



Research article

Supply chain decision making under government subsidies: Considering CSR and consumer fairness concerns

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Abstract: In this paper, we proposed two three-stage game theoretic models consisting of a government-manufacturer-retailer: Government subsidizes to the retailer (RS-strategy) and government subsidizes to the manufacturer (MS-strategy). We found that consumers' fairness concerns always perform a detrimental influence on supply chain members' CSR efforts and overall social welfare. Government subsidies can improve the adverse effects of consumer fairness concerns, supply chain members' performance and social welfare effects. In addition, we conducted a comparative study between no-government subsidies and two subsidy models in the numerical analysis section. Both subsidy strategies achieved Pareto improvement for supply chain members (manufacturer and retailer) compared with the no-subsidy decentralized scenario. The RS-strategy had higher expected returns but also higher risks regarding consumers' fairness concerns. The MS-strategy could optimize the risk of consumers' fairness concerns and address lower subsidy costs. Managerial implications provide insights into the decision-making of supply chain members and the choice of government strategies.

Keywords: government's subsidies; consumers' fairness concerns; retailer efforts; social welfare

Mathematics Subject Classification: 90B50

1. Introduction

Since the outbreak of COVID-19, there has been a dramatic surge in global cases, resulting in the closure of many critical facilities and a substantial impact on economic market activities. This disruption extends beyond the manufacturing and logistics sectors, affecting global supply chain systems worldwide [1,2]. Supply chain management in the post-pandemic era has become a critical issue worldwide: For some supply chains, supply chain demands in industries such as healthcare devices, food, etc. have surged due to the increase in cases, labor shortages due to the embargo, and the rush and hoarding behavior of citizens [3,4].

Furthermore, for other supply chains, demand and supply have plummeted, even leading to production shutdowns at risk of bankruptcy, such as in the automotive industry [5]. Government interventions, particularly through financial subsidies and economic support, have garnered substantial academic interest, as they play a crucial role in mitigating the disease's spread, fostering economic resilience, and reinforcing social cohesion in the face of the pandemic [6]. For example, during the 2022 Shanghai pandemic, local governments provided subsidy supporting to eligible enterprises, increased tax and fee reduction policies, increased financial supporting, and supported the recovery of difficult industries [7]. A total of 35% of customers believe that enterprises' social responsibility will have a huge influence on their purchases, particularly among millennials at 42%. Moreover, 70% of millennials also believe it is more inclined for them to purchase from companies who take care of social concerns. ERKE (a Chinese shoe brand) has achieved significant economic benefits for its socially responsible behaviors. From July 23 to July 25, 2021, the TikTok platform certified a total of four ERKE official accounts. In three days, these four live broadcast accounts sold a total of more than 190 million yuan of goods. From a larger perspective, enterprises' social responsibility may assist corporations to build their relationships with their customers, enhance corporate social image, and obtain positive benefits. Such corporations are embracing social responsibility around COVID-19: Some brands such as Gap, Brooks Brothers, and Uniqlo use their infrastructure to manufacture masks and other needed supplies to support the medical community, whereas many other multinational businesses and corporations such as Moncler, LVMH, and Prada have made considerable measures to assist in reducing the pressure of healthcare systems by giving to groups such as the Red Cross and institutions throughout China and East Europe [8].

Under exceptional circumstances, providing government subsidies to corporations that undertake corresponding social responsibilities appears to be an effective approach to addressing current social issues. However, consumers may have fairness concerns regarding the services offered by enterprises during special periods, and the relative profits of corporations can negatively impact consumers' sense of fairness [9]. However, research has two notable gaps: First, most studies on CSR supply chain subsidies treat government intervention as an exogenous factor or focus on a single subsidy target, failing to endogenize government subsidy decisions and compare the applicability of subsidizing upstream vs. downstream firms. Second, although researchers have explored the influence of fairness concerns on government subsidy decisions, they have predominantly focused on firms' fairness concerns, with limited attention given to consumers' fairness concerns. During public emergencies, price hikes and supply shortages amplify consumers' sensitivity to perceived unfairness of corporate profits, though there has been relatively little discussion on the interaction between consumers' fairness concerns, CSR efforts, and government subsidy strategies. In particular, it remains unclear how consumer fairness perceptions alter the effectiveness of different subsidy

schemes, and how governments should design subsidy strategies to mitigate such negative effects while enhancing social welfare. To address these gaps, we propose the following research questions:

(1) How do the members of the supply chain decide the pricing of an enterprise when considering its CSR?

(2) How is the CSR effort affected by government subsidies and consumer equity? Moreover, how do these factors affect social welfare and supply chains?

(3) Under the influence of consumer equity issues, how does the government design its subsidy strategy to strengthen the operation of the supply chain members?

To answer these questions, we develop two three-stage Stackelberg game frameworks with a government, a manufacturer and a retailer, tailored to the pandemic context. In this scenario, the government acts as the top-level regulator to maximize social welfare, the manufacturer and retailer make pricing and CSR effort decisions sequentially, and consumers' fairness concerns regarding corporate unit profits shape market demand. This setup captures core features of CSR supply chains: Government-led economic relief, firms' CSR practices to boost public reputation, and consumers' heightened fairness sensitivity under supply stress.

The strategies are as follows: Government subsidizes to the retailer (RS-strategy) and government subsidizes to the manufacturer (MS-strategy). Consumer fairness concerns will affect the extent of corporate social responsibility efforts and market pricing. They will also harm the profits of supply chains without government subsidies. These two types of government subsidies can respectively increase supply chain members' profits (RS-strategy) and stabilize the operating conditions of supply chain members (MS-strategy). Moreover, the decisions of supply chain members and consumer fairness concerns will, in turn, affect government subsidies. We analyze and compare the two subsidy models to address the conditions for whether the government subsidizes and the subsidy strategy choices under different situations. Our research reveals that both subsidy strategies can improve social welfare and the level of supply chain participants' CSR efforts and ameliorate the negative impacts of consumer fairness concerns. In addition, the government can flexibly choose two strategies based on its budget cost, efficiency output, and subsidy benefit stability.

The sections of this paper are presented as follows: In Section 2, we analyze the related literature and make comparisons to illustrate different perspectives of our research. In Section 3, we demonstrate the fundamental model, accompanying assumptions, symbols and definitions. In Section 4, we explain the optimal solution of supply chain members and the selection of government strategies under the MS-strategy and RS-strategy, respectively. Numerical analysis explains and proves the relevant conclusions and discusses the impact of consumers' fairness concerns and the regulating effect of government subsidies in Section 5. In Section 6, we conclude the work and describe future research directions. The Appendix shows all illustrations and proofs.

2. Literature review

We synthesize the literature and research, covering aspects such as the government's subsidy strategy, retailers' socially responsible actions, and consumers' fairness concerns in marketing and operations management.

2.1. Government's subsidy strategy

The government may alleviate the financial damage by direct salary subsidies, tax benefits, and bailouts for the air transportation business. Still, the government needs to macro-regulate the objective and scale of subsidies to safeguard the overall society's well-being [10,11]. Pan et al. [12] studied that the government's immediate agricultural policies, including financial aid, subsidies, agricultural technical guidance, and field management, alleviated economic shocks via targeted policy interventions. Selerio et al. [13] adopted the inoperability input-Output Model to capture the interdependencies among economic sectors. Zhang et al. [14] researched that government subsidies and loan incentives for corporate social responsibility lifted corporate value in the post-pandemic period and verified that collaborations between the government and socially responsible enterprises revitalized the economy. Khosroshahi et al. [15] analyzed how government subsidy policies affected the production and sales of eco-friendly green products in green product supply chains.

In recent years, scholars have examined government subsidies within supply chains using various methods and models, emphasizing sustainable management, green networks, and consumer preferences like green and trust considerations, as well as corporate social responsibility. In this paper, we integrate government subsidies into research joint ventures (RJVs) with production and innovation subsidies for manufacturers and retailers in the context of sustainable innovation. Chen et al. [16] investigated how subsidies affected unit production costs, innovation costs, RJV establishment and enterprises' sustainable innovation performance. Liu et al. [17] found that enterprises' higher corporate social responsibility efforts brought greater profit growth to supply chains and proved that appropriate government subsidies positively correlated with supply chain members' CSR participation. Su et al. [18] explored the optimal operational strategies of green supply chains under differentiated subsidy designs. Wang et al. [19] investigated government subsidies' functions in wind farm operation and expansion and confirmed that subsidies reduced project debt costs and blocked the transmission path of sponsors' credit risks. Wang et al. [20] examined the differentiated effects of three subsidy schemes on the timing of wind-farm investment, optimal capacity decisions, and social welfare under uncertain conditions.

In this paper, we apply a fuzzy optimization approach to study the economic recovery of the renewable energy sector after the COVID-19 pandemic, investigating the impact of three subsidy methods on the industry's exposure to risk and robust profitability aspects. Tsao et al. [21] adopted a fuzzy optimization method to study the economic recovery of the renewable energy industry after the COVID-19 pandemic and examined how three subsidy modes influenced the sector's risk exposure and robust profitability. Xie et al. [22] simulated an emergency medical supply chain composed of CSR-practicing manufacturers and retailers with government subsidies.

2.2. Enterprises' CSR behavior

Louis et al. and Nguyen et al. [23,24] studied that enterprises undertaking corporate social responsibility reshaped their brand images, boosted consumer word-of-mouth, and exerted positive influences on consumer loyalty. Schreiner et al. [25] found that retailers' marketing activities integrated with corporate social responsibility programs outperformed traditional promotion means such as price discounts. Kim et al. and Lee et al. [26,27] summarized corporate social responsibility

practices adopted by retailers during the pandemic. Liu et al. [28] analyzed a CSR-invested closed-loop supply chain and verified that enterprises carrying out CSR activities obtained higher profits.

Dang et al. [29] explored consumers' responses to online merchants' CSR strategies via structural equation model analysis. Chang et al. [30] investigated the impact mechanism of corporate environmental, social, and governance (ESG) within the framework of jump ambiguity aversion under climate tail risk. As is shown in the above study, leading retailers will actively contribute to the fight against the COVID-19 pandemic to expand their social reputation and ensure the demand for their products during the pandemic.

2.3. Consumers' fairness concerns in marketing and operations management

Few researchers have considered consumers' fairness concerns with government's subsidies, and the following researches are relevant studies on consumers' fairness concerns when the government subsidizes in particularly specific circumstances: Chen et al. [16] studied the optimal subsidy factors that maximized social welfare in photovoltaic (PV) supply chains.

Yu et al. [31] investigated product pricing and consumer rebate strategies while taking consumers' fairness concerns into consideration. Tackling in the pandemic context, there are few studies on consumers' fairness concerns when government subsidizes members of the supply chain, and few papers include government decisions at the center of the study.

Yang et al. [32] employed a two-stage model to explore the influence of customers' fairness-concerned problems on retailers' pricing tactics. Wang et al. [33] investigated market demand and stochastic cross-network effects in hybrid labor systems under duopolistic competition. Wang et al. [34] investigated the optimal timing of introducing a distributor into a dynamic cooperative advertising supply chain, as well as the impacts of such distributor entry on the pricing and advertising decisions of all supply chain members.

In this study, we seek to elucidate the intricate, interdependent relationship that exists between the government, supply chain entities, and consumers. Additionally, we aim to determine the optimal government subsidy scheme for enterprises and the strategic decisions that should be made under varying circumstances. Our research diverges from the literature in three primary aspects: First, researchers have predominantly treated government subsidies to enterprises as exogenous variables or examined a single subsidy method, whereas we systematically analyze the applicability conditions, interdependencies, and correlations of various government subsidy methods. In these aspects, our research is similar to [13,31,35]. The research contents of these publications all involve the subsidy methods of MS and RS, and the government subsidy is included in the study as a decision variable. We consider the above issues. However, none of the above researchers consider the impact of consumers' fairness concerns on the supply chain and the government. In addition to considering consumer fairness, we also consider social welfare issues. Moreover, our research is also closely related to [14] and [21], except that they gave tax exemptions and cash subsidies when studying the subsidy content. In addition, we analyze how the government should make decisions under different subsidy budgets to regulate more effectively. Finally, our research is based on literature entailing consumer fairness concerns [16,32]. However, our study differs in three key aspects: (1) We endogenize government subsidy decisions for manufacturer and retailer targets, while considering only retailer subsidies and do not model the government as a strategic decision-maker optimizing social welfare [16]. (2) We incorporate bilateral CSR efforts from manufacturers and retailers,

whereas the researchers focus only on supply chain pricing without CSR effort decisions. (3) We identify the asymmetric effect of fairness concerns under different subsidy targets: Fairness concerns always harm supply chain profits under the RS-strategy but may stabilize profits under the MS-strategy, a finding not documented in prior research. Table 1 summarizes the similarities and differences between this study and the literature.

Table 1. Comparison of the literature with our work.

Reference	Subsidy model	Government decision making	Corporates' efforts behavior	Social welfare	Consumers' fairness concerns	Approach
(J. Y. Chen et al., 2019) [31]	MS, RS	√	√			Game-theory
(Su et al., 2020) [18]	MS, CS		√			Game-theory
(Liu et al., 2019) [17]	RS	√	√	√		Game-theory
(Selerio et al., 2021) [13]	MS, RS	√				Dynamic multi-period IO model
(Zhang et al., 2022) [14]	RC		√			Structural equation model
(Tsao et al., 2021) [21]	MS, RC, RS					Scenario-Robust fuzzy
(Xie et al., 2022) [22]	MS		√	√		Game-theory
(Z. Chen et al., 2019) [16]	RS			√	√	Game-theory
(Yu et al., 2022) [32]	N/A				√	Game-theory
This study	RS, MS	√	√	√	√	Game-theory

MS: subsidy to manufacturer; **RC:** renewable credit; **RS:** subsidy to retailer; **CS:** subsidy to consumer; **N/A:** without government subsidy.

3. Model description

We propose two three-stage game theoretic model comprising of government-manufacturer-retailer, and the government is introduced as the decision maker. RS-strategy indicates the government subsidizes to the retailer, while the MS-strategy recommends the government subsidizes to the manufacturer. In these systems, the government acts as the top-level Stackelberg leader, followed by the manufacturer as the supply chain leader and the retailer as the follower. The three parties engage in a three-stage dynamic game solved via backward induction. This game sequence is consistent with real-world policy-making processes: The government first announces subsidy rules based on pre-policy assessments of market size, firm cost structures, and consumer behavioral characteristics; after observing the subsidy policy, the manufacturer sets wholesale prices and CSR effort levels; finally, the retailer determines retail prices and its own CSR efforts accordingly. The consumers' aversion to unfairness, λ , affects the market demand, D , which in turn affects the decisions of the corresponding decision makers. The game sequence in this paper is as follows:

Corporate social responsibility refers to companies' duties for their social, economic, and environmental impacts. The most mentioned issues in the news media are donations, charity, public

welfare, and others. When enterprises make the above efforts, they can usually improve their reputation and operating conditions. For the convenience of research, we generally express the retailer's and the manufacturer's corporate social responsibility behavior as e_r and e_m .

In RS-strategy: First, to guarantee the resumption of production and meet the consumers' demands, the government subsidizes the retailer and determines the amount of his subsidy, s , to the retailer according to the optimal overall utility of society; Second, the wholesale price w is determined by the manufacturer according to maximize manufacturer profits after the above decision is completed; Last, after the government completes his decision on the subsidies and the optimal wholesale price is determined by the manufacturer, the retailer makes his decisions according to his profits. The decision is made based on the profitability of the retailer with the following variables: the level of effort to CSR e_r and the unit product price p .

In The MS-strategy: First, the government determines the subsidies to the manufacturer s for his social responsibility efforts based on maximizing social welfare. Thereafter, the manufacturer decides on his CSR efforts to CSR e_m and product wholesale price w ; in this case, consumers' fairness concerns will arise for the manufacturer. Third, the retailer makes decisions on the unit product sale price p .

Figure 1a shows the model of RS-strategy, while the MS-strategy is indicated in Figure 1b. Solid lines demonstrate the decision variables, and dashed lines demonstrate the remaining parameters, which affect other decision-makers.

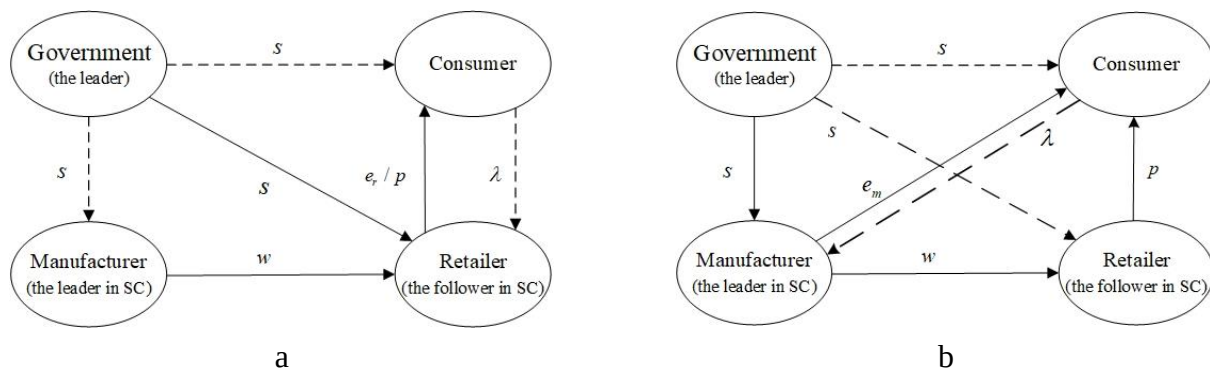


Figure 1. a: Government subsidizes to the retailer (RS-strategy); b: Government subsidizes to the manufacturer (MS-strategy).

With reference to research, the assumptions of this paper are as follows:

Assumption 1: The CSR cost of a firm is quadratically related to its CSR effort level, reflecting the diminishing marginal returns of CSR investment [36]. For the retailer, the CSR cost function is $C_r(e_r) = \frac{\theta e_r^2}{2}$, where $\theta > 0$ is the CSR cost coefficient. Following the standard simplification in supply chain game models [37], we normalize to $\theta = 1$ and simplify algebraic derivation. As shown in the appendix, this normalization does not change the qualitative direction of our core conclusions, and we verify the robustness of results under different θ values in the numerical analysis section.

Assumption 2: The government can subsidize the enterprises based on the level of efforts they put into CSR [38]. Assuming that $s(s > 0)$ is the subsidy coefficient that the government subsidizes the retailer, we express the amount of government subsidy as $S_i = se_i$. Additionally, consumers'

fairness concerns are directed at firms' unit operating profits (retail price minus wholesale price for retailers, wholesale price minus production cost for manufacturers) rather than total subsidy amounts. This is because government subsidies are perceived as public policy transfers, and consumers' fairness judgments focus on the profit margin firms earn from product sales, consistent with the dual-entitlement fairness framework

Assumption 3: Assumption 3: Consumers' product valuation v follows a uniform distribution on $[0, 1]$, and the total market size is normalized to 1. This is a standard setting in supply chain demand modeling [39], which enables us to derive closed-form equilibrium solutions without altering the qualitative properties of the results. The linear demand structure derived from uniform valuation distribution is widely used in fairness concern and CSR research, ensuring comparability with other studies. Under this setting, the market demand function can be derived from the consumer utility function: $D^j = \Pr(U^j > 0)$.

Table 2. Symbols and Definitions.

Symbols	Definitions
Decision variables	
w	Unit product wholesale price
p	Unit product retail price
e_m^j	Manufacturer's efforts level to CSR ($j = RS, MS, N$)
e_r^j	Retailer's efforts level to CSR ($j = RS, MS, N$)
s	Government subsidy coefficient for enterprises
Parameters	
v	Consumer valuation of products, $v \in [0, 1]$
λ	The consumer aversion to unfairness in transactions (consumers' fairness concerns factor)
c	Unit production cost, $0 < c < 1$
θ	Cost factor for enterprises' efforts to combat the CSR
Other symbols	
D^j	Market demands
$C_m^j(e_m^j)$	The cost of CSR for the manufacturer. ($j = RS, MS, N$)
$C_r^j(e_r^j)$	The cost of CSR for the retailer. ($j = RS, MS, N$)
S_m^j	The cost of government subsidies to manufacturer, $S_m^j = se_m^j$ ($j = RS, MS, N$)
S_r^j	The cost of government subsidies to retailer, $S_r^j = se_r^j$ ($j = RS, MS, N$)
CS	Consumer surplus
Π_g^j	Utility functions of the government
Π_r^j	The retailer's profits with different government subsidies
Π_m^j	The manufacturer's profits with different government subsidies

Note: The subscript j indicates the RS-strategy, MS-strategy or no subsidy when its value is RS , MS or N .

Assumption 4: Consumer surplus refers to the discrepancy between the maximum price consumers could pay and the actual market price of a product when consumers purchase a particular quantity of products within their willingness [40], i.e.,

$$CS = \int_p^{p_{\max}} Ddp$$

The relevant symbols and definitions of this research are provided in Table 2.

Following other studies [32,41], we assume consumers form rational expectations of firms' marginal profits based on publicly available market information (e.g., industry average cost levels, retail price ranges) rather than observing exact wholesale prices or costs. This assumption aligns with real-world consumer behavior: Even without precise cost data, consumers can form fairness judgments based on price changes and perceived corporate profitability.

Under the RS-strategy (government subsidizes the retailer), consumers direct their fairness concerns toward the retailer, comparing their own consumer surplus with the retailer's unit profit. Drawing on the demand formation framework, the consumer utility function is specified as follows:

$$U^{RS} = v - p + e_r - \underbrace{\lambda \max\{(p + s - w) - (v - p + e_r), 0\}}_{\text{fairness concerns with the retailer in RS-strategy}} \quad (1)$$

When the government subsidizes to the manufacturer (MS-strategy), we address the MS-consumers' utility function as:

$$U^{MS} = v - p + e_m - \underbrace{\lambda \max\{(w + s - c) - (v - p + e_m), 0\}}_{\text{fairness concerns with the manufacturer in MS-strategy}} \quad (2)$$

where λ indicates the consumers' fairness concerns, and when λ is larger, the consumers' aversion to unfairness is more significant.

4. Analysis

For the convenience of analysis, we consider only the case when the consumers' fairness concerns are satisfied.

When the government subsidizes to the retailer, suppose the consumers' product revenue is lower than the retailer's unit product profit and they have fairness concerns with the retailer, i.e., $v - p + e_r < p + s - w$, we can obtain: $v \leq 2p + s - w - e_r$, and we can express the consumers' utility function under RS-strategy as (Liu et al., 2018; Li et al., 2020) [35,42]:

$$U^{RS} = v - p + e_r - \lambda[(p + s - w) - (v - p + e_r)] \quad (3)$$

When the government subsidizes to the manufacturer, suppose the consumers' product revenue is lower than the manufacturer's unit wholesale profit and they have fairness concerns with the manufacturer, i.e., $v - p + e_m < w + s - c$, and we can address: $v < p + w + s - e_m - c$. The utility function under the MS-strategy is:

$$U^{MS} = v - p + e_m - \lambda[(w + s - c) - (v - p + e_m)] \quad (4)$$

Lemma 1: To effectively encourage enterprises to assume social responsibilities, the government subsidy coefficient needs to meet specific threshold conditions: (1) Suppose government

subsidizes to the retailer, then s needs to satisfy $s > 1 - 2p + w + e_r$; (2) while government subsidizes to the manufacturer, s needs to satisfy $s > 1 - p - w - s + e_m + c$.

Although government subsidies can help stimulate market demand, they are not always effective in encouraging supply chain members to undertake social responsibility [43]. For example, since March 2021, the U.S. Treasury Department has provided subsidies to more than 100,000 companies, including equity investment and credit support. These subsidies have helped many companies tide over the difficulties and stimulated market demand. However, there are also many companies that do not assume their due responsibilities after receiving subsidies, inevitably causing inflation (<https://home.treasury.gov/policy-issues/coronavirus>). **Lemma 1** illustrates that the government subsidy needs to have a minimum standard to motivate supply chain members to assume social responsibility.

4.1. Government subsidizes to the retailer (RS-strategy)

According to **Assumption 3** and **Lemma 1**, we address the consumer demand with government subsidizing the retailer as:

$$D^{RS} = 1 - p + e_r - \frac{\lambda(p + s - w)}{\lambda + 1} \quad (5)$$

When there are government subsidies for the retailer, we represent the manufacturer's profit, and the retailer's profit by Π_m^{RS} and Π_r^{RS} .

$$\Pi_m^{RS}(w) = [1 - p + e_r - \frac{\lambda(p + s - w)}{\lambda + 1}](w - c) \quad (6)$$

$$\Pi_r^{RS}(p, e_r) = (p - w)[1 - p + e_r - \frac{\lambda(p + s - w)}{\lambda + 1}] - \frac{e_r^2}{2} + se_r \quad (7)$$

When the government subsidizes to the retailer, Table 3 displays the optimal destination for the manufacturer and the retailer with determined government subsidy coefficient.

Proposition 1 Under the determined government subsidy coefficient s , government subsidies have a favorable relationship with both the manufacturer's profit and the retailer's profit under RS-strategy. As the government subsidy coefficient improves, so does retailer's efforts level to CSR.

Proposition 1 Proposition 1 posits that government subsidies provided to retailers can incentivize increased efforts to CSR the outbreak, thereby stimulating higher market demand. Additionally, these subsidies can contribute to the profitability of retailers and manufacturers. However, unlike traditional research, government subsidies are not always beneficial to consumers: As government subsidy coefficient increases, the product price increases. Since the government subsidizes the retailer, the wholesale price of the unit product that the retailer can accept will rise. In contrast, the manufacturer's free-riding behavior will determine a higher unit product wholesale price. The unit product price goes up whenever there is an increase in the subsidy coefficient provided by the government; despite this, there will be an increase in the demand for products from consumers. This phenomenon is explained as follows: In the case of government subsidies, although the selling price of unit product increases, consumers can perceive the increases in retailers' efforts to CSR, and the market demand is boosted.

Table 3. Equilibrium solution via the determined government subsidy under RS-strategy.

Symbols	The values of symbols	Partial derivatives	
		On the partial derivative of s	Sign of partial derivative
w^{RS*}	$\frac{1}{2}(1+c+\frac{s}{1+\lambda})$	$\frac{1}{1+\lambda}$	+
p^{RS*}	$\frac{s(1+2\lambda)+(1+\lambda)[1+(2+c)\lambda]}{(1+\lambda)(1+3\lambda)}$	$\frac{1+2\lambda}{(1+\lambda)(1+3\lambda)}$	+
e_r^{RS*}	$\frac{(1-c)(1+\lambda)+s(3+6\lambda)}{2+6\lambda}$	$\frac{3+6\lambda}{2+6\lambda}$	+
D^{RS*}	$\frac{(1+2\lambda)[(1-c)(1+\lambda)+s]}{2(1+\lambda)(1+3\lambda)}$	$\frac{1+2\lambda}{2(1+\lambda)(1+3\lambda)}$	+
CS^{RS*}	$\frac{(1+2\lambda)(1+s+\lambda-c(1+\lambda))^2}{8(1+\lambda)(1+3\lambda)^2}$	$\frac{(1+2\lambda)(s+(1-c)(1+\lambda))}{4(1+\lambda)(1+3\lambda)^2}$	+
Π_m^{RS*}	$\frac{(1+2\lambda)[1+s+\lambda-c(1+\lambda)]^2}{4(1+\lambda)^2(1+3\lambda)}$	$\frac{(1+2\lambda)[s+(1-c)(1+\lambda)]}{2(1+\lambda)^2(1+3\lambda)}$	+
Π_r^{RS*}	A	$\frac{(2-2c)(1+\lambda)+2s(1+2\lambda)(5+6\lambda)}{8(1+\lambda)(1+3\lambda)}$	+

$$A = \frac{(1+c^2)(1+\lambda)^2 + [2s-2c(1+s+\lambda)](1+\lambda) + s^2(1+2\lambda)(5+6\lambda)}{8(1+\lambda)(1+3\lambda)}$$

When there are government subsidies for retailer and consumers' fairness concerns, the price threshold that consumers can afford is $p_{\max}^{RS} = \frac{(\lambda+1)(1+e_r) + \lambda(w-s)}{2\lambda+1}$ (when $D^{RS} = 0$). According to **Assumption 4**, we can obtain the consumer surplus as:

$$CS^{RS} = \frac{(1+e_r - p + \lambda + e_r\lambda - 2p\lambda - s\lambda + w\lambda)^2}{4\lambda^2 + 6\lambda + 2} \quad (8)$$

When determining the level of subsidies to be provided, the government should take into account measures in which it can improve the profitability and the long-term viability of supply chain participants [31]. According to **Lemma 1**, when $s > 1-2p+w+e_r$, $\frac{s+2s\lambda+(-1+c)\lambda(1+\lambda)}{(1+\lambda)(1+3\lambda)} > 0$.

We solve the inequality and address $s > s_1$, where $s_1 = \frac{(1-c)\lambda(1+\lambda)}{1+2\lambda}$. Government's utility function consists of the sum of supply chain participants' profits minus the total subsidies amount

$$\begin{aligned} \Pi_g^{RS}(s) &= \Pi_m^{RS} + \Pi_r^{RS} - S^{RS} + CS^{RS} \\ \text{s.t. } &\frac{s+2s\lambda+(-1+c)\lambda(1+\lambda)}{(1+\lambda)(1+3\lambda)} > 0 \end{aligned} \quad (9)$$

Proposition 2 The optimal government-to-retailer subsidy coefficient is

$$s^{RS} = \frac{(1-c)(2+5\lambda-3\lambda^3)}{4+9\lambda(1+\lambda)(3+2\lambda)} \quad (10)$$

Table 4 shows the equilibrium solution of supply chain members with the optimal subsidy coefficient for government decision-making under the RS-strategy.

Table 4. Equilibrium values of symbols under RS-strategy.

Symbols	Equilibrium value of the symbols
w^{RS}	$\frac{c+3(1+\lambda)^2(1+3\lambda)+3c\lambda(2+\lambda)(2+3\lambda)}{4+9\lambda(1+\lambda)(3+2\lambda)}$
p^{RS}	$\frac{6-2c+3(8+c)\lambda+15(2+c)\lambda^2+6(2+c)\lambda^3}{4+9\lambda(1+\lambda)(3+2\lambda)}$
e_r^{RS}	$\frac{(1-c)(1+\lambda)(5+9\lambda)}{4+9\lambda(1+\lambda)(3+2\lambda)}$
CS^{RS}	$\frac{9(1-c)^2(1+\lambda)^5(1+2\lambda)}{2[4+9\lambda(1+\lambda)(3+2\lambda)]^2}$
D^{RS}	$\frac{3(1-c)(1+\lambda)^2(1+2\lambda)}{4+9\lambda(1+\lambda)(3+2\lambda)}$
Π_m^{RS}	$\frac{9(1-c)^2(1+\lambda)^4(1+2\lambda)(1+3\lambda)}{[4+9\lambda(1+\lambda)(3+2\lambda)]^2}$
Π_r^{RS}	$\frac{(1-c)^2(1+\lambda)^2\{13+3\lambda[22+\lambda(35+24\lambda+12\lambda^2)]\}}{2[4+9\lambda(1+\lambda)(3+2\lambda)]^2}$
Π_g^{RS}	$\frac{(1-c)^2(1+\lambda)^2(5+9\lambda)}{8+18\lambda(1+\lambda)(3+2\lambda)}$

4.2. Government subsidizes to the manufacturer (MS-strategy)

In this section, we evaluate government subsidies for the manufacturer working to CSR. At this time, the point of consumers' fairness concerns is the difference between the benefits obtained from purchasing the product and the profit per unit product obtained by the subsidized manufacturer. To understand the association, we address the consumers' market demand (see the **illustration of Lemma 1** in Appendix) under the MS-strategy as:

$$D^{MS} = 1 - p + e_m - \frac{\lambda}{1+\lambda}(w+s-c) \quad (11)$$

Under the MS-strategy, we denote the manufacturer's and retailer's profits as Π_m^{MS} and Π_r^{MS} , respectively:

$$\Pi_m^{MS}(w, e_m) = [1 - p + e_m - \frac{\lambda}{1+\lambda}(w+s-c)](w-c) - \frac{e_m^2}{2} + se_m \quad (12)$$

$$\Pi_r^{MS}(p) = [1 - p + e_m - \frac{\lambda}{1+\lambda}(w+s-c)](p-w) \quad (13)$$

When the government subsidizes to the manufacturer, we can summarize similar conclusions to **Proposition 1**. Table 5 shows the optimal manufacturer and retailer solutions to the MS-strategy under the determined government subsidy coefficient.

Proposition 3 Under the MS subsidy strategy, manufacturers' and retailers' profits witness a boost as the subsidy coefficient escalates. Notably, this fiscal intervention not only affects the private sector's profitability but also directly impinges on the government's social welfare function and influences the manufacturer's endeavors.

Proposition 3 and **Proposition 1** collectively exemplify the favorable regulatory effect of government subsidies. Intuitively, the government will bear more subsidy costs to expand the subsidy coefficient for enterprises. As market demand has improved, the operating status of supply chain members improves, and the government's social utility is enhanced. Finally, since the manufacturer receives incentives to CSR, they subsequently raise the wholesale price of products, leading to a corresponding increase in the retail price.

Table 5. Equilibrium solution via the determined government subsidy under the MS-strategy.

Symbols	The values of symbols	Partial derivatives	
		On the partial derivative of s	Sign of partial derivative
w^{MS*}	$\frac{c + 5c\lambda + 2(1 + s + \lambda)}{3 + 7\lambda}$	$\frac{2}{3 + 7\lambda}$	+
e_m^{MS*}	$\frac{1 + \lambda - c(1 + \lambda) + s(4 + 7\lambda)}{3 + 7\lambda}$	$\frac{4 + 7\lambda}{3 + 7\lambda}$	+
p^{MS*}	$\frac{s(3 + 4\lambda) + (1 + \lambda)(3 + (4 + 3c)\lambda)}{(1 + \lambda)(3 + 7\lambda)}$	$\frac{3 + 6\lambda}{2 + 6\lambda}$	+
CS^{MS*}	$\frac{(1 + 2\lambda)^2 (1 + s + \lambda - c(1 + \lambda))^2}{2(1 + \lambda)^2 (3 + 7\lambda)^2}$	$\frac{(1 + 2\lambda)^2 (s + (1 - c)(1 + \lambda))}{(1 + \lambda)^2 (3 + 7\lambda)^2}$	+
D^{MS*}	$\frac{(1 + 2\lambda)(1 - c + s + (1 - c)\lambda)}{(1 + \lambda)(3 + 7\lambda)}$	$\frac{1 + 2\lambda}{(1 + \lambda)(3 + 7\lambda)}$	+
Π_m^{MS*}	B	$\frac{(1 - c)(1 + \lambda) + s(4 + 10\lambda + 7\lambda^2)}{3 + 10\lambda + 7\lambda^2}$	+
Π_r^{MS*}	$\frac{(1 + 2\lambda)^2 (1 + s + \lambda - c(1 + \lambda))^2}{(1 + \lambda)^2 (3 + 7\lambda)^2}$	$\frac{2(1 + 2\lambda)^2 (s + (1 - c)(1 + \lambda))}{(1 + \lambda)^2 (3 + 7\lambda)^2}$	+

$$B = \frac{2s(1 + \lambda) + (1 + \lambda)^2 + c^2(1 + \lambda)^2 - 2c(1 + \lambda)(1 + s + \lambda) + s^2(4 + 10\lambda + 7\lambda^2)}{6 + 20\lambda + 14\lambda^2}$$

When the government implements the MS-strategy, the maximum price threshold that consumers can afford is $p_{\max}^{MS} = \frac{1 + (1 + c - s - w)\lambda}{1 + \lambda} + e_m$ (Let Eq. (11) be 0). According to **Assumption 4**, we summarize the consumer surplus as

$$CS^{MS} = \frac{(-1 + p + (-1 - c + p + s + w)\lambda - (1 + \lambda)e_m)^2}{2(1 + \lambda)^2} \quad (14)$$

According to **Lemma 1**, under the MS-strategy, the government needs to consider the condition $s > 1 - p - w - s + e_m + c$, i.e., $\frac{1 - c + 7s + (-1 + c + 15s)\lambda + (-2 + 2c + 7s)\lambda^2}{(1 + \lambda)(3 + 7\lambda)} > 0$. We solve the inequality

and address $s > s_2$, where $s_2 = \frac{(1-c)(1+\lambda)(2\lambda-1)}{7+\lambda(15+7\lambda)}$. The government's utility function is expressed as

$$\begin{aligned} \Pi_g^{MS}(s) &= \Pi_m^{MS} + \Pi_r^{MS} - S^{MS} + CS^{MS} \\ \text{s.t. } &\frac{1-c+7s+(-1+c+15s)\lambda+(-2+2c+7s)\lambda^2}{(1+\lambda)(3+7\lambda)} > 0 \end{aligned} \quad (15)$$

Proposition 4 The optimal government-to-manufacturer subsidy coefficient is

$$s^{MS} = \frac{(1-c)(1+\lambda)(3+\lambda(1+\lambda)(9-7\lambda))}{9+\lambda(64+\lambda(157+7\lambda(22+7\lambda)))} \quad (16)$$

Table 6 shows the supply chain members' equilibrium solution with the optimal subsidy coefficient for government decision-making under the MS-strategy.

Table 6. Equilibrium values of symbols under the MS-strategy.

Symbols	Equilibrium value of the symbols
w^{MS}	$\frac{c+2(1+\lambda)^3(4+7\lambda)+c\lambda(26+\lambda(91+\lambda(104+35\lambda)))}{9+\lambda(64+\lambda(157+7\lambda(22+7\lambda)))}$
p^{MS}	$\frac{(1+\lambda)^2(3+4\lambda)(4+7\lambda)+c(-3+\lambda(1+\lambda)(3+\lambda(40+21\lambda)))}{9+\lambda(64+\lambda(157+7\lambda(22+7\lambda)))}$
e_m^{MS}	$\frac{(1-c)(1+\lambda)(1+2\lambda)(7+10\lambda)}{9+\lambda(64+\lambda(157+7\lambda(22+7\lambda)))}$
CS^{MS}	$\frac{(-1+c)^2(1+\lambda)^4(1+2\lambda)^2(4+7\lambda)^2}{2(9+\lambda(64+\lambda(157+7\lambda(22+7\lambda))))^2}$
D^{MS}	$\frac{(1-c)(1+\lambda)^2(1+2\lambda)(4+7\lambda)}{9+\lambda(64+\lambda(157+7\lambda(22+7\lambda)))}$
Π_m^{MS}	$\frac{(-1+c)^2(1+\lambda)^2(1+2\lambda)(57+2\lambda(182+\lambda(444+\lambda(533+14\lambda(24+7\lambda))))}{2(9+\lambda(64+\lambda(157+7\lambda(22+7\lambda))))^2}$
Π_r^{MS}	$\frac{(-1+c)^2(1+\lambda)^4(1+2\lambda)^2(4+7\lambda)^2}{(9+\lambda(64+\lambda(157+7\lambda(22+7\lambda))))^2}$
Π_g^{MS}	$\frac{(-1+c)^2(1+\lambda)^2(1+2\lambda)(7+10\lambda)}{2(9+\lambda(64+\lambda(157+7\lambda(22+7\lambda))))}$

4.3. Comparison of the RS-strategy and MS-strategy and government's strategy options

Corollary 1 Increasing consumers' fairness concerns will weaken enterprises' efforts to CSR, reduce products' sales prices, and negatively affect government subsidies, i.e.,
$$\begin{cases} \frac{\partial e_r^{RS}}{\partial \lambda} < 0 \\ \frac{\partial e_m^{MS}}{\partial \lambda} < 0 \end{cases},$$

$$\begin{cases} \frac{\partial p^{RS}}{\partial \lambda} < 0 \\ \frac{\partial p^{MS}}{\partial \lambda} < 0 \end{cases}, \begin{cases} \frac{\partial s^{RS}}{\partial \lambda} < 0 \\ \frac{\partial s^{MS}}{\partial \lambda} < 0 \end{cases}.$$

Corollary 1 illustrates that to address consumers' fairness concerns, the retailer will choose to transfer the retail price of products. The retailer reduces the negative impact of consumers' fairness concerns by lowering the retail price of his products. Moreover, consumers' aversion to unfairness also significantly impacts the efforts of supply chain members to CSR. The greater the consumer's fairness concerns are (when $\lambda \rightarrow \infty$, $e_i^j \rightarrow 0$), the lower the enthusiasm of the supply chain in CSR is. The reason is that as consumers' aversion to unfairness increases, the profits of supply chain members decrease. Supply chain members will, therefore, reduce the cost of investment in CSR, and the efforts of enterprises to CSR will be reduced. Furthermore, when consumers' fairness concerns coefficient increases, return benefits from government subsidies will decrease, so the government will also reduce the subsidy cost by reducing the subsidy coefficient.

In particular, under the MS-strategy, the manufacturer will also reduce the wholesale price of products based on the increase in consumers' fairness concern coefficient. Unexpectedly, consumers' fairness concerns under the RS strategy will hurt consumers' own surplus. The increase in consumers' fairness concerns will create a vicious cycle in the operation of the supply chain. Therefore, companies in the supply chain should try to make consumers feel as fair as possible in fighting the epidemic and selling goods.

Corollary 2 The RS-strategy's government's regulatory effect on corporate social responsibility efforts is more operative than that of the MS-strategy, i.e., $\frac{\partial e_r^{RS*}}{\partial s} - \frac{\partial e_m^{MS*}}{\partial s} > 0$.

According to Table 3 and Table 5, reasonable government subsidies can improve corporate social responsibility and increase consumer surplus [43]. Both methods of government subsidies can promote the efficiency of the supply chain. Since retailers are downstream of the supply chain and have direct contact with consumers, consumers are more sensitive to retailers' social responsibilities. Therefore, the RS strategy has a more substantial promotion effect on corporate social responsibilities.

Corollary 3 (i) Optimal RS-strategy's government utility is superior to the MS-strategy's, i.e., $\Pi_g^{RS} > \Pi_g^{MS}$. (ii) Under both government subsidy strategies, government utilities are negatively impacted by the consumers' fairness concerns coefficient, i.e., $\frac{\partial \Pi_g^{RS}}{\partial \lambda} < 0$, $\frac{\partial \Pi_g^{MS}}{\partial \lambda} < 0$.

Corollary 3 shows that if the government does not consider the restriction of the subsidy coefficient and can make both strategies optimal, the social utility generated by the RS-strategy is better than that of the MS-strategy. However, similar to the results shown in **Corollary 1**, consumers' fairness concerns coefficient will have a negative impact on the overall social welfare utility. Intriguingly, **Corollary 3** proves that even if a company adopts a lower product price strategy in the face of

growing consumer fairness concerns, it cannot improve the negative impact of consumer fairness concerns.

Corollary 4 (i) The subsidy cost borne by the government is consistently reduced when employing the MS-strategy as opposed to the RS-strategy; i.e., $S_m^{MS*} < S_r^{RS*}$. (ii) However, the RS-strategy has a greater market demand than the MS-strategy; i.e., $D^{RS*} > D^{MS*}$.

Both subsidy strategies can achieve Pareto improvement, showing that regardless of the consumer fairness concern coefficient, production cost, and subsidy coefficient level, the total subsidy cost of the MS-strategy is always lower than that of the RS-strategy. Note that Propositions 2 and 4 derive the unconstrained optimal subsidy coefficients that maximize social welfare, assuming no fiscal budget limit. In practice, however, governments often face exogenous budget constraints. Proposition 5 below characterizes the optimal strategy selection when the government faces a maximum feasible subsidy coefficient cap due to budget limits. However, fewer subsidies also mean less market demand. Furthermore, according to **Corollary 2** and **Corollary 3**, the regulatory effect of government subsidies in the RS-strategy is also more robust, so when the government budget is sufficient, the RS-strategy is a better choice.

Proposition 5 The government's subsidy strategy options are as follows:

Before presenting the government's strategy selection rules, we first define two critical subsidy coefficient thresholds:

s_2 : The minimum effective threshold of the MS-strategy, i.e., the minimum subsidy coefficient required to stimulate positive manufacturer CSR effort, derived from Lemma 1 as $s_2 = \min(s_{MS})$.

s_1 : The minimum effective threshold of the RS-strategy, i.e., the minimum subsidy coefficient required to stimulate positive retailer CSR effort, derived from Lemma 1 as $s = \min(s_{RS})$.

By construction, $0 < s_2 < s_1$: The MS-strategy has a lower entry threshold and can take effect with a smaller subsidy budget.

When $s < s_2$, the government prefers not to subsidize; when $s_2 < s < s_1$, the government is more inclined to implement the MS-strategy; and when $s_1 < s < s^{SR}$, the government is more inclined to adopt the RS-strategy, which are shown in Figure 2.

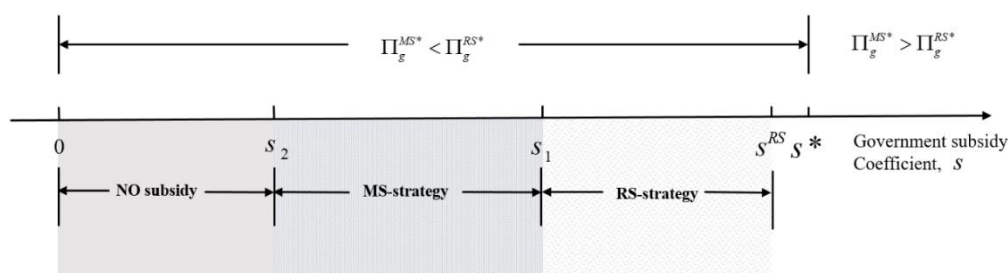


Figure 2. Government's strategy options.

We integrate the lemma and related corollaries to address **Proposition 5**. **Proposition 5** systematically elaborates on the government's strategic choices. When the government's budget is low ($s < s_2$), neither of the two government subsidy strategies can play its due regulatory role (**Lemma 1**), and the government can choose not to subsidize. The result of this situation is that many companies have closed down due to the pandemic, the manufacturing and retail industries have been affected, and market demand cannot be met. When the government budget is within a specific range

($s_2 < s < s_1$), the RS strategy cannot meet the conditions for taking effect. The government can use the MS strategy to subsidize enterprises, and subsidies can encourage manufacturers to assume social responsibilities, improve social welfare levels, and increase the profits of supply chain members (Figure 3). When the government budget is greater than a particular value ($s > s_1$), the significant regulatory effect of RS-strategy becomes apparent. Moreover, the government budget is relatively sufficient, and government subsidies regulate social welfare levels, market demand, and the social responsibilities of supply chain members. The effects are better than those of the MS-strategy.

5. Numerical analysis

In our work mentioned above, we verify how consumers' fairness concerns impact supply chain members and government utility function and subsidy strategies that governments can adopt under different budgets. To further analyze the effectiveness of government subsidies and their impact on social welfare, we conduct numerical analysis. Based on the results of the derivation of the mathematical model within the range allowed by the parameters and referring to the corresponding literature [39,32], the model's parameters have the following values: $c=0.3$, the consumer's aversion to transactional unfairness $\lambda \in [0,1]$. Based on empirical data from key supply-guarantee industries during the COVID-19 pandemic: (1) The unit production cost of medical masks accounts for approximately 30%–60% of their ex-factory prices; for leading enterprises in the mid-to-late stage of the pandemic, this ratio stood at around 30%–40%; (2) the manufacturing cost of medical protective clothing accounts for roughly 27%–42% of the procurement price; and (3) for daily consumer fast-moving goods (FMCG) such as food and beverages, the unit production cost generally ranges from 30% to 50% of the terminal retail price. In summary, the value of $c = 0.3$ falls within the reasonable range of the cost structure of pandemic-related medical supplies and daily necessities industries, and can greatly represent the "essential goods supply chain under the shock of the COVID-19 pandemic" scenario focused on in this study.

To better illustrate the linkage between this study's theoretical contributions and practical implications, Table 7 provides relevant statistics on China's new energy vehicle development spanning 2021 to 2025. The number of consumer complaints related to new energy vehicles can, to a certain extent, be indicative of consumers' fairness concerns. We employ the 2025 consumer complaint volume as the reference point to construct relative annual measures of consumer fairness concerns.

Table 7. Development Status of New Energy Vehicles in China.

Year	Nationwide sales of new energy vehicles ¹	New energy vehicle penetration rate ²	Consumer complaints regarding new energy vehicles ³	Relative value of consumer fairness concerns
2021	3.521 million	13.4%	11,324	0.111
2022	6.887 million	25.6%	20,431	0.200
2023	9.495 million	31.55%	50,738	0.497
2024	12.866 million	40.93%	59,178	0.580
2025	16.49 million	47.9%	102,003	1

¹https://m.cnfin.com/wx/share?url=https://m.cnfin.com/hg-lb/zixun/20260114/4365366_1.html.

²http://finance.ce.cn/stock/gsgdbd/202207/01/t20220701_37822519.shtml

³<https://chejiahao.autohome.com.cn/info/24936960>

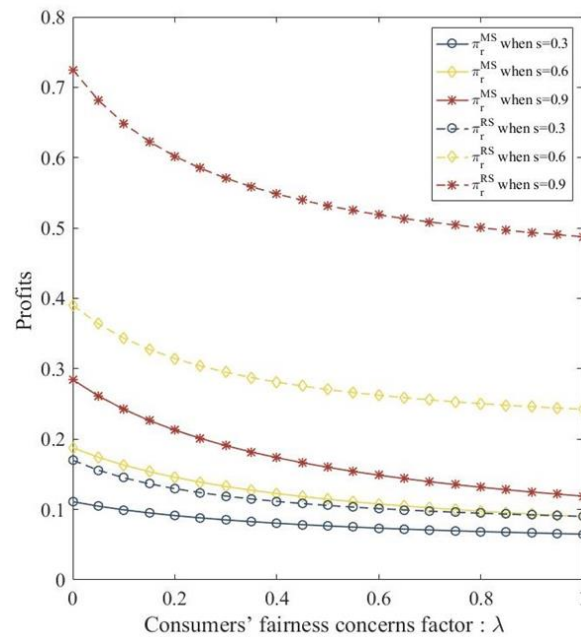


Figure 3. The impact of λ on the retailer's profits.

Figure 3 shows the impact of the consumers' fairness concerns coefficient on retailer profits and the moderating effect of the government subsidy coefficient on retailer profits. First, the consumers' fairness concerns coefficient always harms the retailer's profits. The higher the government subsidy coefficient, the greater the profits of enterprises. Subsequently, we can understand that retailer profits with the RS-strategy are generally more significant than those with the MS strategy. Thus, retailers prefer the government to implement the RS-strategy for subsidies.

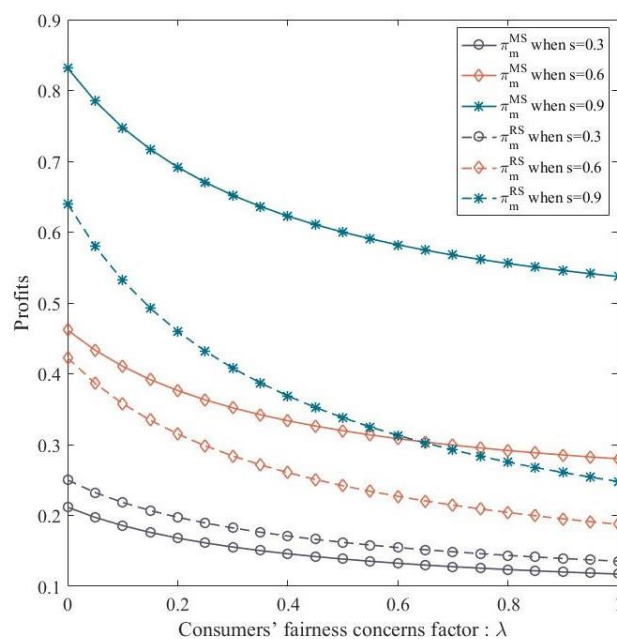


Figure 4. The impact of λ on the manufacturer's profits.

Figure 4 shows the impact of the consumers' fairness concerns coefficient on manufacturer profits and the moderating effect of the government subsidy coefficient on the manufacturer. Together, Figure 3 and Figure 4 demonstrate the positive contribution of government subsidies to enterprises, and the profits of core enterprises have improved because of government subsidies. Clearly, with the increase in government subsidies, the company compensates for the losses caused by consumers' fairness concerns, promotes the level of corporate social responsibility, and improves the profit of the enterprise. In particular, the manufacturer profits for the MS-strategy are overall greater than that for the RS-strategy. Even when the government subsidy coefficient is small (referred to as $s=0.3$ in the figure), the profit difference between the manufacturer under the two strategies is minimal. Therefore, for manufacturers, the RS strategy is more beneficial when the government's subsidy coefficient is small. When the government subsidy coefficient is significant, manufacturers prefer that the government adopt the MS strategy to subsidize.

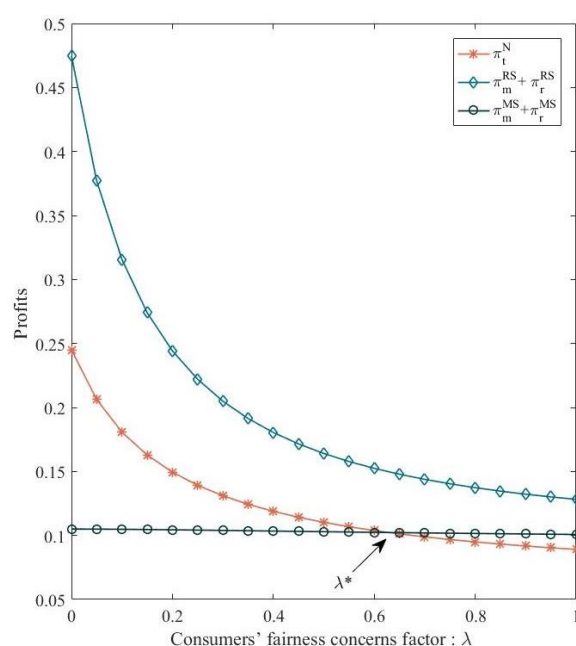


Figure 5. Comparison of supply chain members' optimal profits under different subsidies.

In Figure 5, we compare the total profit of centralized decision-making (A30) in the supply chain without government subsidies with the sum of profits of the manufacturer and the retailer under two government subsidy strategies. We find that the government's implementation of the RS strategy can consistently achieve Pareto improvements for supply chain members, and the sum of profits of the manufacturer and the retailer is always higher than that of centralized decision-making without government subsidies. However, even if the government implements the RS strategy, supply chain members' profits will be severely disturbed by the negative impact of consumer fairness concerns. Instead, when the government implements the MS-strategy to subsidize, supply chain members' profits will rise steadily as consumers' fairness concerns coefficient increases. The MS-strategy solves the negative impact caused by consumers' fairness concerns. Analytically, we can derive the threshold $\lambda_0 \approx 0.628$ by equating the total supply chain profit under the MS-strategy with the profit under the no-subsidy centralized benchmark. When $\lambda > \lambda_0$, the MS-strategy achieves

higher total supply chain profit than the no-subsidy centralized case; when $\lambda < \lambda_0$, the profit improvement effect of the MS-strategy is not sufficient to exceed the centralized benchmark. This threshold arises because the risk-stabilizing effect of the MS-strategy becomes more pronounced as fairness concerns intensify. However, because government subsidies can share corporate risks, for supply chain members, accepting government subsidies can prevent integration by the upstream and downstream of the supply chain.

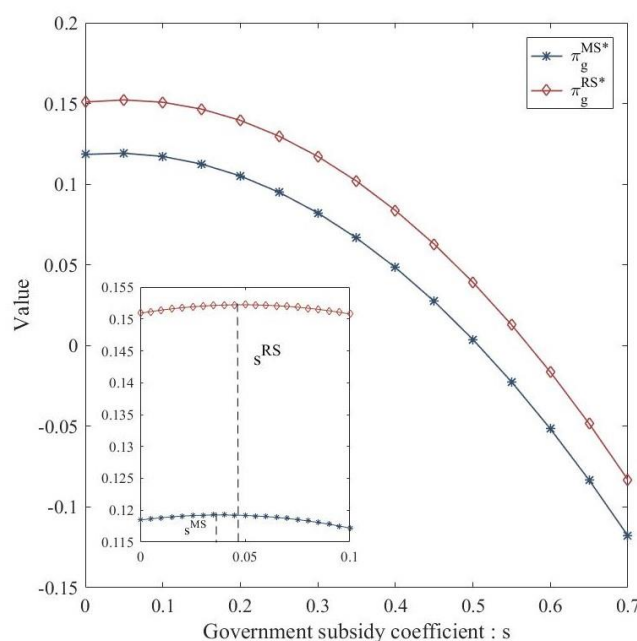


Figure 6. The impact of s on government utility function.

Figure 6 shows the effect of the government's utility function on the government subsidy coefficient under the two subsidy strategies. The government's utility function increases and then decreases. In this paper, government's utility function declines as the government subsidy coefficient increases, which can be explained from the following aspects: First, the government's utility function specified in this paper does not incorporate the tax revenues from new energy vehicles, resulting in a portion of the benefits not being accounted for. Second, the marginal effect of government subsidies diminishes as the industry develops. For instance, from 2021 to 2025, Chinese new energy vehicle sales surged from 3.52 million units to over 16 million units; yet, over the same period, consumer-side government subsidies decreased drastically. From 2016 to 2020, cumulative promotional and application subsidy funds totaled 1.654 billion yuan, peaking in 2017 with a pre-allocated amount of 917 million yuan. In contrast, the pre-allocated subsidy amount for 2021–2022 plummeted to 168 million yuan, a decline of over 80% from the 2017 peak. Universal purchase subsidies were largely phased out after 2021, with national fiscal funds redirected toward settling legacy accounts and supporting new directions such as charging infrastructure and cutting-edge technologies. This counterintuitive data combination precisely demonstrates that the industry has developed endogenous growth drivers and no longer relies on direct subsidies. Supply chain participants will benefit from the increase in the government subsidy coefficient (Figures 3 and 4), because that the government will sacrifice their interests to maintain social stability operations. Second, the government utility

under the RS-strategy is better than that under the MS-strategy, further proving the conclusion of **Proposition 5**.

6. Conclusion and future research direction

6.1. Major findings

In this paper, we discuss consumers' fairness concerns from two perspectives: The RS-strategy and the MS-strategy. Within the CSR, we investigate the influence of consumers' fairness concerns and how the government subsidies regulate the market. First, we answer the questions raised in the introduction and illustrate our major findings:

(1) Supply chain members will appropriately reduce product prices to deal with the negative impact of consumers' fairness concerns. Intriguingly, when the consumers' fairness concern factor continues to rise, supply chain members will reduce the cost of social responsibility efforts.

(2) Whether the MS-strategy or the RS-strategy is used, government subsidies can stimulate companies' efforts to CSR and improve the negative impact of consumers' fairness concerns. These improvements are promoted in consumer surplus, social welfare profits of supply chain members, etc. However, when the government subsidy coefficient exceeds a specific value, the government's utility function will decrease accordingly. Without government subsidies and RS-strategy, consumer fairness concerns will harm the profits of supply chain members. Interestingly, under the MS strategy, the profits of supply chain members will slowly increase as the consumers' fairness concern coefficient rises.

(3) Compared with no government subsidy, both government subsidy strategies can achieve Pareto improvement. Among them, the government utility function of the RS-strategy is always better than the MS-strategy's. However, the MS-strategy requires lower subsidy costs and can optimize the risk of disruptions caused by consumer fairness concerns. When the government has a sufficient budget and needs more social benefits, the government can choose the RS subsidy strategy. When the government's budget is low, and the social benefits are expected to be more stable, the government can choose the MS-strategy for subsidies.

6.2. Management implications

Based on our research findings, we propose essential management implications for the supply chain and government.

(1) Supply chain enterprises: First, firms should proactively manage consumers' fairness perceptions to mitigate negative impacts. Specifically, retailers can adopt transparent pricing mechanisms, such as disclosing cost composition and price adjustment reasons for essential goods, to reduce consumers' misperceptions of excessive profits. Second, firms can communicate CSR efforts (e.g., material donations and guaranteed supply measures) to consumers through official channels, so that consumers can perceive the social value of enterprises, thereby weakening the negative effect of fairness concerns on demand. Third, enterprises should flexibly match government subsidy strategies: Retailers should actively apply for downstream subsidy policies to expand CSR investment, while manufacturers should prioritize leveraging upstream subsidies to stabilize operational costs, especially when consumer fairness concerns are strong.

(2) Government: The government should adopt differentiated subsidy strategies based on fiscal budget and market characteristics. When the budget is sufficient and the market demands strong CSR output (e.g., public health supplies), the RS-strategy is preferred to maximize social welfare and CSR levels. When the budget is limited or consumer fairness concerns fluctuate sharply, the MS-strategy is more suitable since it requires lower fiscal expenditure and provides more stable profit support for the supply chain. In addition, the government can guide consumers to form reasonable fairness perceptions through public opinion guidance, reducing the vicious cycle of fairness.

6.3. Future research direction

In this study, we adopt an analytical game-theoretic approach and use numerical simulations to verify conclusions without employing empirical data from the COVID-19 pandemic. In future studies, researchers can use industry-level data from the pandemic period to empirically test the theoretical propositions and calibrate model parameters. Moreover, since we operationalize consumers' fairness concerns using an inequity-aversion specification (Table 7), this inherently leads to a negative effect of consumer fairness concerns on corporate social responsibility (CSR) efforts. Researchers should refine the aforementioned aspects.

In terms of research content, we focus on the positive role of government subsidies for enterprises, such as alleviating operational pressure caused by consumer fairness concerns, stabilizing supply chain profits, and improving social welfare. Whether considering that the government simultaneously subsidizes consumers can also optimize the supply chain operation will be the direction of our future research. Cooperation among supply chain members is also particularly important when facing risks. Therefore, studying how supply chain members cooperate in response to particular business environments and consumer fairness concerns may be another important research direction. Moreover, fairness concerns among supply chain members are also a hot research issue. When there may be fairness concerns from manufacturers, retailers, and consumers in the context of government subsidies, interactions and decision-making of supply chain members and the government are also worthy of research. We will continue to explore these in-depth in our future research.

Author contributions

Xiaogang Cao: Funding acquisition, Investigation, Project administration, Supervision, Validation, Writing-review & editing. Zhaoyu Xu: Formal analysis, Methodology, Software, Writing original draft. Kewei Li: Data curation, Validation, Visualization. Hui Wen: Conceptualization, Data curation, Resources, Visualization.

Use of Generative-AI tools declaration

We declare that AI-assisted tools such as ChatGPT were used solely to improve grammar and language clarity, which have been reviewed and revised by the authors, without contributing to the scientific content.

Conflict of interest

We state that there is no conflict of interest within this manuscript.

Data availability statement

All the data within this manuscript will be provided upon request.

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