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Original Research

Decision Analysis of Green Supply Chain Considering Information Misreporting and Corporate Social Responsibility

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Abstract

In the 21st century, the world is facing increasingly scarce natural resources and environmental pollution. The green supply chain has attracted attention, as it emphasizes the implementation of green environmental protection concepts in every link, especially the recycling and remanufacturing activities, which are very important for reducing negative environmental impacts and improving the economic efficiency of enterprises. Due to the existence of proprietary information in many parts of the green supply chain remanufacturing process, manufacturers may lie about the quality and quantity of recycling. By providing inaccurate or misleading information, manufacturers can mask actual environmental performance or gain an unfair economic or competitive advantage. Meanwhile, consumers and the market are increasingly concerned about corporate social responsibility in green supply chains. It is widely believed that enterprises should bear the corresponding social responsibility and environmental responsibility.

Based on these points, the article delves into the problem of misreporting during the recycling process within green supply chains, particularly the potential for manufacturers to misreport during the recycling of old mobile phones, as well as the impact of corporate social responsibility (CSR) on green supply chains. Remanufactured mobile phones consume less energy during the production process, effectively reducing the carbon footprint and protecting natural resources. This study employs the Stackelberg game approach, with the retailer as the leader and the manufacturer as the follower. It establishes a two-level green supply chain model that considers the manufacturer's information misreporting and corporate social responsibility. The optimal decisions of the supply chain members are analyzed within this framework. Following this, theoretical derivations are used to reveal the strategic choices and equilibrium outcomes of manufacturers and retailers under varying degrees of misreporting

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and social responsibility. Finally, through numerical simulations, the conclusions derived from these methods are validated, and the potential negative impact of false positives on supply chain efficiency is demonstrated. Based on these findings, corresponding management recommendations are proposed.

Keywords: green supply chain, information misreporting, corporate social responsibility, recycling effort difficulty, Stackelberg game

Introduction

In the 21st-century economic landscape, the rapid advancement of the technology-driven economy has brought to light the growing scarcity of natural resources and the escalation of environmental pollution, drawing global attention. As the global community increasingly emphasizes the concept of sustainable development, green growth has gained consensus internationally. For instance, the European Union initiated a carbon emissions trading scheme for pilot companies to encourage energy-saving practices, aiming to promote worldwide implementation [1]. The United Nations (UN) has also outlined seventeen Sustainable Development Goals (SDGs) that cover economic, environmental, and social dimensions [2]. Similarly, in 2024, the U.S. Securities and Exchange Commission (SEC) proposed amendments requiring firms to disclose climate-related risks. At the same time, consumers are more inclined to choose environmentally friendly, energy-efficient, and low-pollution products. This consumption pattern can effectively mitigate environmental damage and prevent energy waste [3].

Against this backdrop, green supply chains have emerged as an effective means to mitigate adverse environmental impacts and reduce corporate environmental risks, becoming a significant subject of both academic and practical inquiry [4]. It specifically refers to a management approach that emphasizes environmental protection and resource conservation across all stages of the supply chain. Recycling and remanufacturing activities are particularly important for reducing the negative impact on the environment and improving the economic efficiency of enterprises. Zhou et al. [5] point out that this necessitates the establishment of a closed-loop supply chain by relevant firms to facilitate the recycling of used batteries within the market. This also illustrates the importance of recycling and remanufacturing. Additionally, the Stackelberg game, a widely recognized theoretical framework, is frequently utilized to analyze the optimal decision-making of supply chain members under various influencing factors [6].

However, in the globalization of green supply chains, the opacity and complexity of supply chain information transmission have highlighted the growing issue of information misreporting [7]. Information misreporting refers to the intentional or unintentional provision of inaccurate, incomplete, or misleading information during the process of information transmission. This might result in quality issues with remanufactured products, environmental and resource wastage, and decreased market trust, severely affecting the sustainable development of green supply chains. For instance, Samsung faced information misreporting regarding the battery explosion issues of the Note 7 smartphone in 2016. This led to a massive global product recall, substantial financial losses, and damage to its brand reputation, compelling the company to strengthen its supply chain and quality control measures.

Furthermore, the problems of misreporting in green supply chains are closely linked to corporate social responsibility (CSR) issues. CSR refers to the concept that businesses should not only focus on generating economic profits but also take responsibility for their impacts on society, the environment, and their stakeholders. In the background of green supply chains, the practice of CSR affects not only the corporate image and market competitiveness but also the challenges related to the healthy development of green supply chains. For instance, failure to uphold CSR can lead to consumer distrust, impacting a company's brand image and market competitiveness. This was evident in the 2010 Toyota vehicle recall, which involved issues with sticking accelerator pedals and brake system failures and significantly affected Toyota's reputation and financial status.

Information misreporting can impede a company’s ability to accurately identify and address social and environmental issues, thereby affecting its capacity to fulfill its social responsibility. Correspondingly, companies committed to social responsibility typically establish stringent information disclosure standards to ensure the accuracy and reliability of their data, reducing the likelihood of information misreporting. Thus, studying the issues of misreporting within green supply chains alongside CSR issues not only helps address the misreporting itself but also promotes sustainable corporate development and the fulfillment of social responsibilities. Tachizawa et al. [8] developed a multi-level sustainable supply chain theory, analyzing the application of CSR within multi-tier supply chains and its impact on transparency and overall supply chain performance.

In the current context, many businesses have started to focus on and practice CSR to enhance their CSR capabilities and market competitiveness. However, many companies still face issues with misreporting, posing severe threats to the healthy development of green supply chains. Therefore, it is necessary to strengthen research in this area, explore the relationship between CSR and misreporting from multiple perspectives, and develop more effective measures and strategies to promote the sustainable development of green supply chains.

Based on the aforementioned factors, this paper examines a sustainable supply chain in which manufacturers may misrepresent the challenges of recycling efforts and bear the costs of corporate social responsibility. In light of this, four supply chain models are developed. This study also addresses the following research questions:

Research question 1: What impact do misinformation reporting and CSR practices have on the profits of manufacturers and retailers in the green supply chain? How do these factors affect the manufacturer's wholesale price per unit, the retailer's level of green marketing investment in mobile phones, the old mobile phone recovery rate, and the CSR level?

Research question 2: Is misreporting information still advantageous for manufacturers when they are required to undertake corporate social responsibility?

Research question 3: How does the recyclability of old mobile phones affect the optimal decision-making of green supply chain members in the recycling process?

The rest of this article is organized as follows. In section: Literature Reviews provides a literature review. In section: Models, we briefly describe the problem and outline some necessary assumptions. Then, four models are established, and their optimal strategies are solved. In section: Comparative analysis, the results of the different models are compared and analyzed. In section: Numerical Analysis is performed to verify the proposed model. Finally, section: Conclusion and Discussion concludes the paper by discussing contributions, management implications, limitations, and future research questions.

Literature reviews

This paper primarily uses the Stackelberg game to construct a supply chain decision model influenced by behavioral factors and investigates the impact of misreporting behavior and corporate social responsibility on the optimal decisions of green supply chain members. Consequently, the literature relevant to this study predominantly encompasses two aspects: research on green supply chain decisions considering information misreporting behavior and research on supply chain decisions considering corporate social responsibility.

Research on Green Supply Chain Decisions Considering Information Misreporting Behaviors

In green supply chain management, the accuracy and transparency of information are crucial factors in ensuring supply chain efficiency and environmental performance. In recent years, as businesses increasingly focus on environmental responsibility, the phenomenon of information misreporting and its impact on green supply chains have become significant topics of academic research. Information misreporting occurs when a business or individual in a supply chain knowingly provides inaccurate or misleading information to mask their actual environmental performance or gain an undue economic or competitive advantage. This behavior not only undermines trust and cooperation between businesses but also poses a threat to achieving environmental sustainability goals. Existing research in this area generally encompasses three aspects:

1) Misreporting product quality information. In markets where products are differentiated, businesses may misreport product quality information to consumers, who often judge quality based on price, thus providing an opportunity for businesses to use false quality information [9]. Zhou et al. [10] investigated the quality misreporting behavior of a single enterprise with vertically differentiated products, finding that businesses are motivated to employ false quality strategies for both high-quality and low-quality products. Song et al. [11] explored pricing issues in a duopoly market of quality-differentiated products under product quality information misreporting, discovering that both businesses are driven by profit maximization to use false information. Joshi et al. [12] developed a two-stage model to further examine how businesses misreport product quality information when consumers can learn about quality through observation or word-of-mouth. Wang et al. [13] suggested that if consumers' valuation of products is heterogeneous, price signals can more effectively convey quality information, preventing misreporting.

2) Misreporting cost information. Qin et al. [14] studied the misreporting behaviors of businesses under the asymmetry of supplier cost information and retailer fairness concerns, as well as its impact on supply chain performance and the optimal decisions for both parties. Yan et al. [15] examined misreporting behaviors in a dual-channel supply chain, indicating that manufacturers with dual channels do not misreport cost information, whereas manufacturers with retail channels only do so when consumers are highly sensitive to cross-price. Qu et al. [16] discussed the issues of manufacturers misreporting production costs and retailers focusing on fairness concerns within the supply chain, attempting to ascertain the impacts of information misreporting and fairness concerns. Chen et al. [17] investigated how supplier cost misreporting affects supply chain decisions in a two-period strategic inventory model consisting of retailers and suppliers, finding that misreporting harms retailers and exacerbates the double marginalization effect, leading to inefficient supply chain performance.

3) Misreporting carbon information. Under carbon quota trading policies, carbon emissions and carbon prices become private information for businesses. In fierce market competition, some businesses may misreport their own carbon information to offset the profit loss caused by low-carbon policies. Zhang et

al. [18] studied the misreporting behavior of members in a dual-channel supply chain under asymmetric information about carbon emissions and prices. Several scholars have explored carbon information misreporting behaviors in supply chains with different power structures. Zhou et al. [19] examined the behavior of supply chain members under initial carbon emission information misreporting, showing that manufacturers report higher carbon emissions to gain more profits under various power structures. Zong et al. [20] introduced manufacturers inclined to misreport the environmental degree of products and discussed its impact on supply chain decisions and profits using a dual-channel Stackelberg game model. Wu et al. [21] considered misreporting of both unit product initial carbon emission costs and emission reduction investment costs, exploring the misreporting behaviors of suppliers under different supply chain power structures and their impact on supply chain decisions and profits.

In the past, most literature has focused on information misreporting behaviors regarding product quality, cost, and carbon emissions, while few scholars have discussed information misreporting during the recycling process of old products. Moreover, the production costs of new products are relatively public information in the supply chain. Therefore, this paper incorporates the information misreporting behavior of manufacturers during the reproduction process into a Stackelberg game model, with the retailer as the leader and the manufacturer as the follower, to explore the impact of manufacturers' information misreporting during the production of remanufactured mobile phones in the two-level green supply chain.

Research on Supply Chain Decisions Considering Corporate Social Responsibility

In the current socio-economic environment, fulfilling corporate social responsibility (CSR) is not only a requirement from stakeholders for businesses but has also become a strategic tool for many companies to gain competitive advantages in the market. Additionally, as consumer social awareness strengthens, traditional supply chains are unable to meet current market demands. Zhou et al. [22] point out that in any domestic service market, there will be service seekers who receive imprecise and non-professional services. If businesses don't actively change, they may be replaced by other companies. Golden et al. [23] argue that businesses need to undergo green transformations, establish correct green production and business philosophies, and actively develop and implement codes of conduct for CSR within the supply chain system. The operation of businesses should not solely target their own profits but also take on responsibilities toward the environment, consumers, and societal contributions. Currently, scholars in various fields have incorporated CSR into the management and decision-making of supply chains.

Nassani et al. [24] studied the moderating role of CSR in green supply chains between green technology and zero waste management. Long et al. [25] investigated the crucial role of environmental regulations and CSR in the GSCM of agrifood companies. Using questionnaire surveys and PLS-SEM, they explore the relationship between corporate responsibility and performance management, highlighting the mediating effect of CSR in this context. Khosroshahi et al. [26] explored the impact of transparency and CSR on the decisions of supply chain members and their profits from green products. Wang et al. [27], based on stakeholder theory, discussed the relationship between CSR, green supply chain management, and business performance, concluding that green supply chain management has a positive impact on business performance, and big data analytics capabilities positively moderate the relationship between external CSR and green supply chain management. Khan et al. [28], based on social exchange theory, social capital theory, and Carroll's CSP model, studied the impact of CSR on the duality of sustainable innovation, sustainable supply chain management, and second-order social capital. Huang et al. [29] explored the impact of CSR undertaken by manufacturers or retailers and different power structures on their joint green marketing decisions and profits in green supply chains. Chen et al. [30] researched the impact of CSR and consumer green preferences on the performance and green level of products in a dual-channel green supply chain, finding that collaborative contracts can coordinate the dual-channel green supply chain, ensuring profitability for supply chain businesses. Liu et al. [31] constructed profit models for renewable energy supply chain members under different power structures and CSR subjects, analyzing the optimal decisions under various decision models. Le et al. [32] investigated the relationship between CSR and sustainable business performance of small and medium-sized enterprises in emerging economies, mediated by green innovation and green supply chain management. Maiti et al. [33] found that companies considering CSR are more competitive than those focusing solely on economic benefits. Li et al. [34], based on a shared economy platform, discovered the links between CSR and sustainable supply chain management practices, noting that the CSR methods adopted by shared economy platforms improved internal supply chain management and promoted customer willingness to use shared economy platforms. Vuong et al. [35] explored how brand dimensions, particularly brand identity, awareness, love, and loyalty, are influenced by perceived environmental and social responsibility among milk product consumers in Ho Chi Minh City, emphasizing that social responsibility significantly improves customer satisfaction and loyalty.

These studies have revealed the importance of CSR in improving corporate performance and customer loyalty, but there is a lack of literature exploring both information misreporting behaviors and CSR undertakings by supply chain members simultaneously. Through theoretical deduction and numerical simulation, this paper will analyze and verify information misreporting behavior of varying degrees and the optimal decisions of supply chain members under corporate social responsibility, and put forward corresponding management suggestions. This not only helps to deepen the understanding of information transparency and social responsibility in green supply chain management but also provides a reference for the practical decision-making of supply chain members.

Models

This paper constructs a supply chain system comprised of a manufacturer and a retailer, as shown in Fig. 1. The manufacturer processes raw materials into mobile phones and also engages in the remanufacturing of old mobile phones collected from consumers to reduce environmental pollution. Remanufactured mobile phones consume less energy during the production process, effectively reducing the carbon footprint and protecting natural resources. The retailer employs a series of green marketing measures to sell these mobile phones, which include both new and remanufactured mobile phones. At the beginning of the sales process, the order quantity placed by the retailer matches the consumer demand D directed towards the manufacturer. Subsequently, the manufacturer produces the corresponding quantity of mobile phones and sells them to the retailer at a wholesale price w. Consumers purchase mobile phones from the retailer at a retail price p. Simultaneously, the supply chain exhibits information asymmetry, with the manufacturer possessing private information about the recycling of mobile phones. Driven by its own interests, the manufacturer may misreport the costs of recycling old mobile phones to the retailer and undertake corresponding corporate social responsibilities.

Assumption 1. It is assumed that remanufactured mobile phones, recycled and remanufactured by manufacturers from old mobile phones, are identical to new mobile phones in terms of functionality and quality. Both types of mobile phones enter the consumer market in the same manner, possessing equivalent market recognition and selling prices.

Assumption 2. The total production of new mobile phones and remanufactured mobile phones by the manufacturer exactly matches market demand. Market demand is influenced by the selling price p and the retailer's level of greenness v. The higher the level of greenness, the higher the consumer demand. Consequently, the market demand for the mobile phones is:

$$D = a - p + \theta v$$

In the model, a represents the basic market capacity and is significantly larger than other parameters, p denotes the retail price set by the retailer, θ is the sensitivity of market demand to the retailer's level of green marketing, and v represents the retailer's green level. To better construct a green supply chain model dominated by retailers, this section also assumes:

$$p = w + s$$

The variable s represents the unit product revenue for the retailer.

Assumption 3. The manufacturer's recycling effort cost for recycling old mobile phones is $C_r = \lambda t^2$, where λ is a coefficient of difficulty in recycling effort, and the cost is a quadratic convex function of the recovery rate, indicating that excessive pursuit of high recovery rate is not economical.

Assumption 4. The retailer's investment in green marketing for mobile phones is $C_a = \frac{1}{2} b v^2$. The manufacturer's cost of producing a unit of new mobile phones is C_m, and the manufacturer's cost of recycling a unit of old mobile phones is C_n. It is assumed that $C_m > C_n$ must hold.

Assumption 5. In the model of the manufacturer assuming social responsibility, the level of social responsibility it assumes will have an impact on market demand, expressed as:

$$D = a - p + \theta v + \gamma e$$

Among them, e represents the level of social responsibility assumed by the manufacturer, and γ represents the sensitivity of consumers to the level of social responsibility. The cost of the manufacturer's social responsibility level is represented as $\frac{1}{2}\beta e^2$.

Assumption 6. In the supply chain, except for the manufacturer's information on recycling old mobile phones, all other information is symmetric. The members of the supply chain are risk-neutral and fully rational, and they make decisions based on the principle of maximizing their own interests.

Assumption 7. In this supply chain, the retailer, who occupies a larger market share, makes decisions as the dominant party, while the manufacturer makes decisions as the follower.

In which i denotes the different scenarios under different decision models, 1 denotes the standard model, 2 denotes the model that only considers false reporting behavior, 3 denotes the model that only considers the cost of corporate social responsibility, and 4 denotes the model that considers both false reporting behavior and the cost of corporate social responsibility.

Basic Model: NN Model

In the NN model, all information in the supply chain is symmetric. Manufacturers report their true cost information, and retailers bear certain costs for green marketing efforts. There is no misreporting or corporate

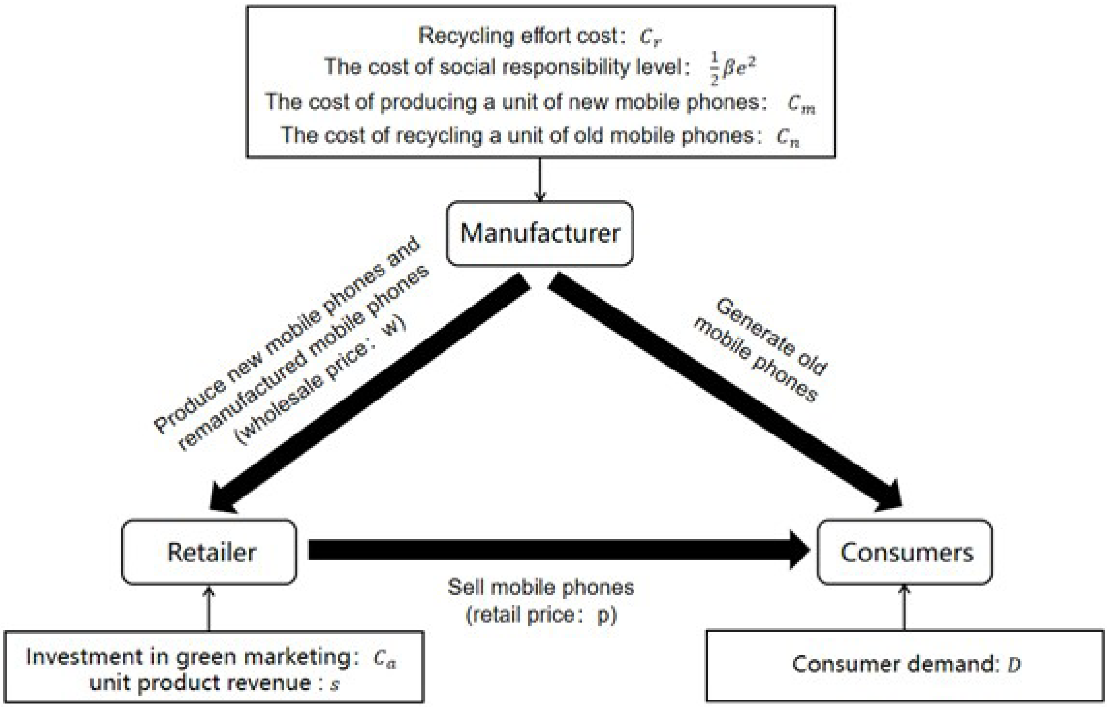


Fig. 1. The relationships of supply chain members.
Related parameters and meanings are shown in the following table and the parameters involved in the model are all positive numbers.

Table. 1. Notations.

Notations	Definitions
w_i	Manufacturer's wholesale price per unit, i = 1,2,3,4
p	Retailer's unit selling price
D	The market demand for mobile phones
a	Base market capacity
θ	Consumer sensitivity to the level of green marketing
C_a	Retailers' investment in green marketing of mobile phones
b	Green marketing input cost coefficient
v_i	Green marketing investment level, i = 1,2,3,4
s_i	Retailers' unit revenue of mobile phones, i = 1,2,3,4
t_i	Waste recovery rate, i = 1,2,3,4
λ	Manufacturer recovery effort difficulty factor
δ	Recycled old mobile phones can be reused
C_m	Manufacturer's unit cost of production
C_n	Manufacturer's recycling cost per unit of old mobile phones
C_r	The cost of recycling efforts to recycle old mobile phones
ϕ	False positives in recycling efforts
e_i	CSR level, i = 3,4
β	Cost coefficient of manufacturer's CSR level
π_r^i	Retailer profit, i = 1,2,3,4
π_m^i	Manufacturer's profit, i = 1,2,3,4

social responsibility-related behavior. Considering that the retailer is the dominant party and the manufacturer is the follower, both aim to maximize their respective profits. Therefore, the manufacturer's profit function and the retailer's profit function are, respectively:

$$\pi_m{}^1(w,t) = (w - C_m)D + (C_m - C_n)Dt\delta - \lambda t^2 \tag{3.1}$$

$$\pi_r{}^1(s,v) = sD - \frac{1}{2}bv^2 \tag{3.2}$$

At this point, the decision sequence for the green supply chain is as follows: the retailer first decides its optimal unit product revenue s and optimal green marketing level *v*, and then the manufacturer decides the wholesale price *w* and the old mobile phones recovery rate *t* after observing the retailer's optimal decision.

First, for the manufacturer, by using formula (3.1), the first-order derivative of $\pi_m{}^1(w,t)$ with respect to *w* and *t* is:

$$\frac{\partial \pi_m{}^1(w,t)}{\partial w} = C_m + a - s - 2w + \theta v - t\delta(C_m - C_n) \tag{3.3}$$

$$\frac{\partial \pi_m{}^1(w,t)}{\partial t} = \delta(C_m - C_n)(a - s - w + \theta v) - 2\lambda t \tag{3.4}$$

The Hessian matrix of $\pi_m{}^1(w,t)$ is:

$$H_1 = \begin{bmatrix} -2 & -\delta(C_m - C_n) \\ -\delta(C_m - C_n) & -2\lambda \end{bmatrix}$$

When $\lambda > \frac{\delta^2(C_m - C_n)^2}{4}$, the matrix H_1 is a negative definite matrix. Therefore, the manufacturer's profit function is a concave function and has a maximum value. Let the first-order derivative condition equal 0, and solve the system of equations to obtain the manufacturer's optimal decision.

$$w_1 = \frac{2\lambda(C_m+a-s)+(C_m{}^2+C_n{}^2)[s(\delta^2-sa)]+2\lambda\theta v+2\delta^2 C_m C_n(a-s)-\theta v\delta^2(C_m-C_n)^2}{-\delta^2(C_m-C_n)^2+4\lambda} \tag{3.5}$$

$$t_1 = \frac{\delta(-C_m+a-s+\theta v)(C_m-C_n)}{-\delta^2(C_m-C_n)^2+4\lambda} \tag{3.6}$$

Next, substitute equations (3.5) and (3.6) into equation (3.2), and take the first-order partial derivatives of $\pi_r{}^1(s,v)$ with respect to *s* and *v*. Setting the first-order derivatives equal to zero, we obtain the Hessian matrix of $\pi_r{}^1(s,v)$.

$$H_2 = \begin{bmatrix} \frac{-4\lambda}{-\delta^2(C_m - C_n)^2 + 4\lambda} & \frac{2\theta\lambda}{-\delta^2(C_m - C_n)^2 + 4\lambda} \\ \frac{2\theta\lambda}{-\delta^2(C_m - C_n)^2 + 4\lambda} & \frac{\delta^2(C_m - C_n)^2 - 4b\lambda}{-\delta^2(C_m - C_n)^2 + 4\lambda} \end{bmatrix}$$

When $\lambda > \frac{\delta^2(C_m - C_n)^2}{4}$, the matrix H_2 is a negative definite matrix. Therefore, the retailer's profit function is concave and has a maximum value. Solving the system of equations, we obtain the optimal unit product revenue and level of green marketing investment for the retailer as:

$$s_1 = a - C_m + \frac{(C_m - a)\lambda\theta^2}{2[b\delta^2(C_m-C_n)^2+\theta^2\lambda-4b\lambda]} \tag{3.7}$$

$$v_1 = \frac{\theta\lambda(C_m-a)}{b\delta^2(C_m-C_n)^2+\theta^2\lambda-4b\lambda} \tag{3.8}$$

Finally, formulas (3.7) and (3.8) are substituted into formulas (3.5) and (3.6) to obtain the manufacturer's optimal wholesale price and optimal waste recovery rate

$$w_1 = C_m + a + \frac{b\lambda(\theta^2-2b)(C_m-a)}{2[b\delta^2(C_m-C_n)^2+\theta^2\lambda-4b\lambda]} \tag{3.9}$$

$$t_1 = \frac{b\delta(C_m-C_n)(C_m-a)}{b\delta^2(C_m-C_n)^2+4\lambda(\theta^2-2b)} \tag{3.10}$$

By substituting equations (3.7)~(3.10) into equations (3.1) and (3.2), the optimal profit of manufacturers and retailers can be obtained as:

$$\pi_m{}^1(w,t) = \frac{\lambda b^2(C_m - a)^2[-\delta^2(C_m-C_n)^2+4\lambda]}{4[b\delta^2(C_m-C_n)^2+\theta^2\lambda-4b\lambda]^2} \tag{3.11}$$

$$\pi_r{}^1(s,v) = \frac{-\lambda b(C_m - a)^2}{2[b\delta^2(C_m-C_n)^2+\theta^2\lambda-4b\lambda]} \tag{3.12}$$

Model with Misreport: MN Model

In the MN model with misreport, due to information asymmetry, manufacturers will misreport the effort required for recycling old mobile phones, and retailers cannot obtain this information. In this case, the publicly disclosed profit function for manufacturers is given by equation (3.13). Since retailers always make optimal decisions based on the publicly disclosed wholesale price and the recycling rate of old mobile phones when misreporting behavior occurs, their profit function is given by equation (3.14), which is the same as equation (3.2). At this point, the profit functions for manufacturers and retailers are, respectively:

$$\pi_m{}^2(w,t) = (w - C_m)D + (C_m - C_n)Dt\delta - \Phi\lambda t^2 \tag{3.13}$$

$$\pi_r{}^2(s,v) = sD - \frac{1}{2}bv^2 \tag{3.14}$$

Similar to the no-lie model, first for the manufacturer, find the first derivative of $\pi_m{}^2(w,t)$ with respect to w and t

$$\frac{\partial \pi_m{}^2(w,t)}{\partial w} = C_m + a - s - 2w + \theta v - t\delta(C_m - C_n) \tag{3.15}$$

$$\frac{\partial \pi_m{}^2(w,t)}{\partial t} = \delta(C_m - C_n)(a - s - w + \theta v) - 2\Phi\lambda t \tag{3.16}$$

The Hessian matrix of $\pi_m{}^2(w,t)$ is:

$$H_3 = \begin{bmatrix} -2 & -\delta(C_m - C_n) \\ -\delta(C_m - C_n) & -2\Phi\lambda \end{bmatrix}$$

When $\Phi > \frac{\delta^2(C_m - C_n)^2}{4\lambda}$, the matrix H_3 is a negative definite matrix. Therefore, the manufacturer's profit function is a concave function and has a maximum value. Let the first-order derivative condition equal 0, and solve the system of equations to obtain the manufacturer's optimal decision.

$$w_2 = \frac{2\lambda(C_m+a-s)+(C_m{}^2+C_n{}^2)[s(\delta^2-sa)]+2\Phi\lambda\theta v+2\delta^2 C_m C_n(a-s)-\theta v\delta^2(C_m-C_n)^2}{-\delta^2(C_m-C_n)^2+4\Phi\lambda} \tag{3.17}$$

$$t_2 = \frac{\delta(-C_m+a-s+\theta v)(C_m-C_n)}{-\delta^2(C_m-C_n)^2+4\Phi\lambda} \tag{3.18}$$

Next, substitute equations (3.17) and (3.18) into equation (3.14) to obtain the first-order partial derivatives of $\pi_r{}^2(s,v)$ with respect to s and v, and set the first-order partial derivatives equal to zero to obtain the Hessian matrix of $\pi_r{}^2(s,v)$

$$H_4 = \begin{bmatrix} \frac{-4\Phi\lambda}{-\delta^2(C_m - C_n)^2 + 4\lambda} & \frac{2\theta\Phi\lambda}{-\delta^2(C_m - C_n)^2 + 4\Phi\lambda} \\ \frac{2\theta\Phi\lambda}{-\delta^2(C_m - C_n)^2 + 4\Phi\lambda} & \frac{\delta^2(C_m - C_n)^2 - 4b\Phi\lambda}{-\delta^2(C_m - C_n)^2 + 4\Phi\lambda} \end{bmatrix}$$

When $\Phi > \frac{\delta^2(C_m - C_n)^2}{\lambda(4b-\theta^2)}$, the matrix H_4 is a negative definite matrix. Therefore, the retailer's profit function is concave and has a maximum value. Solving the system of equations, we obtain the optimal unit product revenue and level of green marketing investment for the retailer as:

$$s_1 = a - C_m + \frac{(C_m-a)\Phi\lambda\theta^2}{2[b\delta^2(C_m-C_n)^2+\Phi\theta^2\lambda-4\Phi b\lambda]} \tag{3.19}$$

$$v_2 = \frac{\theta\Phi\lambda(C_m-a)}{b\delta^2(C_m-C_n)^2+\Phi\theta^2\lambda-4\Phi b\lambda} \tag{3.20}$$

Finally, equations (3.19) and (3.20) are substituted into equations (3.17) and (3.18) to obtain the manufacturer's optimal wholesale price and optimal waste recovery rate

$$w_2 = C_m + a + \frac{b\Phi\lambda(\theta^2-2b)(C_m-a)}{2[b\delta^2(C_m-C_n)^2+\Phi\theta^2\lambda-4\Phi b\lambda]} \tag{3.21}$$

$$t_2 = \frac{b\delta(C_m-C_n)(C_m-a)}{b\delta^2(C_m-C_n)^2+\Phi\lambda(\theta^2-4b)} \tag{3.22}$$

By substituting equations (3.19)~(3.22) into equations (3.13) and (3.14), the optimal profit of manufacturers and retailers can be obtained as:

$$\pi_r{}^2(s,v) = \frac{-\lambda\Phi b(C_m - a)^2}{2[b\delta^2(C_m-C_n)^2+\Phi\theta^2\lambda-4\Phi b\lambda]} \tag{3.23}$$

$$\pi_m{}^2(w,t) = \frac{\lambda\Phi b^2(C_m - a)^2[-\delta^2(C_m-C_n)^2+4\lambda\Phi]}{4[b\delta^2(C_m-C_n)^2+\theta^2\lambda\Phi-4b\lambda\Phi]^2} \tag{3.24}$$

Model with CSR: NC Model

In the NC model with CSR, the manufacturer assumes full corporate social responsibility, according to hypothesis 5, when the market demand becomes:

$$D = a - p + \theta v + \gamma e$$

Where γ represents the sensitivity of market demand to the level of corporate social responsibility, e represents the level of corporate social responsibility in the supply chain, and the social responsibility cost is expressed as $\frac{\beta e^2}{2}$, where β is the cost coefficient of corporate social responsibility level, and β indicates the high or low cost of corporate social responsibility that the supply chain needs to bear. Thus, the profit functions of the members in the supply chain, manufacturers, and retailers, are, respectively:

$$\pi_m{}^3(w,t,e) = (w - C_m)D + (C_m - C_n)Dt\delta - \lambda t^2 - \frac{\beta e^2}{2} \tag{3.25}$$

$$\pi_r{}^3(s,v) = sD - \frac{1}{2}bv^2 \tag{3.26}$$

Similar to the above model calculation process, first for the manufacturer, find the first derivative of $\pi_m^3(w, t, e)$ with respect to w, t and e

$$\frac{\partial \pi_m{}^3(w,t,e)}{\partial w} = C_m + a - s - 2w + \gamma e + \theta v - \delta t(C_m - C_n) \quad (3.27)$$

$$\frac{\partial \pi_m{}^3(w,t,e)}{\partial t} = \delta(C_m - C_n)(a - s - w + \gamma e + \theta v) - 2t\lambda \quad (3.28)$$

$$\frac{\partial \pi_m{}^3(w,t,e)}{\partial e} = \gamma\delta t(C_m - C_n) - e\beta - \gamma(C_m - w) \quad (3.29)$$

The Hessian matrix of $\pi_m^3(w, t, e)$ is:

$$H_5 = \begin{bmatrix} -2 & -\delta(C_m - C_n) & \gamma \\ -\delta(C_m - C_n) & -2\lambda & \gamma\delta(C_m - C_n) \\ \gamma & \gamma\delta(C_m - C_n) & -\beta \end{bmatrix}$$

When $\lambda > -\frac{\beta\delta^2(C_m - C_n)^2}{2(\gamma^2 - 2\beta)}$, the matrix H_5 is a negative definite matrix. Therefore, the manufacturer's profit function is concave and has a maximum value. Let the first-order derivative condition equal 0, and solve the system of equations to obtain the manufacturer's optimal decision.

$$w_3 = \frac{2\lambda\gamma^2 C_m - 2\lambda\beta(a - s + C_m) + \beta\delta^2(C_m - C_n)^2(a - s + \theta v) - 2\beta\lambda\theta v}{\delta^2\beta(C_m - C_n)^2 + 2\lambda(\gamma^2 - 2\beta)} \quad (3.30)$$

$$t_3 = \frac{\delta\beta(C_m - C_n)(C_m - a + s - \theta v)}{\delta^2\beta(C_m - C_n)^2 + 2\lambda(\gamma^2 - 2\beta)} \quad (3.31)$$

$$e_3 = \frac{2\lambda\gamma(C_m - a + s - \theta v)}{\delta^2\beta(C_m - C_n)^2 + 2\lambda(\gamma^2 - 2\beta)} \quad (3.32)$$

Secondly, by substituting the formula (3.30)~(3.32) into (3.26), finding the first derivative of $\pi_r^3(s, v)$ with respect to s and v, and setting the first derivative equal to 0, the Hessian matrix of $\pi_r^3(s, v)$ is:

$$H_6 = \begin{bmatrix} \frac{4\beta(\delta^2\beta(C_m - C_n)^2 + \lambda(2\gamma^2 - 4\beta)}{(\delta^2\beta(C_m - C_n)^2 + 2\lambda(\gamma^2 - 2\beta))^2} & \frac{-2\beta\theta(\delta^2\beta(C_m - C_n)^2 + 2\lambda(\gamma^2 - 2\beta)}{(\delta^2\beta(C_m - C_n)^2 + 2\lambda(\gamma^2 - 2\beta))^2} \\ \frac{-2\beta\theta(\delta^2\beta(C_m - C_n)^2 + 2\lambda(\gamma^2 - 2\beta)}{(\delta^2\beta(C_m - C_n)^2 + 2\lambda(\gamma^2 - 2\beta))^2} & 0 \end{bmatrix}$$

The matrix H_6 is negative definite when $\lambda > -\frac{\beta\delta^2(C_m - C_n)^2}{2(\gamma^2 - 2\beta)}$. Therefore, the profit function of the retailer is concave and has a maximum value. By simultaneous equations, the optimal unit product revenue and green marketing investment level of retailers can be obtained

$$s_3 = a - C_m + \frac{(C_m - a)\lambda\beta\theta^2}{2[b\beta\delta^2(C_m - C_n)^2 + \beta\lambda(\theta^2 - 4b) + 2b\lambda\gamma^2]} \quad (3.33)$$

$$v_3 = \frac{\beta\theta\lambda(C_m - a)}{b\beta\delta^2(C_m - C_n)^2 + \beta\lambda(\theta^2 - 4b) + 2b\lambda\gamma^2} \quad (3.34)$$

Finally, formula (3.33) and (3.34) are substituted into formula (3.30)~(3.32), and the optimal wholesale price, waste recovery rate and CSR level of the manufacturer are obtained

$$w_3 = C_m + a + \frac{\lambda(C_m - a)[2b\gamma^2 + \beta(\theta^2 - 2b)]}{2[b\beta\delta^2(C_m - C_n)^2 + \beta\lambda(\theta^2 - 4b) + 2b\lambda\gamma^2]} \quad (3.35)$$

$$t_3 = \frac{b\beta\delta(C_m - a)(C_m - C_n)}{2[b\beta\delta^2(C_m - C_n)^2 + \beta\lambda(\theta^2 - 4b) + 2b\lambda\gamma^2]} \quad (3.36)$$

$$e_3 = \frac{\gamma b\beta(C_m - a)}{b\beta\delta^2(C_m - C_n)^2 + \beta\lambda(\theta^2 - 4b) + 2b\lambda\gamma^2} \quad (3.37)$$

By substituting equations (3.33) to (3.37) into equations (3.25) and (3.26), the optimal profit of the manufacturer and retailer can be obtained as:

$$\pi_m{}^3(w,t,e) = \lambda\beta b^2(C_m - a)^2 \left\{\frac{\beta\delta^2(C_m - C_n)^2 + 2\lambda\gamma^2 - 4\beta\lambda}{4\beta[b\delta^2(C_m - C_n)^2 + \lambda(\theta^2 - 4b) + 2b\lambda\gamma^2]^2}\right\} \quad (3.38)$$

$$\pi_r{}^3(s,v) = \frac{-b\beta\lambda(C_m - a)^2}{2[b\beta\delta^2(C_m - C_n)^2 + \beta\lambda(\theta^2 - 4b) + 2b\lambda\gamma^2)]} \quad (3.39)$$

Model with Misreport and CSR: MC Model

In view of the fact that information misrepresentation occurs in the retailer-led green supply chain and the manufacturer undertakes CSR, it often has a great impact on the overall benefits of the supply chain and its members. Therefore, this part describes the green supply chain model under the circumstances of misrepresentation and when the manufacturer undertakes CSR. Thus, the profit function of the manufacturer and the retailer is respectively

$$\pi_m{}^4(w,t,e) = (w - C_m)D + (C_m - C_n)Dt\delta - \Phi\lambda t^2 - \frac{\beta e^2}{2} \quad (3.40)$$

$$\pi_r{}^4(s,v) = sD - \frac{1}{2}bv^2 \tag{3.41}$$

Similar to the above model calculation process, first for the manufacturer, find the first derivative of $\pi_m{}^4(w,t,e)$ with respect to w, t and e

$$\frac{\partial \pi_m{}^4(w,t,e)}{\partial w} = C_m + a - s - 2w + \gamma e + \theta v - \delta t\Phi(C_m - C_n) \tag{3.42}$$

$$\frac{\partial \pi_m{}^4(w,t,e)}{\partial t} = \delta\Phi(C_m - C_n)(a - s - w + \gamma e + \theta v) - 2t\lambda \tag{3.43}$$

$$\frac{\partial \pi_m{}^4(w,t,e)}{\partial e} = \gamma\delta t\Phi(C_m - C_n) - e\beta - \gamma(C_m - w) \tag{3.44}$$

The Hessian matrix of $\pi_m{}^4(w,t,e)$ is:

$$H_7 = \begin{bmatrix} -2 & -\delta(C_m - C_n) & \gamma \\ -\delta(C_m - C_n) & -2\lambda\Phi & \gamma\delta(C_m - C_n) \\ \gamma & \gamma\delta(C_m - C_n) & -\beta \end{bmatrix}$$

When $\Phi > -\frac{\beta\delta^2(C_m - C_n)^2}{2\lambda(\gamma^2 - 2\beta)}$, the matrix H_7 is negative definite. Therefore, the manufacturer's profit function is concave and has a maximum value. Let the first derivative condition equal to 0, set the equations together, the manufacturer's optimal decision is solved

$$w_4 = \frac{2\Phi\lambda\gamma^2 C_m - 2\lambda\Phi\beta(a - s + C_m) + \beta\delta^2(C_m - C_n)^2(a - s + \theta v) - 2\beta\Phi\lambda\theta v}{\delta^2\gamma\beta(C_m - C_n)^2 + 2\lambda\Phi(\gamma^2 - 2\beta)} \tag{3.45}$$

$$t_4 = \frac{\delta\beta(C_m - C_n)(C_m - a + s - \theta v)}{\delta^2\beta(C_m - C_n)^2 + 2\lambda\Phi(\gamma^2 - 2\beta)} \tag{3.46}$$

$$e_4 = \frac{2\Phi\lambda\gamma(C_m - a + s - \theta v)}{\delta^2\beta(C_m - C_n)^2 + 2\lambda\Phi(\gamma^2 - 2\beta)} \tag{3.47}$$

Secondly, by substituting the formula (3.45)~(3.47) into (3.41), finding the first derivative of $\pi_m{}^4(s,v)$ with respect to s and v, and setting the first derivative equal to 0, the Hessian matrix of $\pi_m{}^4(s,v)$ is:

$$H_8 = \begin{bmatrix} \frac{4\beta(\delta^2\beta(C_m - C_n)^2 + \Phi\lambda(2\gamma^2 - 4\beta)}{(\delta^2\beta(C_m - C_n)^2 + 2\Phi\lambda(\gamma^2 - 2\beta))^2} & \frac{-2\beta\theta(\delta^2\beta(C_m - C_n)^2 + 2\Phi\lambda(\gamma^2 - 2\beta)}{(\delta^2\beta(C_m - C_n)^2 + 2\Phi\lambda(\gamma^2 - 2\beta))^2} \\ \frac{-2\beta\theta(\delta^2\beta(C_m - C_n)^2 + 2\Phi\lambda(\gamma^2 - 2\beta)}{(\delta^2\beta(C_m - C_n)^2 + 2\Phi\lambda(\gamma^2 - 2\beta))^2} & 0 \end{bmatrix}$$

When $\Phi > -\frac{\beta\delta^2(C_m - C_n)^2}{2\lambda(\gamma^2 - 2\beta)}$, the matrix H_8 is negative definite. Therefore, the profit function of the retailer is concave and has a maximum value. By simultaneous equations, the optimal unit product revenue and green marketing investment level of retailers can be obtained

$$s_4 = a - C_m + \frac{(C_m - a)\Phi\lambda\beta\theta^2}{2[b\beta\delta^2\Phi^2(C_m - C_n)^2 + \beta\Phi\lambda(\theta^2 - 4b) + 2b\Phi\lambda\gamma^2]} \tag{3.48}$$

$$v_4 = \frac{\beta\theta\Phi\lambda(C_m - a)}{b\beta\delta^2\Phi^2(C_m - C_n)^2 + \beta\Phi\lambda(\theta^2 - 4b) + 2b\Phi\lambda\gamma^2} \tag{3.49}$$

Finally, formula (3.48) and (3.49) are substituted into formula (3.45)~(3.47), and the optimal wholesale price, waste recovery rate and CSR level of the manufacturer are obtained

$$w_4 = C_m + a + \frac{\Phi\lambda(C_m - a)[2b\gamma^2 + \beta(\theta^2 - 2b)]}{2[b\beta\delta^2(C_m - C_n)^2 + \beta\Phi\lambda(\theta^2 - 4b) + 2b\Phi\lambda\gamma^2]} \tag{3.50}$$

$$t_4 = \frac{b\beta\delta\Phi(C_m - a)(C_m - C_n)}{2(b\beta\delta^2\Phi^2(C_m - C_n)^2 + \beta\Phi\lambda(\theta^2 - 4b) + 2b\Phi\lambda\gamma^2)} \tag{3.51}$$

$$e_4 = \frac{\gamma b\beta(C_m - a)}{b\beta\delta^2(C_m - C_n)^2 + \beta\Phi\lambda(\theta^2 - 4b) + 2b\Phi\lambda\gamma^2} \tag{3.52}$$

By substituting equations (3.48) to (3.52) into equations (3.40) and (3.41), the optimal profit of manufacturers and retailers can be obtained as:

$$\pi_m{}^4(w,t,e) = \Phi\lambda\beta b^2(C_m - a)^2 \left\{\frac{\beta\delta^2(C_m - C_n)^2 + 2\Phi\lambda\gamma^2 - 4\beta\Phi\lambda}{4\beta[(b\delta^2(C_m - C_n)^2 + \Phi\lambda(\theta^2 - 4b) + 2b\Phi\lambda\gamma^2]^2}\right\} \tag{3.53}$$

$$\pi_r{}^4(s,v) = \frac{-b\beta\lambda(C_m - a)^2}{2[b\beta\delta^2\Phi^2(C_m - C_n)^2 + \beta\lambda(\theta^2 - 4b) + 2b\lambda\gamma^2)]} \tag{3.54}$$

Comparative Analysis

In this section, the following four propositions can be obtained by comparing the optimal strategy and profit of the four models.

Proposition 4.1. 1) In the four models, the retailer's optimal unit product revenue is satisfied

(i). When $-\frac{\beta\delta^2(C_m - C_n)^2}{2\lambda(\gamma^2 - 2\beta)} < \Phi < 1 + \frac{2b\gamma^2(\theta^2 - 4b)}{\beta}$, $s_4 > s_2 > s_3 > s_1$

(ii). When $1 + \frac{2b\gamma^2(\theta^2 - 4b)}{\beta} \le \Phi < 1$, $s_4 > s_3 > s_2 > s_1$

2) The manufacturer's optimal wholesale price is satisfied

(i). When $\theta^2 > 2b$ and $-\frac{\beta\delta^2(C_m - C_n)^2}{2\lambda(\gamma^2 - 2\beta)} < \Phi < 1 + \frac{2b\gamma^2(\theta^2 - 4b)}{\beta}$, $w_4 > w_2 > w_3 > w_1$

(ii). When $\theta^2>2b$ and $1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}\le\Phi<1$, $w_4>w_3>w_2>w_1$

(iii). When $\theta^2\le 2b$ and $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)}<\Phi<1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $w_3>w_1>w_4>w_2$

(iv). When $\theta^2\le 2b$ *and* $1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}\le\Phi<1$, $w_3>w_4>w_1>w_2$

Proof. First, it is proved that the optimal unit revenue can be obtained when there is an optimal solution between the manufacturer's price and the retailer's unit revenue, because the manufacturer tries to expand its profit by lying about the difficulty of old mobile phones recycling efforts $\lambda>\phi\lambda$, it can be inferred from this $s_2>s_1$, $s_4>s_3$ and $s_3>s_1$,

Classical simplification,

$$\frac{s_2-a+C_m}{s_3-a+C_m}=\frac{b\beta\delta^2(C_m-C_n)^2+\lambda\beta(\theta^2-4b)+2b\lambda\gamma^2}{\beta(b\delta^2(C_m-C_n)^2+\theta^2\Phi\lambda-4b\Phi\lambda)}$$

On account of $2b\lambda\gamma^2>0$,and $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)}<\Phi$,when $\Phi<1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $\frac{s_2-a+C_m}{s_3-a+C_m}>1$, $s_2>s_3$ can be derived. It can be proved that $s_4>s_2>s_3>s_1$.

In a similar way, when $1>\Phi\ge 1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $s_3>s_2$ can be derived, it can be proved that $s_4>s_3>s_2>s_1$.

Secondly, prove the optimal wholesale price, when $\theta^2\le 2b$, the proof process of the manufacturer's wholesale price is similar to s, so it is omitted.

When $\theta^2<2b$, based on the above assumptions, $C_m-a<0$, therefore, $\lambda(\theta^2-2b)(C_m-a)>0$, $w_1>w_2$, $w_3>w_4$ can be derived, and $w_3>w_1$.

Because $-2b\phi\lambda\gamma^2>0$, so can get $w_2>w_4$.

It can be proved that when $\theta^2\le 2b$ and $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)}<\Phi<1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $w_3>w_1>w_4>w_2$. The same can be obtained when $\theta^2\le 2b$ and $1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}\le\Phi<1$, $w_3>w_4>w_1>w_2$.

Proposition 4.1 shows that when manufacturers assume corporate social responsibility, the optimal unit revenue of retailers is always higher than the optimal unit revenue when they do not assume it; when manufacturers lie, the optimal unit revenue of retailers is always higher than the optimal unit revenue when they do not assume it. There is a threshold such that the optimal unit product revenue of retailers when only lying behavior occurs is greater than the optimal unit product revenue when only assuming corporate social responsibility. In fact, whether or not to consider manufacturers assuming corporate social responsibility, when manufacturers lie, retailers will also raise their selling prices based on the increased manufacturing cost they know, so the optimal unit product revenue of retailers is always greater than the optimal unit product revenue without lying behavior. Therefore, retailers are always inclined to manufacturers to engage in lying behavior and assume corporate social responsibility.

Furthermore, for the optimal wholesale price of manufacturers, when the coefficient of green marketing input cost of retailers is small, the relationship between the optimal wholesale price of manufacturers and the optimal unit revenue of retailers is similar. When the cost coefficient of green marketing investment by retailers is relatively large, there is a threshold at which the optimal wholesale price is lower than the wholesale price when the manufacturer lies and assumes social responsibility. Therefore, from the perspective of optimal unit product revenue and optimal wholesale price, on the one hand, retailers should achieve consistency in their decision-making by reducing their own green marketing investment costs; on the other hand, retailers can share the manufacturer's costs through cooperation or external incentives, which will make the manufacturer more inclined to lie and actively assume corporate social responsibility.

Furthermore, for the optimal wholesale price of manufacturers, when the coefficient of green marketing input cost of retailers is small, the relationship between the optimal wholesale price of manufacturers and the optimal unit revenue of retailers is similar. When the cost coefficient of green marketing investment by retailers is relatively large, there is a threshold at which the optimal wholesale price is lower than the wholesale price when the manufacturer lies and assumes social responsibility. Therefore, from the perspective of optimal unit product revenue and optimal wholesale price, on the one hand, retailers should achieve consistency in their decision-making by reducing their own green marketing investment costs; on the other hand, retailers can share the manufacturer's costs through cooperation or external incentives, which will make the manufacturer more inclined to lie and actively assume corporate social responsibility.

Proposition 4.2. 1) In the four models, the retailer's optimal green marketing input is satisfied

(i). When $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)}<\Phi<1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $v_4>v_2>v_3>v_1$

(ii). When $1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}\le\Phi<1$, $v_4>v_3>v_2>v_1$

2) Manufacturer's optimal old mobile phone recovery rate is satisfied:

(i). When $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)}<\Phi<1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $t_4>t_2>t_3>t_1$

(ii). When $1+\frac{2b\gamma^2(\theta^2-4b)}{\beta}\le\Phi<1$, $t_4>t_3>t_2>t_1$

3) The optimal level of social responsibility is satisfied

When $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)}<\Phi<1$, $e_3>e_4$

Proof. First, it is proved that the optimal green marketing input can be obtained when there is an optimal solution between the manufacturer's price and the retailer's price $\lambda>\phi\lambda$, $v_2>v_1$, $v_4>v_3$ and $v_3>v_1$ can be derived.

Classical simplification,

$$\frac{v_2 - a + C_m}{v_3 - a + C_m} = \frac{b\beta\delta^2(C_m - C_n)^2 + \beta\lambda(\theta^2 - 4b) + 2b\lambda\gamma^2}{\beta(b\delta^2(C_m - C_n)^2 + \theta^2\Phi\lambda - 4b\Phi\lambda)}$$

On account of $2b\lambda\gamma^2>0$, and $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)} < \Phi$,when $\Phi < 1 + \frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $v_2>v_3$ can be derived. It can be proved that $v_4>v_2>v_3>v_1$.

The same can be obtained when $1 + \frac{2b\gamma^2(\theta^2-4b)}{\beta} \le \Phi < 1$, $v_4>v_3>v_2>v_1$.

Secondly, the optimal recovery rate of old mobile phones is proved due to $\lambda>\phi\lambda$, $C_m-a<0$, $C_m-C_n<0$, $t_2>t_1$ and $t_4>t_3$ can be derived. And because $2b\lambda\gamma^2>0$, therefore $t_3>t_1$, the rest of the proof process is similar v, it is omitted.

Finally, it is proved that the optimal level of social responsibility is due to $\lambda>\phi\lambda$, and therefore $C_m-a<0$, when $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)} < \Phi < 1$, $e_3<e_4$.

Proposition 4.2 demonstrates that the optimal level of green marketing investment by retailers always satisfies a condition where it is higher when lying behavior occurs than when it does not occur. The proactive assumption of corporate social responsibility by manufacturers will prompt retailers to increase their optimal level of green marketing investment. There exists a threshold such that the optimal level of green marketing investment for retailers when only lying behavior occurs is greater than the optimal level when only assuming corporate social responsibility.

The relationship between the recycling rate of manufacturers' old mobile phones is similar. Regarding the level of corporate social responsibility in a green supply chain, there exists a threshold at which lying behavior by manufacturers leads to an increase in the supply chain's level of corporate social responsibility.

This indicates that lying behavior always brings positive effects on the level of corporate social responsibility in a green supply chain and has a positive impact on both the optimal level of green marketing investment for retailers and the recycling rate for manufacturers' old mobile phones. At the same time, the proactive assumption of corporate social responsibility by manufacturers also brings about positive effects for a green supply chain. Therefore, members within the supply chain have sufficient internal motivation to engage in lying behavior and assume corporate social responsibility. However, from both consumer and long-term development perspectives within a green supply chain, this approach is clearly unreasonable. At this point, external intervention is needed to promote more standardized development within the supply chain.

Proposition 4.3.

1) In the four models, the manufacturer's optimal profit is satisfied

(i). When $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)} < \Phi < 1 + \frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $\pi_m^4>\pi_m^2>\pi_m^3>\pi_m^1$.

(ii). When $1 + \frac{2b\gamma^2(\theta^2-4b)}{\beta} \le \Phi < 1$, $\pi_m^4>\pi_m^3>\pi_m^2>\pi_m^1$

2) Retailer optimal profit satisfaction is satisfied

(i). When $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)} < \Phi < 1 + \frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $\pi_r^4>\pi_r^2>\pi_r^3>\pi_r^1$

(ii). When $1 + \frac{2b\gamma^2(\theta^2-4b)}{\beta} \le \Phi < 1$, $\pi_r^4>\pi_r^3>\pi_r^2>\pi_r^1$

Proof. First, the manufacturer's optimal profit is proved, which can be obtained by simplification

$$\pi_m^3 = \lambda\beta b(C_m - a)^2 \left\{\frac{\theta^2\lambda}{4\beta[b\delta^2(C_m-C_n)^2+\lambda\gamma^2(\theta^2-4b)+2b\lambda\gamma^2]^2} - \frac{1}{4[b\beta\delta^2(C_m-C_n)^2+\beta\lambda\gamma^2(\theta^2-4b)+2b\lambda\gamma^2]}\right\}$$

Due to $2b\lambda\gamma^2>0$ and $\lambda>\phi\lambda$, therefore when $-\frac{\beta\delta^2(C_m-C_n)^2}{2\lambda(\gamma^2-2\beta)} < \Phi < 1 + \frac{2b\gamma^2(\theta^2-4b)}{\beta}$, $\pi_m^4>\pi_m^2>\pi_m^3>\pi_m^1$.

The same can be obtained when $1 + \frac{2b\gamma^2(\theta^2-4b)}{\beta} \le \Phi < 1$, $\pi_m^4>\pi_m^3>\pi_m^2>\pi_m^1$.

The retailer profit proof process is similar to the proof process above, so omitted.

Proposition 4.3 shows that regardless of whether the manufacturer bears the cost of CSR, the optimal profit of the manufacturer and retailer will always increase with the occurrence of the manufacturer's misreporting behavior. At the same time, after they bear the cost of corporate social responsibility, the optimal profit of the two will increase. There is a threshold where, when only misreporting occurs, the optimal profit of the manufacturer and the retailer is greater than the optimal profit of those who only undertake corporate social responsibility.

This indicates that manufacturers' misreporting will have a positive impact on the profits of manufacturers and retailers. Therefore, proper misreporting is conducive to improving the profits of the supply chain, but excessive misreporting will also bring disadvantages because manufacturers will increase the recycling efforts of old mobile phones and increase the recovery rate of old mobile phones while underreporting the difficulty of their recycling efforts. At the same time, the level of green marketing investment of retailers will increase, so retailers can ease the cost pressure by raising the retail price. As a result, retailers make more money, but consumers pay higher prices for their mobile phones, and demand for them falls. Therefore, manufacturers' false reporting is not conducive to the sustainable development of the supply chain.

Although this will bring short-term growth in supply chain profits, the cost of this profit growth will be borne by consumers. This will lead to a lack of consumer trust in supply chain members in the long run, and once the misreporting behavior is disclosed, it will greatly affect the credibility of the supply chain. Therefore, it is necessary to adopt relevant external factors to adjust the supply chain.

Table. 2. Green supply chain decision parameters and related settings.

Argument	δ	λ	k	a	θ	b	C_m	C_n	γ
Statistics	0.4	12	8	50	0.5	6	4	2	0.4

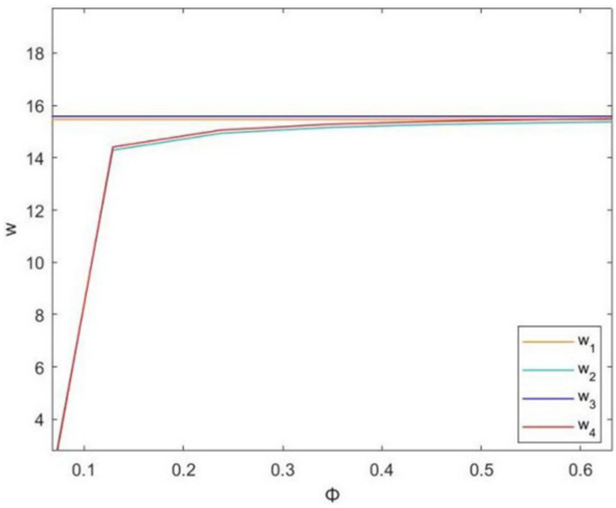


Fig. 2. Impact of misreporting on *w*.

Numerical Analysis

In this section, comparative analysis and numerical research are used to explore the influence of manufacturers' misreporting behavior on supply chain members' decision-making and the influence of CSR and its different commitment ratios on supply chain members' decision-making. In proposition 4.1, when $\theta^2>2b$, because the marketing factor of green marketing input is too small, the influence of manufacturers' misreporting behavior is not significant. Therefore, in this part, in order to more intuitively show the influence of manufacturers' misreporting behavior on the decision-making of supply chain members, the situation $\theta^2>2b$ at that time is selected for numerical analysis. With reference to relevant literature and combined with the previous assumptions in this paper, the setting of relevant parameters is shown in Table 2.

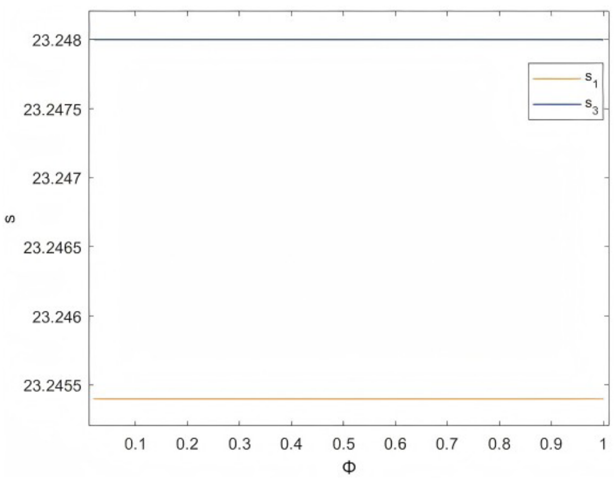
Influence of Misrepresentation on the Decision-making of Supply Chain Members

In order to more intuitively compare the impact of misrepresentation on the price, green behavior, social responsibility level, and profit of members in the supply chain, this section further verifies the propositions mentioned above through simulation analysis. In order to conform to the assumptions mentioned above, the misrepresentation factor should be satisfied $0.02<\phi<1$.

1) The influence of misreporting on *w* and *s*

The effects of misreporting on the prices of members in the supply chain under different behavioral decisions are shown in Fig. 2 to Fig. 3, where Fig. 2 to Fig. 3 respectively show the effects of misreporting on wholesale prices and retailers' marginal revenue. Since the retailer's marginal revenue does not differ much from the standard model with CSR alone, the two models are presented separately for a clearer view.

As can be seen from Fig. 2, the manufacturer's misreporting behavior will reduce its wholesale price, while taking corporate social responsibility will increase its wholesale price. In the case of misrepresentation, the manufacturer's optimal wholesale price increases with the degree of misrepresentation, indicating a positive correlation between the two. As can be seen from Fig. 3, the manufacturer's misreporting and CSR behavior will lead to the improvement of the retailer's unit benefit, and



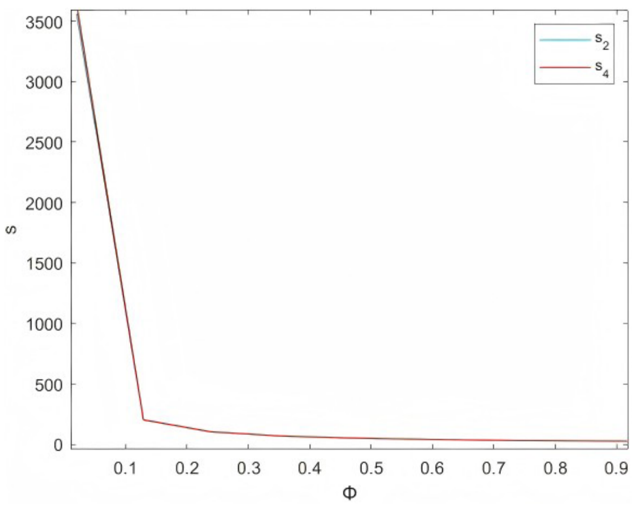


Fig. 3. Impact of misreporting on *s*

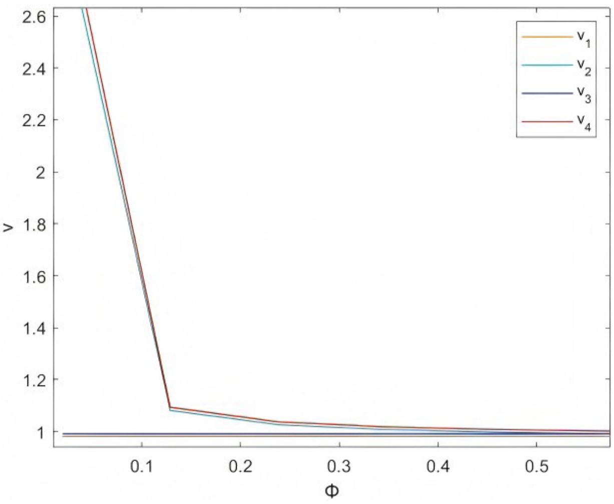


Fig. 4. Impact of misreporting on *v*.

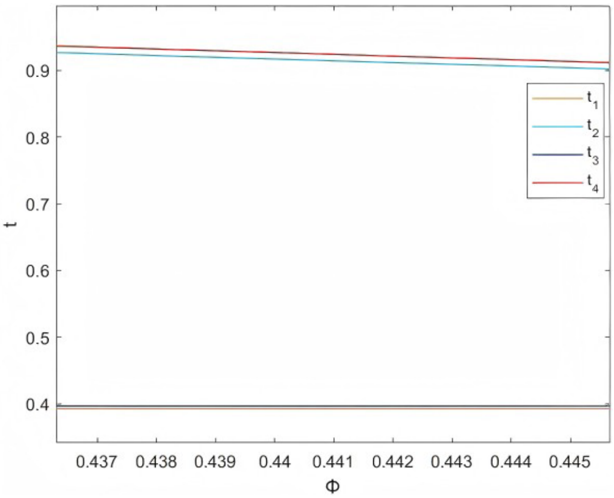


Fig. 5. Impact of misreporting on *t*.

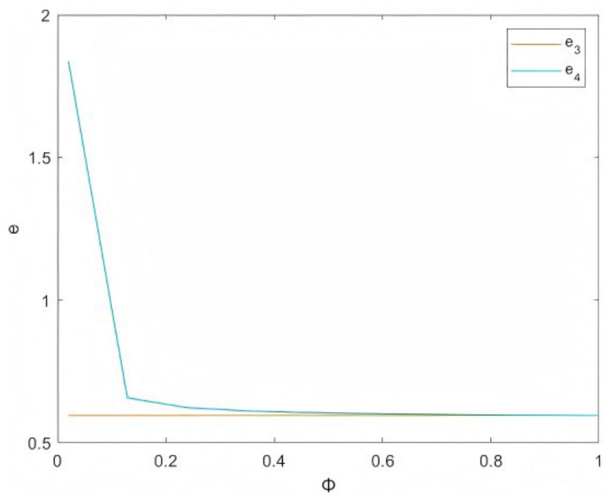


Fig. 6. Impact of misreporting on *e*.

when the misreporting behavior occurs, the retailer's optimal unit benefit will decrease with the increase of the manufacturer's degree of misreporting, indicating that there is a negative correlation.

According to Fig. 2, CSR can always improve the optimal wholesale price and unit product revenue of supply chain members, so supply chain members usually actively undertake CSR. For manufacturers, however, the optimal wholesale price decreases once misreporting occurs due to underreporting of recycling efforts. Despite the decline in wholesale prices, manufacturers face certain risks regarding mobile phone quality due to the failure to meet old mobile phone recycling standards. This situation is not conducive to the healthy development of the supply chain. On the contrary, for retailers, the act of misreporting leads to a decrease in the wholesale price of purchased mobile phones, thereby increasing their unit revenue. While retailers may benefit from lower wholesale prices in the short term, in the long term, misreporting can have a negative impact on sustainability and partnerships across the supply chain. Therefore, although CSR commitment positively impacts the optimal wholesale price and unit revenue of supply chain members, misreporting may negatively affect the stability and development of the supply chain. Manufacturers need to be aware that misrepresentation may lead to mobile phone quality risks, and take measures to avoid misrepresentation to ensure the healthy development of the supply chain. Retailers need to recognize that short-term gains are not sustainable and work in good faith with their supply chain partners to achieve a win-win situation.

2) The influence of misreporting on *v, t* and *e*

The influence of misreporting behavior under different behavioral decisions on the level of green marketing investment of products, the recovery rate of old mobile phones, and the level of corporate social responsibility in the supply chain is shown in Fig. 4 to Fig. 6.

From Fig. 4 and Fig. 5, it can be concluded that the manufacturer's misreporting behavior and CSR behavior will both improve the retailer's green marketing investment level and the manufacturer's old mobile phone recovery rate and in the case of misreporting behavior, the retailer's optimal green marketing investment level and the manufacturer's old mobile phone recovery rate will decrease as the manufacturer's degree of misreporting increases. This indicates a negative correlation. In addition, it can be seen from Fig. 6 that manufacturers' misreporting will lead to an increase in the level of CSR in the supply chain, and will decrease with the increase of the degree of misreporting.

In summary, moderate misreporting by manufacturers may have a positive impact on the green supply chain in the short term. However, it needs to be recognized that misreporting can have a negative impact on the level of green marketing investment of retailers and the recycling rate of old mobile phones of manufacturers, as well as the level of corporate

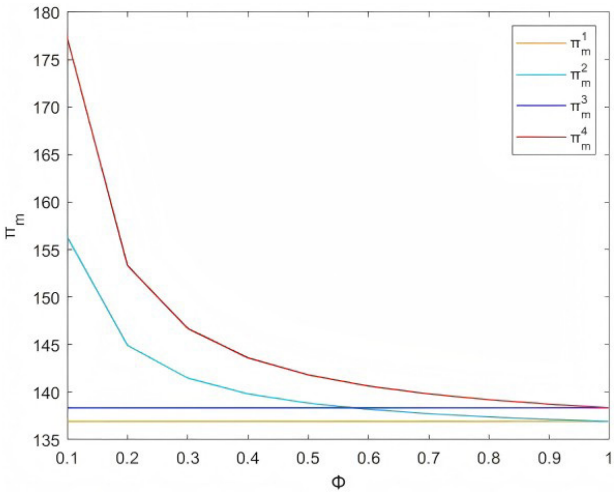


Fig. 7. Impact of misreporting on π_m.

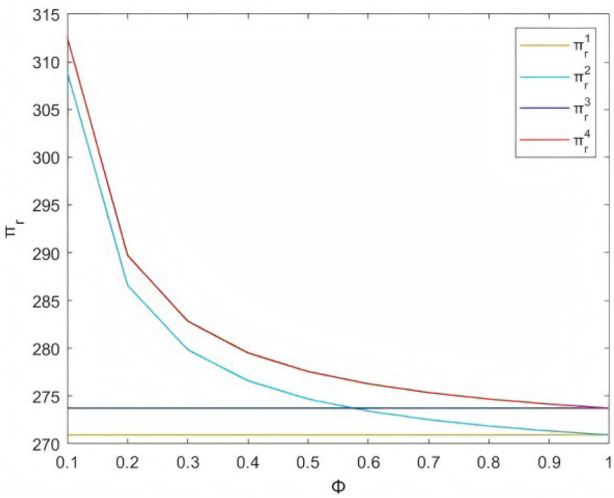


Fig. 8. Impact of misreporting on π_r.

social responsibility in the supply chain. Therefore, manufacturers should carefully balance the relationship between short-term benefits and long-term sustainable development, and avoid the negative impact of excessive misreporting.

(3) The influence of misreporting on π_m and π_r

The influence of misreporting behavior on the optimal profit of manufacturers and retailers under different behavioral decisions is shown in Fig. 7 to Fig. 8.

As can be seen from Fig. 7 and Fig. 8, the optimal profit of both the manufacturer and the retailer will increase when the manufacturer's misreporting behavior and CSR undertaking behavior occur, and the optimal profit of both will decrease with the increase of the manufacturer's misreporting degree. It is not difficult to see from the figure that when the degree of misrepresentation is greater than a certain threshold, the optimal profit sum of manufacturers and retailers π_m^2 and π_r^2 will be lower than π_m^3 and π_r^3 respectively.

Fig. 7 and Fig. 8 show that in a retailer-dominated green supply chain, moderate misreporting by manufacturers can have a positive impact on all links of the supply chain and promote all members of the supply chain to reach a consensus behavioral decision in the short term. However, it can be observed from the above chart that profit growth is achieved by increasing the selling price, which means that the supply chain passes the cost pressure to the consumers, which will inevitably have a negative impact on the supply chain in the long run, and is not conducive to the long-term health and sustainable development of the supply chain. Therefore, it is necessary to make appropriate adjustments to the supply chain, which requires the restraint and supervision of external forces. Such constraints can include government regulation, the establishment of industry standards, and the participation of consumer organizations to ensure that supply chains operate in accordance with ethical and legal requirements and do not harm consumer interests or disrupt market order through improper means. Through the restriction and adjustment of external forces, members of the supply chain can be urged to pay more attention to long-term development and sustainability, avoiding short-sighted behavior and improper competitive practices. Only under reasonable supervision and constraints can the green supply chain achieve sound development and bring more benefits and value to society, the environment, and enterprises.

Impact of the Recyclable Utilization Rate of Manufacturers' Old Mobile Phones on the Supply Chain

In order to more intuitively explain the impact of the recyclable utilization rate of manufacturers' old mobile phones on the supply chain, this part conducts a simulation analysis on the basis of the previous section. In order to meet the research assumptions mentioned above, this section shall be satisfied $1>\delta>0$. By referring to the parameter Settings in the relevant literature, the numerical simulation analysis was carried out to supplement the parameters $\phi=0.5$.

1) The influence of recyclable utilization rate of old mobile phones on *w, s, v* and *e*

The influence of the recyclable utilization rate of recycled old mobile phones on the optimal decision in the supply chain under different behavioral decisions is shown in Fig. 9 to Fig. 13, in which Fig. 9 to Fig. 13 respectively show the influence of misreporting behavior on wholesale price, retailers' marginal income, product green marketing investment level, old mobile phones recovery rate, and corporate social responsibility level in the supply chain.

From Fig. 9 to Fig. 13, it can be seen that the post-recycling reutilization rate of old mobile phones has a

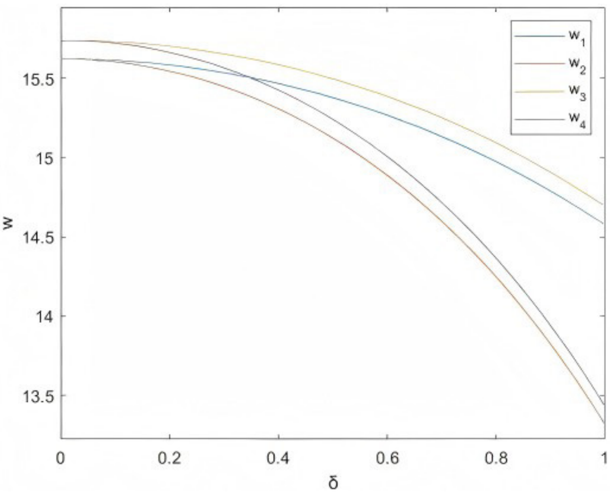


Fig. 9. Impact of reusable rate on *w*.

negative correlation with the manufacturer's wholesale price, and the post-recycling reutilization rate of old mobile phones has a positive impact on the retailer's unit revenue, marketing investment level, the recycling rate of old mobile phones, and the level of corporate social responsibility.

Although the post-recycling reusability rate of old mobile phones may have a certain negative impact on the manufacturer's wholesale price, this impact is not significant from the perspective of the entire supply chain and is only evident when the reusability rate of old mobile phones is high. Therefore, increasing the reusability of recycled old mobile phones has a positive effect on the green supply chain, and all members of the supply chain should take measures to actively improve this indicator. On the one hand, manufacturers can improve the reusability of old mobile phones by adopting advanced recycling technologies and other means; on the other hand, supply chain members should

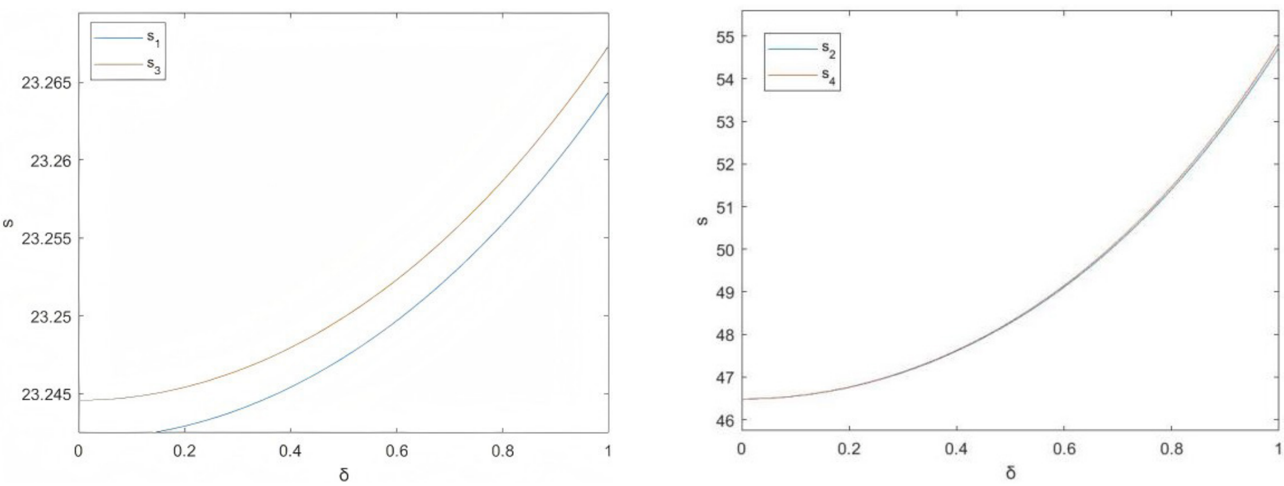


Fig. 10. Impact of reusable rate on *s*.

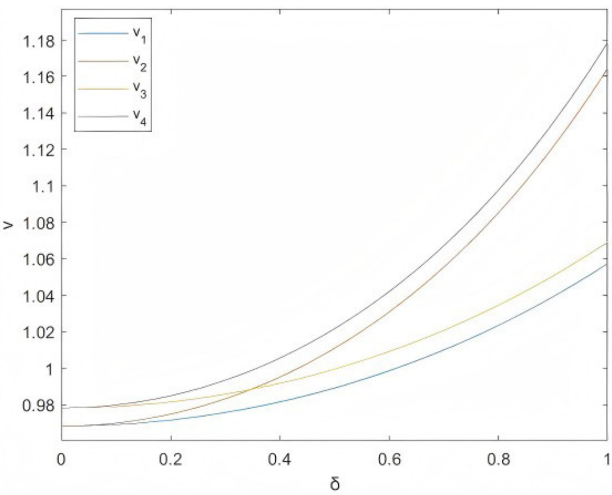


Fig. 11. Impact of reusable rate on *v*.

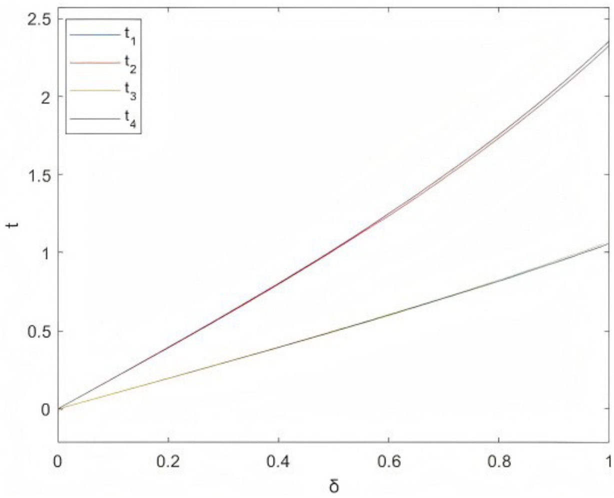


Fig. 12. Impact of reusable rate on *t*.

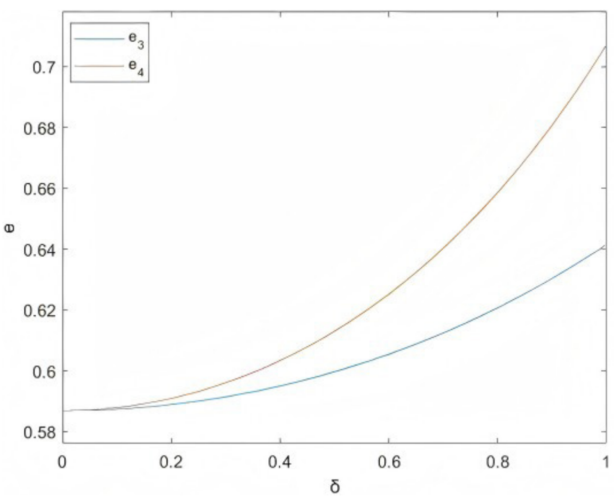


Fig. 13. Impact of reusable rate on *e*.

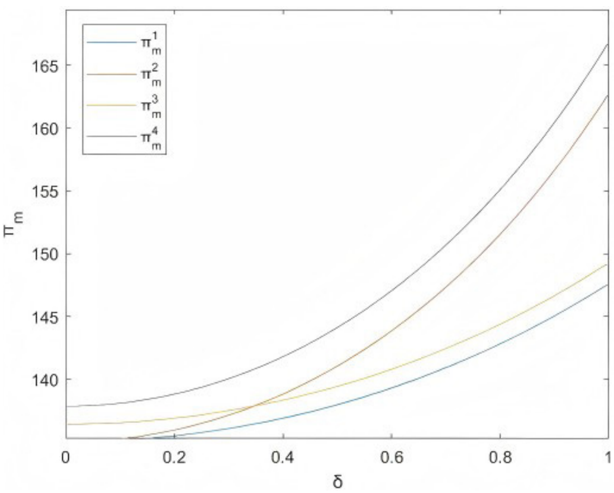


Fig. 14. Impact of reusable rate on π_m

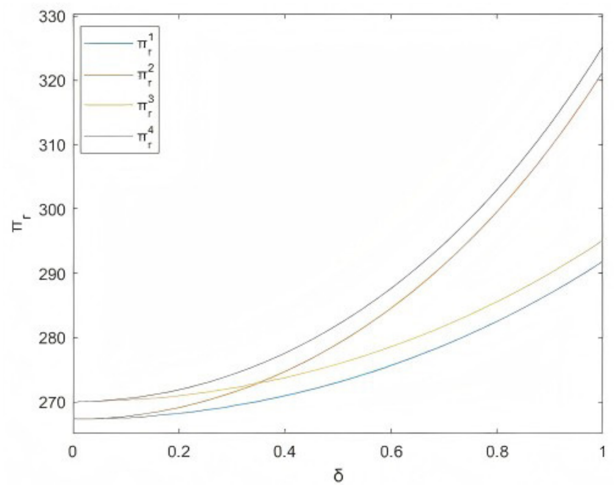


Fig. 15. Impact of reusable rate on π_r.

actively cooperate and adopt other ways to improve the reusability of old mobile phones after recycling. Improving the recycling rate of old mobile phones not only reduces the negative impact of waste on the environment but also effectively saves resources and reduces the over-exploitation of natural resources. In addition, increasing the reusability rate also helps to reduce the consumption of new resources, which in turn reduces production costs and improves the overall efficiency and competitiveness of the supply chain. Therefore, manufacturers and other members of the supply chain should be aware of the importance of increasing the reusability rate of old mobile phones after recycling and take active measures to achieve this goal. By working together, a green supply chain can better realize sustainable development and bring more benefits to society, the environment, and the economy.

2) The influence of recyclable utilization rate of old mobile phones on π_m and π_r

The influence of the recyclable utilization rate of recycled old mobile phones on the optimal decision of supply chain members under different behavioral decisions is shown in Fig. 14 to Fig. 15, in which Fig. 14 to Fig. 15 respectively represent the influence of recyclable utilization rate on the optimal profit of manufacturers and retailers.

From the perspective of the optimal profit of supply chain members, the conclusion of proposition 4.3 is further verified. Improving the recyclability of old mobile phones after recycling has a positive impact on the green supply chain, especially in the case of false reporting. At the same time, improving the reuse rate of old mobile phones after recycling helps to enhance the image of social responsibility of enterprises. For those consumers who pay more attention to environmental protection and sustainable development, the higher the recycling rate of old mobile phones, the more attractive it is, which helps to enhance the brand image and market competitiveness of enterprises. Therefore, the supply chain still needs to strive to improve the reuse rate of its old mobile phones after recycling.

Therefore, the green supply chain should constantly strive to improve the recycling and reuse rate of old mobile phones, and achieve this goal through policy support, technological innovation, and win-win cooperation. Only in this way can we better meet the needs of consumers, enhance the corporate image, improve market competitiveness, and achieve the goal of sustainable development.

Conclusion and Discussion

With the growing environmental awareness among consumers and the increasingly evident preference for mobile phones, green supply chain management has gradually become an indispensable component of corporate sustainability strategies. Simultaneously, corporate social responsibility has emerged as a key factor in shaping the decisions of consumers and customers, profoundly impacting market performance. Consequently, many companies have begun to introduce the recycling and remanufacturing of old mobile phones into their new product production processes, aiming to enhance their supply chain's green level to achieve economic benefits and fulfill environmental responsibilities. Within this framework, companies must focus not only on increasing their profits and market share but also on their impact on society and the environment. By implementing sustainable supply chain management practices, companies can attract a broader consumer and investor base, achieving long-term competitive advantages. Therefore, this paper addresses the issues of information misreporting and undertaking CSR in the green supply chain for recycling old mobile phones, using the Stackelberg game method to explore their impacts on supply chain decisions and profits. The specific conclusions are as follows:

1) In terms of information misreporting behavior, our findings are different from previous studies. Joshi et al. [12] believe that misreporting product cost information can increase the manufacturer's profit. However, our research found that although information misreporting behavior in the supply chain can lead to increased profits for manufacturers and retailers, their profits decrease as the misreporting factor increases. Specifically, aside from slight differences in the manufacturer's wholesale price, other factors such as the retailer's marginal revenue, the level of green marketing investment, the recycling rate of old mobile phones, and the level of CSR in the supply chain all increase due to misreporting and increase with the misreporting factor. It is evident that appropriate misreporting can increase supply chain profits, but excessive profits from misreporting behaviors come at the cost of consumers paying higher prices and the supply chain bearing greater reputation risks. Therefore, supply chain members must recognize that although such behaviors may bring short-term benefits, they will negatively impact the company's sustainable development, consumer trust, and brand reputation in the long run.

2) In terms of the recyclability of old mobile phones, its improvement has a positive impact on the decision variables and profits of supply chain members. Notably, this effect is not significant when misreporting behaviors do not occur, but is more significant when they do. These findings align with real-world development patterns; in the market, enhancing the recyclability of old mobile phones not only helps establish a good corporate image and build an excellent industry reputation but also enhances the profits of both the individual company and the supply chain.

3) In terms of corporate social responsibility, Peng et al. [36] find that actively undertaking CSR is beneficial for enterprises, consumers, and the environment. This study also supports this point and additionally discovers that corporate social responsibility can mitigate the impact of misreporting and increase the profits of supply chain members. Specifically, when manufacturers undertake corporate social responsibility, the optimal profits of both manufacturers and retailers increase, prompting retailers to raise their optimal level of green marketing investment. Simultaneously, the recycling rate of old mobile phones also increases. When the cost coefficient of retailers' green marketing investment is relatively high, the manufacturer's optimal wholesale price is always higher when they undertake corporate social responsibility compared to when they do not. Introducing a level of CSR in the supply chain significantly enhances the profits of the supply chain and has a positive effect on various factors for supply chain members.

The behavior of information misreporting erodes the fundamental ethics and credibility of enterprises. Once the issue of enterprise integrity is exposed, the resulting negative effects are often long-term and difficult to reverse. This can lead to a loss of consumer trust, a decline in market share, and even legal lawsuits and regulatory penalties. Enterprises should actively cooperate with their supply chain partners to achieve a win-win situation. Manufacturers should carefully balance the relationship between short-term benefits and long-term sustainable development and avoid the negative impact of excessive misreporting. In addition, supply chain members need to strive to explore ways to increase the manufacturer's willingness to actively undertake corporate social responsibility costs and enhance the reusability of old mobile phones after recycling. This requires not only cooperation and coordination among internal members of the supply chain but also the support of external forces to achieve improvement. Given the potential adverse consequences of information misreporting in the green supply chain, companies should take measures to enhance transparency and information sharing within the supply chain. This includes implementing advanced information technologies, such as blockchain, to ensure the accuracy and traceability of data at each stage of the supply chain. Establishing effective incentives and penalties can also encourage all parties within the supply chain to report information honestly and avoid misreporting behaviors.

Although this paper makes certain contributions to the decision-making of green supply chain members considering information misreporting and CSR behaviors, it also has its limitations, and the scope and depth of further research remain to be expanded. Firstly, the current model is limited to analyzing the dynamic relationship between a single manufacturer and a single retailer, whereas the actual supply chain environment is often more complex, involving competition and cooperation among multiple manufacturers and retailers. Additionally, this study mainly discusses the Stackelberg game scenario with the retailer as the leader, not fully covering the possible variety of leader-follower relationships and the Nash equilibriums that may be achieved. These issues are highly suitable for further research.

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Conflicts of Interest

The authors declare no conflict of interest.

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