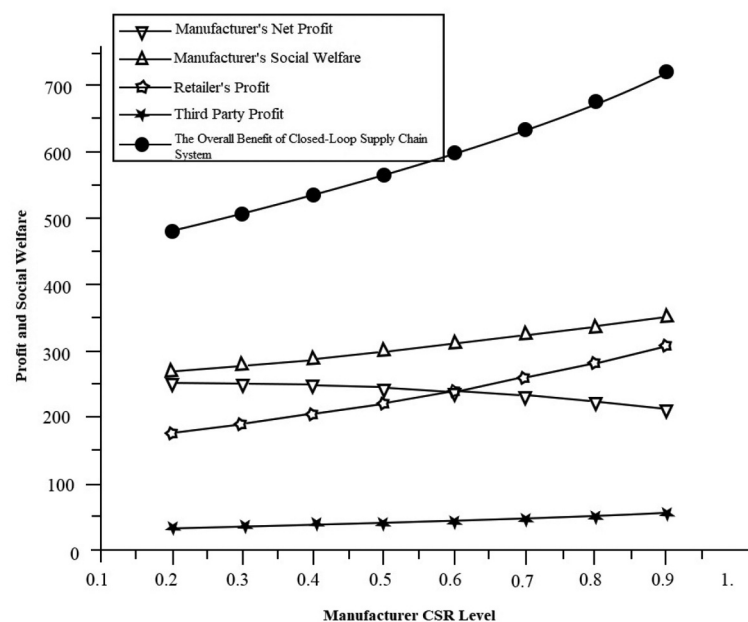
From Table 2, it can be seen that the wholesale and retail prices of new products are decreasing as manufacturers become more aware of CSR behavior, while the recycling rate of waste products and the market demand for new products are increasing. The level of CSR investment by retailers is also increasing, which further validates the relevant findings of both Property 1 and Property 2 of this paper.

Figure 1 shows that as the manufacturer's level of CSR behavioral awareness increases, the manufacturer's social welfare, retailer, third party and the closed-loop supply chain system as a whole increase, while the manufacturer's net profit decreases accordingly, further indicating that the manufacturer's CSR behavioral awareness reflects the process by which it benefits its stakeholders. Further, when the manufacturer's level of CSR behavioral awareness is low, the manufacturer's net profit is higher than the retailers. When the manufacturer's level of CSR behavioral awareness is high, the manufacturer's net profit would be lower than retailers, but regardless of the manufacturer's level of CSR behavioral awareness, the manufacturer's social welfare (total profit) is always higher than the retailer's net profit. The third party's net profit is always the lowest. It also verifies research theories related to Property 3 and Proposition 2 of this paper.

Table 2. Decision variables under different CSR behavior awareness

r value	0.01	0.2	0.5	0.7	0.9
w^{D*}	78.862	77.714	75.625	74.163	72.143
τ^{D*}	0.318	0.34	0.377	0.408	0.444
d^{D*}	0.212	0.23	0.251	0.272	0.296
p^{D*}	88.11	87.344	85.912	84.762	83.407
q^{D*}	12.739	13.56	15.56	16.327	17.778

Figure 1. Social welfare and profits of different CSR behavioral awareness.



6.2. Analysis of the influence of consumers' sensitivity to the retailer's CSR investment level on optimal decision-making

This section mainly analyzes the impact of changes in consumers' sensitivity to the retailer's CSR investment level on the optimal decision-making of the closed-loop supply chain through numerical simulation. The settings of the relevant parameters in section 6.1 are still used, and it is assumed that the manufacturer's CSR behavior awareness $r = 0.5$ at this time. According to the relevant research results of this paper, the specific simulation results are shown in Table 3 and Figure 2.

From Table 3, we can see that as consumers' sensitivity to retailers' CSR investment level increases, the wholesale price of new products decreases, while the retail price of new products, market demand, retailers' CSR investment level and the recycling rate of waste products all increase accordingly. As long as the CSR investment level of the retailer meets the consumers' expectation, even if the product price rises, it will not affect the consumers' purchasing behavior. On the contrary, it will promote the sales of new products and the recycling of waste products.

Figure 2 shows that as consumers become more sensitive to the level of retailer CSR investment, manufacturers' net profits, social welfare, and the profits of retailers, third parties, and closed-loop supply chain systems all increase. At the same time, manufacturers' social welfare and net profits are higher than those of retailers and third parties, regardless of consumer sensitivity to retailers' CSR investment levels.

6.3. Analysis of contract coordination effectiveness

This section analyzes and verifies the coordination effectiveness of the "revenue sharing-cost sharing" contract proposed in the fourth section of this article. The settings of relevant parameters in Section 6.1 still used; It also assumes that the manufacturer's CSR behavior awareness level is $r = 0.5$. Further, the proportion of sales revenue received by the retailer satisfies $x \in (0.130, 0.202)$, and the portion of the third party sharing the recovery cost should satisfy $y \in (0.027, 1)$.

Based on satisfying the above conditions, assuming that the retailer's ratio of sales revenue $x = 0.2$, the manufacturer's ratio of sales revenue is $1 - x = 0.8$; the third party's share of the recovery cost is $y = 0.5$, and the manufacturer's share the recovery cost ratio of is $1 - y = 0.5$. Table

Figure 2. Social welfare and the profits of all parties under the sensitivity of different CSR investment levels.

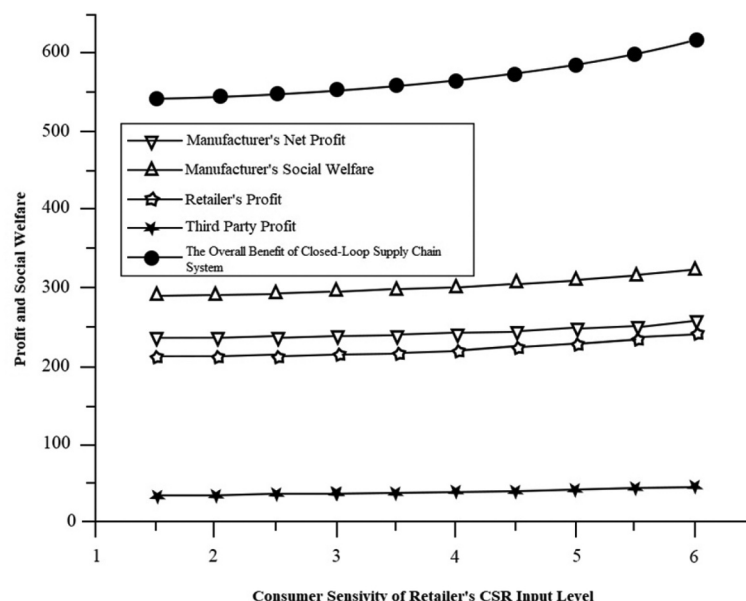


Table 3. Decision variables under different CSR investment level sensitivity

θ value	1.5	2.5	4	5	6
w^{D*}	75.754	75.725	75.625	75.475	75.367
τ^{D*}	0.281	0.323	0.377	0.428	0.479
d^{D*}	0.108	0.153	0.251	0.325	0.397
p^{D*}	85.531	85.67	85.912	86.298	86.604
q^{D*}	14.631	14.713	15.094	15.327	15.778

4 shows the equilibrium results under the given parameter values, decentralized and centralized decisions, and after contract coordination.

Table 4 shows that under the “benefit-sharing-cost-sharing” contract, the optimal wholesale and retail prices of new products are reduced. In contrast, the market demand for new products, the optimal recycling rate of waste products, and the level of retailers’ CSR investment are reduced compared to decentralized decision making. The profitability of each member of the closed-loop supply chain system is improved, and the total profitability of the system as a whole reaches the overall profitability under centralized decision-making. Therefore, the “benefit-sharing-cost-sharing” contract designed in this paper achieves the purpose of coordinating the closed-loop supply chain system and making a win-win situation for all members.

7. Conclusions, limitations and future research

This article considers the manufacturer’s CSR behavioral awareness and the retailer’s CSR investment assumptions, constructs a third-party recycling closed-loop supply chain operation and coordination model, and analyzes the manufacturer’s CSR behavioral awareness and the retailer’s CSR investment to the closed-loop supply chain members. And the impact of the system’s overall performance designed a “revenue sharing-cost sharing” contract to coordinate the closed-loop supply chain system. The main conclusions are as follows:

- (1) The manufacturer’s CSR behavior awareness and the retailer’s CSR investment are always conducive to expanding the market demand for relevant products and increase the recycling rate of waste products.
- (2) The manufacturer’s awareness of CSR behavior will reduce its net profit, but it can bring higher social welfare and help increase the earnings of other members and the overall system.
- (3) Consumers increased sensitivity to retailers’ CSR investment levels is conducive to expanding the market demand for new products, increasing the recycling rate of waste products, and improving the overall performance of the closed-loop supply chain system (subject to the manufacturer being interested in the CSR behavior and has put in place a recycling initiative)

Table 4. Closed-loop supply chain equilibrium results under different decision-making models

	Decision Model	w^*	τ^*	d^*	p^*	q^*	V_m^*	π_r^*	
π_t^*	V_s^*								
D Model	75.625	0.377	0.252	85.912	15.094	271.887	222.143	42.720	536.750
S Model	4.635	0.762	0.635	64.444	38.095	362.812	253.968	145.125	761.905
C Model	\	0.762	0.635	64.444	38.095	\	\	\	761.905

- (4) When the manufacturer's awareness of CSR behavior is weak, it gains to achieve more channel net profit than retailers. Conversely, the retailer's net profit may exceed that of the manufacturer, while the net profit of the third party is always the least.
- (5) The "revenue sharing-cost sharing" contract can not only achieve the coordination of the closed-loop supply chain system but also encourage the manufacturer to enhance CSR behavior awareness. Retailers improve CSR investment.

Since this article focuses on the situation where the market demand is determined, and only considers the CSR behavioral awareness of a single manufacturer and the CSR investment of a single retailer, this is a deficiency of this article. Future research can examine the closed-loop supply chain operation and coordination under stochastic demand with multiple entities with CSR awareness and CSR investment.

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