Original Research

Coordination of green supply chain considering fairness concern and distribution-free approach

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Abstract

Firms that prioritize environmental considerations and actively embrace sustainability practices can achieve a significant competitive edge in the market. However, the high costs of investing in green initiatives and reducing short-term profit margins for investors can raise concerns about fairness. This paper examines fairness concerns within a green supply chain, featuring a manufacturer committed to fair profit distribution and a fairness-neutral retailer. The issue is analyzed using a distribution-free approach across different decision-making processes in the context of stochastic demand with partial information. Moreover, to achieve a win-win situation for all members involved, a profit-sharing through bargaining (PSB) contract is used. The results show that using a contract that allows the manufacturer to negotiate the profit-sharing percentage with the retailer can bring significant benefits. This coordination mechanism effectively addresses the manufacturer's concerns about fairness while enhancing product sustainability and green initiatives. Additionally, conducting sensitivity analyses on key parameters provides valuable managerial insights for decision-making.

Keywords- Green Supply Chain Coordination, Fairness Concern, Stochastic Demand, Partial Information, Bargaining.

INTRODUCTION

Recently, there has been a growing emphasis on implementing environmentally sustainable practices across various industries. Key drivers such as government regulations, increasing consumer demand for sustainable products, competitive pressures, and strategic marketing initiatives have encouraged firms to adopt eco-friendly approaches. Companies are increasingly integrating sustainable practices throughout their production processes, from product design to pricing and promotion, to contribute to a green economy [1, 2]. Green supply chain management (GSCM) enhances economic, environmental, and operational performance, fostering overall growth and sustainability [3].

Green products are designed to align with environmental protection principles throughout their life cycle, encompassing production, usage, and recycling [4]. Manufacturers can demonstrate their commitment to social and environmental responsibility by investing in advanced green production technologies, despite the higher initial costs. Although sustainable production necessitates specialized resources and processes, it offers long-term advantages such as reduced energy consumption, waste minimization, and improved brand reputation. By embracing sustainability, manufacturers can differentiate their products, attract environmentally conscious consumers, and contribute to a more sustainable future [5]. However, allocating funds for green research and development raises concerns about the fairness of profit distribution, as firms aim to balance utility maximization with equitable resource allocation [6, 7]. Addressing these fairness concerns is crucial for ensuring effective coordination among supply chain members and enhancing both efficiency and environmental sustainability.

Numerous studies have also investigated green supply chains from different perspectives, including pricing strategies [8], competitive market conditions [9, 10], multi-channel sales models [11, 12], the role of government as an external driver [13], fairness-related interactions among supply chain members [1, 9, 14, 15], and decision-making under stochastic demand conditions [16, 17].

Literature Review

To outline the key distinctions between this study and other relevant research works, the recent literature on the main topics of this paper is reviewed.

In recent years, researchers have explored various approaches to green supply chain coordination, focusing on collaboration, strategic interactions, and contract mechanisms to enhance both sustainability and efficiency. Basiri and Heydari [18] proposed a collaborative approach to optimize supply chain efficiency for green and non-green products, enabling a win-win situation without a supplementary contract for Pareto improvement. Song and Gao [19] considered the impact of revenue-sharing contracts on decision-making, profit conflict resolution, and consumer sensitivity in the green supply chain, presenting both a retailer-led and a bargaining model. Similarly, Rong and Xu [20] recommended two enhanced bargaining contracts for revenue sharing, which can improve coordination among members and increase the greening level, while Davoudi, Seifbarghy [21] examined green supply chain models by integrating nonlinear demand patterns and assessing the effects of bargaining on customer attraction and sales.

Another essential dimension of green supply chain coordination is how consumer awareness shapes firms' strategic approaches and decision-making processes. Several studies have focused on consumer awareness and its effect on green supply chain decisions. Hosseini-Motlagh, Nematollahi and Nouri [22] evaluated consumer purchasing behavior under the combined effect of green quality and product warranty period in a setting with a dominant manufacturer and two competing duopoly retailers. Heydari, Govindan and Basiri [3] emphasized enhancing channel coordination by incorporating consumer awareness of environmental issues and green quality to increase demand through a hybrid greening contract. Next, Li, Wang [4] analyzed how consumer green awareness and retail competition affect manufacturers' green investment and online selling formats, by highlighting the complex dynamics between agency and reselling strategies for eco-friendly products. Pricing mechanisms and information strategies have also been widely studied as key levers for optimizing green supply chain management. Zhang, Liu and Han [23] explored the two-stage dynamic pricing model within the green supply chain. Shi, Yang [24] explored the relationship between green product development (GPD) and green marketing strategies. As a further development, Cai, Sun [25] examined the impact of pricing and sustainability on retailers' information disclosure strategies, demonstrating how information acquisition capabilities shape optimal disclosure choices. Beyond firm-level strategies, broader regulatory and policy interventions have been explored as key drivers of supply chain coordination.

Guo, Cheng and Liu [12] investigated the performance of an eco-labeling strategy on products. Additionally, Taleizadeh, Alizadeh-Basban and Sarker [8] studied supply chain pricing under cap-and-trade regulations, highlighting how emissions policies affect firms' pricing and coordination decisions. He, Jiang and Hu [26] investigated the impact of government subsidies and corporate social responsibility (CSR) within an omnichannel supply chain (OSC), presenting a model that considers low-carbon products and suggesting a cost-sharing contract to achieve Pareto optimization in carbon reduction. Unlike most studies, this research examines green supply chain coordination through PSB contracts while addressing the challenge of high investment costs in green practices.

In the cases with stochastic demand, there are different approaches for representing partial demand information that include cases where the demand distribution is known but its parameters are unknown or where the parameters are known but the distribution function remains unknown, as initially explored by Scarf [27]. In most real-world scenarios, complete information about the demand distribution is unavailable; however, key parameters such as the mean and variance can often be determined [28]. Zhao and Yin [29] developed the supply chain coordination with stochastic demand following a uniform distribution, highlighting the effects of pricing and CSR investments. Raza [30] developed a CSR investment model considering price-dependent stochastic demand with partial demand information, and then Raza and Govindaluri [17] extended this research by incorporating the concept of demand leakage. Dehghan-Bonari, Bakhshi [31] proposed call option and revenue-sharing contracts as mechanisms for managing stochastic demand within supply chains. Wang, Fan [14] explored the role of contracts in coordinating supply chain members when demand is influenced by pricing decisions. More recently, Malik, Sarkar [16] introduced a flexible manufacturing system utilizing a minimax distribution-free approach to address stochastic demand uncertainties. This paper addresses stochastic demand with partial information to enhance the model's realism.

Behavioral economics research has demonstrated that decision-makers often exhibit irrational tendencies, a phenomenon that also affects supply chain participants. In particular, fairness concerns frequently influence supply chain decisions, as firms prioritize the equitable distribution of profits among channel members. As a result, numerous studies have examined the role of fairness in decision-making and supply chain coordination. Liu, Zheng [32] explored carbon tax policies to reduce carbon emissions and found that fairness concerns can adversely impact supply chains. Similarly, Li, Guan [33] demonstrated that fairness considerations can lead to suboptimal manufacturer decisions. Yoshihara and Matsubayashi [10] explored coordination between competing retailers and a manufacturer, showing how fairness concerns influence quantity-discount contracts. Zhang, Liu and Han [23] further investigated profit distribution methods aimed at ensuring equitable surplus allocation among green supply chain participants. Numerous studies have explored the impact of fairness considerations on contract design to enhance supply chain coordination. Nie and Du [34] proposed a dual-fairness model considering incomplete information. Liu, Wang and Xu [35] examined coordination between a fairness-concerned supplier and a leading retailer using a cost-sharing contract that facilitates both Pareto improvement and sustainability. To guarantee fair profit distribution within a closed-loop supply chain, Jian, Li [36] proposed a profit-sharing contract that incorporates both manufacturer fairness concern and retailer efforts. Yang, Shao [15] developed a green supply chain model that considers payment delays and risk-free interest rates under varying fairness concern scenarios. Toktaş-Palut [37] implemented a fair integrated two-part tariff contract to promote sustainability. Li, Wang [38] examined a dual-channel supply chain with stochastic demand to investigate the effects of fairness concerns and then compared revenue-sharing, buy-back, and wholesale price contracts under Nash bargaining. Jiang, Ji [39] developed a game theory model to address profit distribution in a green closed-loop supply chain, focusing on fairness concerns from the manufacturing side.

This study delves into fairness concern within a supply chain incorporating environmental initiatives by examining stochastic demand. Unlike previous research, this study investigates fairness issues within a supply chain considering a distribution-free approach. As shown in Table I, none of them have concurrently explored a supply chain with fairness concerns, stochastic demand, and partial information. Furthermore, to counteract the adverse impacts of the manufacturer's fairness concern and maximize the supply chain profitability, a profit-sharing mechanism through bargaining is introduced.

TABLE I
SUMMARIZED REVIEW OF THE MOST RELATED LITERATURE

Related Articles	Demand		Partial Information	Decision Variables			Fairness concern	Bargaining	Contract
	D	S		Pricing	Quantity	Greening			
Nie and Du [34]	✓			✓			✓		Quantity discount
Raza [30]	✓	✓	✓	✓	✓			✓	Revenue-sharing
Raza and Govindaluri [17]	✓	✓	✓	✓	✓	✓			–
Rong and Xu [20]	✓			✓		✓	-	✓	Revenue-sharing
Adhikari and Bisi [1]	✓			✓			✓	✓	Cost-sharing Profit-sharing
Zhao and Yin [29]		✓			✓				Call option
Wang, Fan [14]	✓			✓		✓	✓		Cost-sharing joint commission
Jian, Li [36]	✓			✓			✓		Profit-sharing
Yang, Shao [15]	✓			✓		✓	✓	✓	_
Wang, Zhang [40]		✓		✓	✓				Buy-back

Dehghan-Bonari, Bakhshi [31]		✓		✓	✓				Call option, Revenue-sharing
Li, Wang [38]		✓		✓	✓		✓	✓	Wholesale price, Buy-back, and Revenue-sharing
Jiang, Ji [39]	✓			✓		✓	✓		_
Malik, Sarkar [16]		✓	✓	✓	✓			✓	_
This paper	✓	✓	✓	✓	✓	✓	✓	✓	PSB

* D, Deterministic; S, Stochastic.

PROBLEM STATEMENT

This study examines a supply chain that includes an environmentally friendly manufacturer upstream and a retailer downstream under stochastic demand with partial information, as shown in Figure 1, in a Stackelberg game. Given the substantial cost of green investment, profit and equitable distribution are of the manufacturer's priorities. This paper seeks to explore how fairness concern influence decision-making. The assumptions are considered as follows:

Assumption 1. The decision-making process follows the Stackelberg mechanism.
Assumption 2. There is information symmetry, which implies that at the start of the period, both players have the same information.
Assumption 3. The surplus inventory and shortage are ignored.
Assumption 4. The stochastic demand consists of a deterministic part similar to Rong and Xu [20] and a stochastic part, represented as follows:

$$D = y(p, \theta) + \varepsilon = 1 - bp + \gamma\theta + \varepsilon \qquad (1)$$

The stochastic part, ε, is independent, and it is defined within a range of $[\underline{\varepsilon}, \overline{\varepsilon}]$. ε has a probability distribution function f(ε) and a cumulative probability distribution F(ε) with a mean of μ and a standard deviation of σ [17, 30].
Assumption 5. The expense of green investments increases significantly, which can be represented by the equation $i\theta^2$ [41].

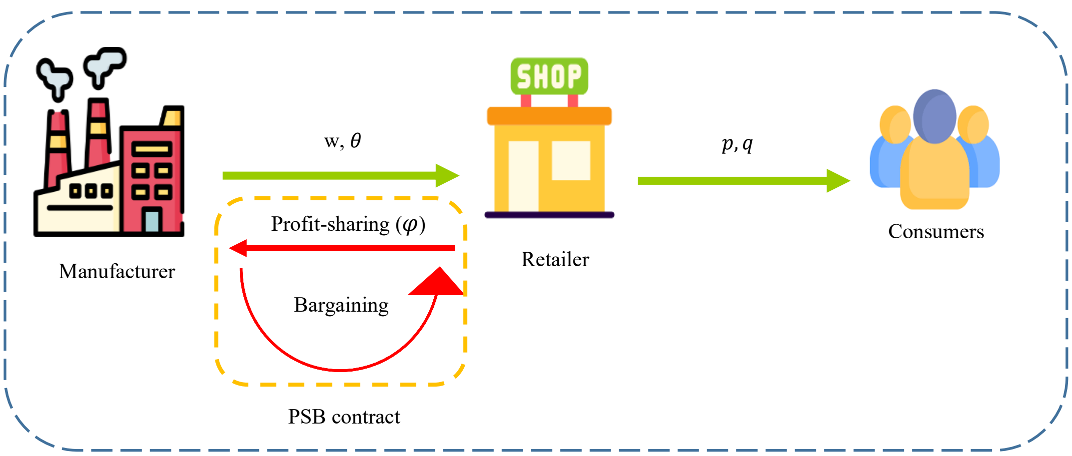


FIGURE 1
SUPPLY CHAIN STRUCTURE

Based on the problem definition, the symbols are provided in Table II.

TABLE II
SYMBOLS

Parameters & decision variables	
b	Product price sensitivity coefficient $b \in (\mathbf{0}, \mathbf{1})$
c	Production cost of green product $c \in (\mathbf{0}, \mathbf{1})$
i	Green investment level coefficient $i \in (\mathbf{0}, \mathbf{1})$
γ	Consumer sensitivity coefficient to the green level $\boldsymbol{\gamma} \in (\mathbf{0}, \mathbf{1})$
λ_0	Basic fairness concern coefficient $\boldsymbol{\lambda_0} \geq \mathbf{0}$
λ	fairness concern coefficient $\boldsymbol{\lambda} \in (\mathbf{0}, \mathbf{1})$
μ	Mean of stochastic demand factor
σ	Standard deviation of stochastic demand factor
$f(\cdot)$	Probability distribution function
$F(\cdot)$	Cumulative probability distribution function
π_r	Profits of retailer
π_m	Profits of manufacturer
U_m	Utility of manufacturer
w	Wholesale price
θ	Green level of the product
p	Retail price per green product
q	Quantity of orders
φ	Retailer's PSB ratio
Superscripts	
x^d	Optimal value, x ∈ R in decentralized decision-making
x^c	Optimal value, x ∈ R in centralized decision-making
x^b	Optimal value, x ∈ R in PSB

MODELLING

In this section, the problem is formulated using a distribution-free approach across three decision-making structures.

I. Decentralized Decision-making with Fairness Concern

In a decentralized structure, each player aims to independently maximize their profits. The manufacturer faces a production cost, c for each product with the green level of θ and sells them at a wholesale price, w $(w > c)$. The retailer must also decide on the inventory level, q based on its own perception of ε, and determine the retail price, p based on w. The profit functions of the members are formulated as follows:

$$\pi_m(w, \theta) = (w - c)q - i\theta^2 \tag{2}$$

$$\pi_r(p, q) = p\, min\{q, D\} - wq \tag{3}$$

Thereafter,

$$min\{D, q\} = q - E[q - D]^+ \tag{4}$$

Where $E[q - D]^+ = \max\{0, q - D\}$.
Based on (4), the retailer's profit function is rewritten as:

$$\pi_r(p, q) = (p - w)q - pE[q - D]^+ \tag{5}$$

As shown in (6), the retailer utilized a distribution-free approach to determine an upper bound on the expected remaining inventory, given demand distribution partial information [17, 30, 42].

$$E[q-D]^{+} \leq \frac{\sqrt{\sigma^{2}+(q-\mu-y)^{2}}+(q-\mu-y)}{2} \quad (6)$$

Whenever $\mu = 0$, the updated profit function for the retailer, considering the maximum remaining inventory, is expressed in (7):

$$\pi_r(p,q) = (p-w)q - p\frac{\sqrt{\sigma^{2}+(q-y)^{2}}+(q-y)}{2} \quad (7)$$

Hence, considering $\beta = \frac{p-w}{p}$, for any given p, the optimal order value of q is achieved.

$$q = y + \frac{\sigma(2\beta-1)}{2\sqrt{\beta(1-\beta)}} \quad (8)$$

By substituting (8) into (7) and simplifying the resulting expression, (9) is obtained:

$$\pi_r(p,w) = (p-w)\tilde{y} - \sigma\sqrt{w(p-w)} \quad (9)$$

Where $\sqrt{w(p-w)} = p\sqrt{\beta(\beta-1)}$

$$\pi_r(p,w) = (p-w)y - \sigma p\sqrt{\beta(\beta-1)} \quad (10)$$

Considering $\partial\delta(\beta) = \partial\sqrt{\beta(\beta-1)}$, and by solving partial derivatives $\frac{\partial\delta}{\partial p} = 0$ and $\frac{\partial\delta}{\partial w} = 0$ using Chain Rule, it becomes evident that only $\frac{\partial\delta}{\partial\beta} = 0$ is valid, resulting in $\beta = \frac{1}{2}$ to maximize the function δ. Finally, the retailer's profit function can be rewritten as follows:

$$\pi_r(p,w) = (p-w)y - \frac{p\sigma}{2} \quad (11)$$

Due to the high expenses of green investment, the manufacturer is mainly concerned with the fairness of returns and profit distribution in their channel. The fairness concern coefficient is denoted by λ_0, and when $\lambda_0 > 0$, the manufacturer uses the retailer's profit used as the reference point for comparison [36]. The manufacturer's utility is denoted as follows:

$$U_m = \pi_m - \lambda_0(\pi_r - \pi_m) = (1+\lambda_0)\pi_m - \lambda_0\pi_r \quad (12)$$

Based on Jian's approach [36], $\breve{U}_m \equiv \frac{U_m}{1+\lambda_0} = \pi_m - \frac{\lambda_0}{1+\lambda_0}\pi_r$, and $\lambda = \frac{\lambda_0}{1+\lambda_0}$. In this study, the fairness concern coefficient is denoted by λ where $\lambda \epsilon [0,1]$. If the manufacturer is fairness neutral, $\lambda = \lambda_0 = 0$. However, if $\lambda_0 \to \infty$, and $\lambda \to 1$, indicate that the manufacturer is extremely concerned. The manufacturer's utility function, incorporating fairness concern, can be derived as follows:

$$U_m = \pi_m - \lambda\,\pi_r = \left((w-c)y - i\theta^2\right) - \lambda\left((p-w)y - \frac{p\sigma}{2}\right) \quad (13)$$

This utility function captures the manufacturer's trade-off between maximizing its own profit and a negative response to profit differences with the retailer. As the fairness concern coefficient, λ increases, the manufacturer becomes more concerned when the retailer earns significantly more, leading to decisions aimed at addressing perceived inequities and achieving a fairer profit distribution.

To analyze the concavity conditions of manufacturer's utility function, refer to Appendix.

The decisions of the manufacturer are determined by solving $\frac{\partial U_m}{\partial w} = 0$, and $\frac{\partial U_m}{\partial \theta} = 0$, as follows:

$$w^d = \frac{4bi(1+bc+\lambda) - bc\gamma^2 + (1+\lambda)(2bi+\gamma^2\lambda)\sigma}{b(-\gamma^2 + 4bi(2+\lambda))} \quad (14)$$

$$\theta^d = \frac{\gamma(2 - 2bc + \sigma + 2\lambda(2 + \lambda)\sigma)}{-2\gamma^2 + 8bi(2 + \lambda)} \tag{15}$$

Then, considering $\frac{\partial^2 \pi_r}{\partial p^2} = -2b \leq 0$, the retailer's best response is:

$$p^d = \frac{4b^2ci + \gamma^2(1 + \lambda)(1 + 2\lambda)\sigma - 2b\left(c\gamma^2 + i(-6 - 4\lambda + \sigma)\right)}{2b\left(-\gamma^2 + 4bi(2 + \lambda)\right)} \tag{16}$$

II. Centralized Decision-making

In this scenario, the main objective is the overall performance of the system. The decisions are optimized using the Nash equilibrium. In the centralized system, the profit of the whole system can be represented as:

$$\pi_{sc}(p, \theta) = (p - c)y - \frac{p\sigma}{2} - i\theta^2 \tag{17}$$

Next, the optimality conditions, $\frac{\partial^2 \pi_{sc}}{\partial p^2} = -2b \leq 0$, and $\frac{\partial^2 \pi_{sc}}{\partial \theta^2} = -2i \leq 0$ are given in the Hessian matrix in (18). $|H| \geq 0$, if $4bi \geq \gamma^2$. So, that proves the supply chain's concavity.

$$H = \begin{bmatrix} \frac{\partial^2 \pi_{sc}}{\partial p^2} & \frac{\partial^2 \pi_{sc}}{\partial p \partial \theta} \\ \frac{\partial^2 \pi_{sc}}{\partial \theta \partial p} & \frac{\partial^2 \pi_{sc}}{\partial \theta^2} \end{bmatrix} = \begin{bmatrix} -2b & \gamma \\ \gamma & -2i \end{bmatrix} \tag{18}$$

The optimal centralized decisions are as follows:

$$p^c = \frac{i(2 + 2bc - \sigma) - c\gamma^2}{4bi - \gamma^2} \tag{19}$$

$$\theta^c = \frac{\gamma(-2 + 2bc + \sigma)}{2(-4bi + \gamma^2)} \tag{20}$$

III. Coordination Model with Fairness Concern Through PSB

When fairness concerns arise across supply chain members, contracts become essential for achieving coordination and satisfaction. The PSB contract addresses fairness issues, allowing both parties to negotiate the profit-sharing percentage for fairness distribution. To motivate the retailer to increase its profit share, the environmentally conscious manufacturer commits to reduced pricing and enhanced sustainability measures. The variable φ represents the retailer's PSB ratio, while the remaining portion of the profit for the retailer is represented by $1 - \varphi$, where $\varphi \in [0,1]$. The functions under the coordination model, are as follows:

$$\pi_m(w, \theta) = (w - c)y - i\theta^2 + (\varphi)\left((p - w)y - \frac{p\sigma}{2}\right) \tag{21}$$

$$\pi_r(p) = (1 - \varphi)\left((p - w)y - \frac{p\sigma}{2}\right) \tag{22}$$

$$U_m(w,\theta) = (w-c)y - i\theta^2 + (\varphi)\left((p-w)y - \frac{p\sigma}{2}\right) - \lambda\left((1-\varphi)\left((p-w)y - \frac{p\sigma}{2}\right)\right) \tag{23}$$

As outlined in the PSB contract, the optimal decision variables are:

$$w^b = w^b(\varphi) = \frac{b(c\gamma^2 + 2i(1+\lambda)(2+\sigma)(-1+\varphi)) - 4b^2ci - \gamma^2(1+\lambda)\sigma(-1+\varphi)(\lambda(-1+\varphi)+\varphi)}{b(\gamma^2 + 4bi(-2+\lambda(-1+\varphi)+\varphi))} \tag{24}$$

$$\theta^b = \theta^b(\varphi) = \frac{\gamma(-2+2bc+\sigma(-1-2\lambda(2+\lambda)+4\varphi+4\lambda(2+\lambda)\varphi - 2(1+\lambda)^2\varphi^2))}{2(\gamma^2+4bi(-2+\lambda(-1+\varphi)+\varphi))} \tag{25}$$

$$p^b = p^b(\varphi) = \frac{2b(c\gamma^2 + i(-6-4\lambda+\sigma+4(1+\lambda)\varphi)) - 4b^2ci - \gamma^2(1+\lambda)\sigma(-1+\varphi)(-1+2\lambda(-1+\varphi)+2\varphi)}{2b(\gamma^2+4bi(-2+\lambda(-1+\varphi)+\varphi))} \tag{26}$$

Assuming a Nash bargaining game is being played, the negotiation process can be described as:

$$max\pi_b = \pi_b(\varphi^b) = {U_m}^b\, {\pi_r}^b \tag{27}$$

To find the optimal value of φ^b, $\frac{\partial \pi_b}{\partial \varphi} = 0$ must be solved. However, due to the complexity of (27), it is impractical to find a closed-form solution for φ^b. Therefore, it is important to highlight that the optimal value of φ^b is obtained by solving the numerical equation and placed in the principal equations.

NUMERICAL ANALYSIS

This paper is inspired by a real-world case from Pars Paper Industrial Group, an Iranian company specializing in the production of environmentally friendly paper products. Pars Paper invests in new technologies to prevent deforestation, with a green investment level coefficient of $i = 0.6$ Toman per paper, under an extreme fairness concern coefficient of $\lambda = 1$. Due to growing awareness, the consumer sensitivity coefficient to the green level is considered to be $\gamma = 0.7$. Furthermore, the company incurs a production cost of $c = 0.5$ Toman per paper. It should be noted that the known parameter for stochastic demand is $\sigma = 0.001$.

I. The Effect of Consumer Sensitivity on the Green Level of the Product

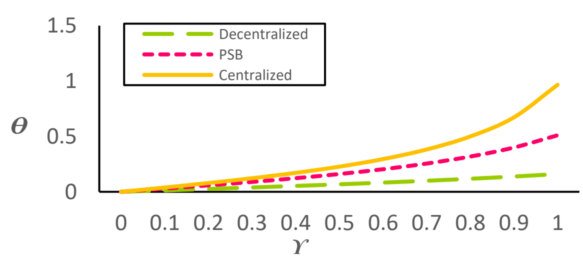
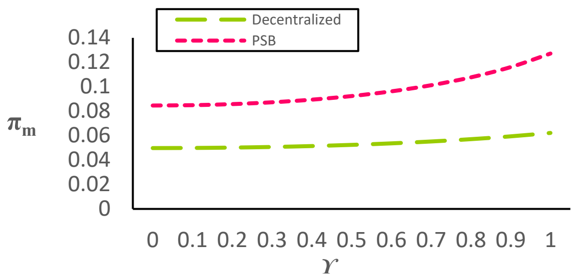
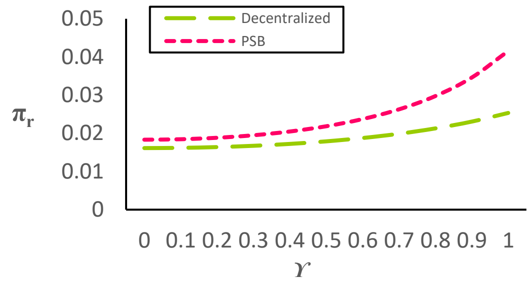


FIGURE 2
EFFECT OF CONSUMER SENSITIVITY ON THE GREEN LEVEL OF THE PRODUCT

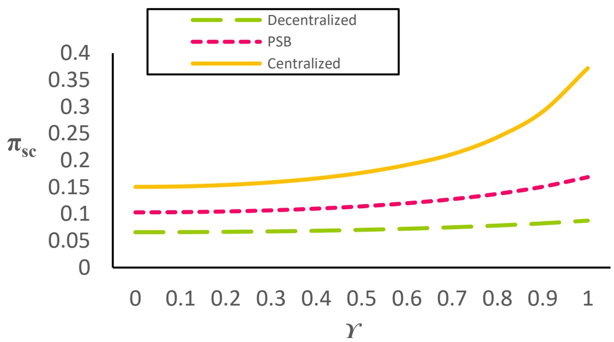
Figure 2 illustrates the influence of consumers' environmental consciousness on manufacturer' green decisions. Consequently, as consumers demonstrate interest in purchasing environmentally friendly products, it becomes evident that manufacturers will improve the environmental sustainability of their products by increasing their investments, even with high levels of fairness concerns in decentralized and PSB contract models.



a: Manufacturer’s profit



b: Retailer’s profit



c: Supply chain’s profit

FIGURE 3
EFFECT OF CONSUMER GREEN SENSITIVITY ON THE PROFIT OF MEMBERS AND THE ENTIRE GREEN SUPPLY CHAIN.

According to Figure 3(a) through Figure 3(c), increasing the customer's sensitivity to the green level leads to improved profits. The PSB scenario can bring the results of the decentralized model closer to the centralized model and enhance them. This implies that PSB can effectively control the manufacturer's high concern, leading to the satisfaction and advantage for the retailer as well.

II. The Effect of Fairness Concern

Considering fairness concerns in mathematical modelling can provide organizations with effective management insights. Overall, the findings suggest that employing PSB contract can effectively minimize the adverse impacts of fairness issues.

Figure 4 illustrates the effect of fairness concerns on green decision-making. As the green level of products increases, higher investment costs are inevitably required. Consequently, the manufacturer may focus on the immediate financial burden and underestimate the long-term economic, environmental, and reputational benefits such investments offer. As fairness concerns increase, in both PSB and decentralized scenarios, decision-making shifts toward maximizing utility and reducing investment, leading to a decline in product greenness. However, under the PSB scenario, the green level, θ is significantly higher compared to the decentralized case.

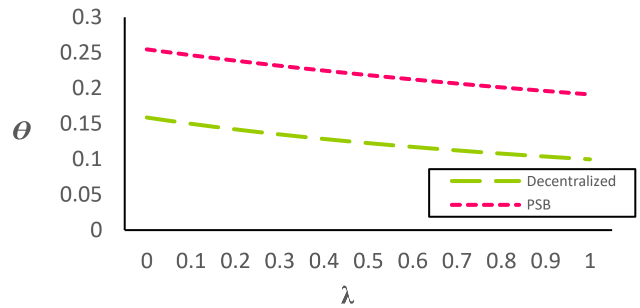


FIGURE 4
EFFECT OF THE FAIRNESS CONCERN ON THE GREEN LEVEL OF THE PRODUCT

Figure 5 illustrates how rising fairness concerns affect the order quantity in both decentralized and PSB scenarios. Amid growing concerns about manufacturer fairness and conservative strategies, such as reducing green product features, a fairness-neutral retailer, responding to the preferences of environmentally conscious customers, is compelled to reduce the inventory level, q. This decision aims to balance customer satisfaction and profitability amid rising demand for sustainable products and environmental efforts, though reducing inventory risks lower profits. However, in the PSB scenario, the retailer increases the inventory level.

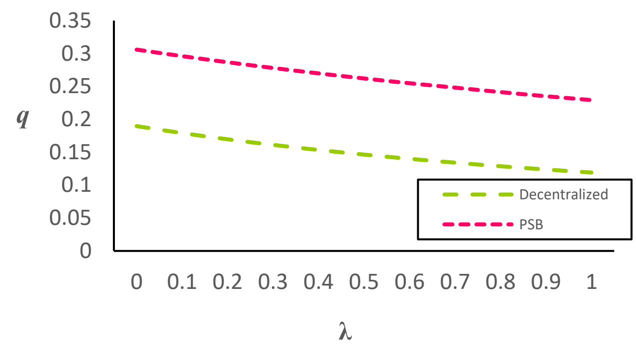
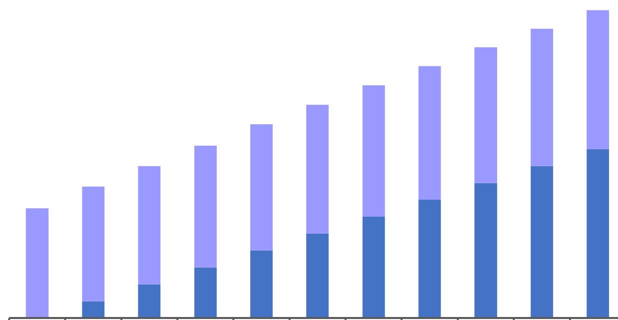


FIGURE 5
EFFECT OF THE FAIRNESS CONCERN ON THE ORDER QUANTITY

According to Figure 6, it is evident that fairness concerns positively influence the PSB ratio. As fairness concerns intensify, the resulting conservative decision-making can undermine the interests of both the fairness-concerned manufacturer and the fairness-neutral retailer. To mitigate this potential loss, supply chain members with bargaining power negotiate the profit-sharing rate under the adopted PSB contract. These negotiations seek to ensure a fair distribution of profits and help maintain the satisfaction of environmentally conscious consumers, whose continued support is a critical driver of long-term competitiveness in green markets.



	1	2	3	4	5	6	7	8	9	10	11
PSB ratio	0.65	0.678	0.7	0.72	0.747	0.763	0.778	0.791	0.803	0.813	0.823
Fairness concern	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

FIGURE 6
EFFECT OF THE FAIRNESS CONCERN ON THE ORDER QUANTITY

In Figures 7(a) to (c), it is evident that the profit functions for members and supply chains in both decentralized and PSB scenarios exhibit a decreasing trend with increasing fairness concerns. As the manufacturer becomes more concerned with fairness, their conservative decisions prompt the fairness-neutral retailer to adopt a similarly cautious approach to protect its own interests. Collectively, these conservative strategies reduce overall supply chain efficiency, ultimately leading to decreased consumer demand and profitability. However, the PSB scenario proves to be more favorable. By aligning incentives and promoting cooperation, the PSB contract mitigates fairness concerns, leading to higher profitability compared to the decentralized model. The results illustrate that the combination of profit-sharing contracts and bargaining, plays an essential role in determining the retailer's share of profits. It should be noted that if $\lambda < 0.3$, this contract is not advantageous for the fairness-neutral retailer. Conversely, if $\lambda \geq 0.3$, both parties can come to a consensus on the contract, leading to higher profits for the entire supply chain compared to the decentralized scenario.

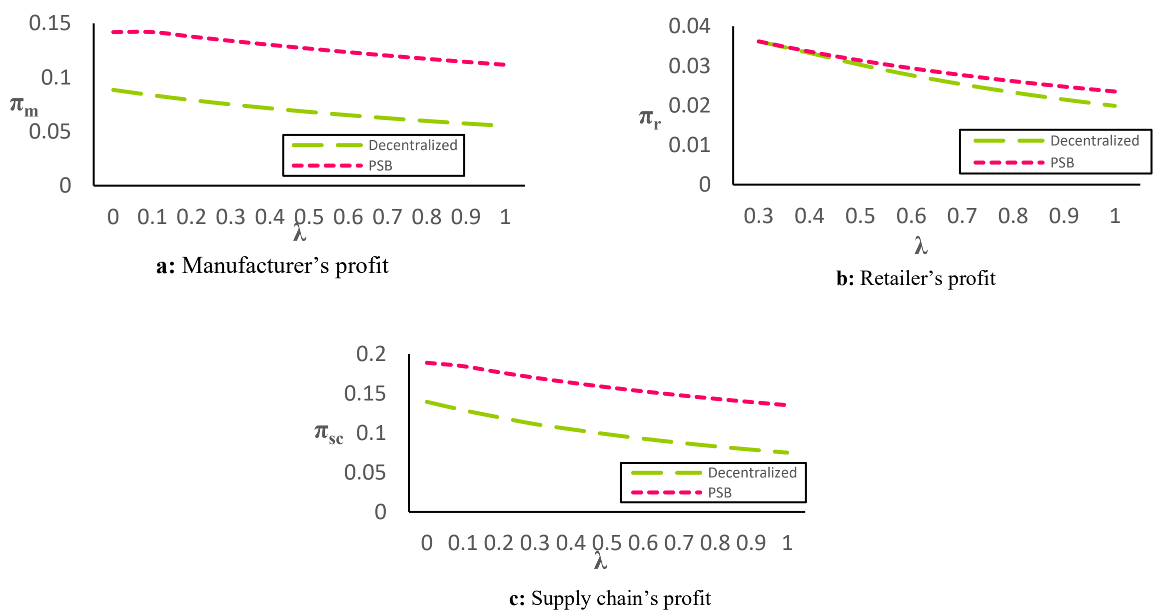


FIGURE 7
EFFECT OF THE FAIRNESS CONCERN ON THE ORDER QUANTITY

DISCUSSION

This section offers managerial and practical insights to support more effective decision-making for industries pursuing sustainability and environmental responsibility.

I. Managerial Implications

Since the primary focus of the proposed model is on decision-making under fairness concerns within the green supply chain facing consumers' stochastic demand with partial information, the key managerial implications are outlined as follows:

- Given the constant changes in the economic landscape and intense market competition, supply chains must address the challenge of operating with partial information about consumers' stochastic demand. To remain competitive and avoid losses, companies must evaluate their predictive models under stochastic conditions that reflect real-world scenarios.
- In reality, supply chain demand often involves incomplete information or follows from unknown distribution functions. This paper demonstrates that, by using the free-distribution approach, total profit can still be maximized, even under the worst case.
- Given the growing public awareness of environmental issues, adopting green initiatives despite initial costs offers significant long-term profitability benefits and strengthens the company's market position.
- The model results reveal that when fairness concerns guide the manufacturer's decisions, they adopt a more cautious approach, prioritizing short-term utility over long-term benefits. By focusing on fairness, manufacturers often reduce the green product level to cut costs, potentially alienating environmentally conscious consumers. This approach leads to financial losses for both the manufacturer and retailer, ultimately reducing overall system profitability due to the "double marginalization effect".
- Supply chain coordination contracts can take different forms, each designed for specific conditions. In this study, where fairness concerns surrounding profit distribution play a main role in decision-making, the PSB contract was chosen to counter conservative behavior. The results highlight its effectiveness in addressing these concerns.

II. Practical Implications

- Nowadays, consumers prefer products with a reduced ecological impact, so companies must adopt green initiatives to remain competitive and protect their brand reputation. For instance, Pepsi Cola, a leading beverage manufacturer, utilizes innovative technology to take the place of plastic containers, thereby helping to reduce environmental pollution [23].
- As environmentally conscious consumers increasingly seek products with lower ecological footprints, manufacturers can find significant economic benefits in investing in sustainable production practices. To facilitate this transition, policymakers and environmental regulators should introduce market-based incentives, such as green credits, targeted subsidies, or public recognition programs. These measures can help overcome the challenge of high upfront costs and encourage manufacturers to adopt green technologies, ultimately driving advantages for both the environment and the economy.
- Given the significant costs of sustainable investments, environmentally conscious manufacturers often adopt conservative strategies to ensure an equitable distribution of profits and maximize their utility, which can impact on efficiency of other members and the total supply chain. For example, during the initial phase of collaboration between Wal-Mart and Procter & Gamble, an imbalanced allocation of advantages gave rise to significant tensions and conflicts [36]. To address this issue, a profit-sharing agreement that incorporates equal bargaining power can create a mutually beneficial situation for all parties involved.
- Since a coordination agreement without negotiation can shift the distribution of benefits in one direction, flexible contracts negotiated through bargaining, such as the PSB contract, can help avoid bias and ensure that parties can fairly address their concerns. A case in point is BMW's $117 million partnership with Contemporary Amperex Technology Ltd., the biggest battery manufacturer globally, aims to produce energy-efficient automotive batteries. [43]. To encourage the wider adoption of these contracts, clear communication, legal expertise, and fair negotiation

frameworks are crucial. To support practical implementation, industry groups can offer standardized contract templates, share proven best practices, and provide impartial guidance to ensure smooth and successful execution.

CONCLUSION T AND RECOMMENDATION

Recently, increasing consumer awareness and government pressure have led firms to embrace sustainable practices to achieve a competitive edge. Although investing in environmentally friendly initiatives can be costly in the short term and negatively impact profit margins, this paper investigates green issues within the supply chain framework, focusing on manufacturers' fairness concern and addressing partial information through a free-distribution approach. The manufacturer prioritizes fairness in returns, deciding on wholesale prices and green level, while the retailer establishes a retail price and decides on the order quantity in a stochastic demand situation.

This study proposes a game theory model to address profit appropriation among members, considering centralized, decentralized, and PSB contract models for stochastic demand, utilizing a distribution-free approach in scenarios with incomplete information. Numerical analysis demonstrates that the PSB contract effectively coordinates the supply chain, even with incomplete demand information. It allows manufacturers concerned about fairness to enhance profitability by increasing investments in environmental sustainability. The results emphasize the importance of fair behavior, consumer sensitivity, and environmental awareness in boosting stakeholder profitability, suggesting that manufacturers' motivation for green investment increases in response to customer sensitivity to environmental issues.

Future research should broaden the scope of the supply chain to investigate competition among members, focusing on peer concerns and distributional issues. Additionally, incorporating fairness considerations into blockchain-based green supply chains is recommended to encourage the development of innovative concepts for future exploration.

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APPENDIX

By calculating the First order optimal conditions of the utility function with respect to w and θ, the following are obtained:

$$\frac{\partial U_m}{\partial w}=\frac{-2b(1+\gamma\theta)(1+\lambda)(-1+\varphi)+b^2w(-2+\lambda(-1+\varphi)+\varphi)+b^2(2c+w(-2+\lambda(-1+\varphi)+\varphi))}{4b} \quad (A.1)$$

$$\frac{\partial U_m}{\partial \theta} = \frac{-2b(c\gamma + 4i\theta + w\gamma(1+\lambda)(-1+\varphi)) + 2\gamma(1+\gamma\theta)(\lambda(-1+\varphi)+\varphi)}{4b} \tag{A.2}$$

$\frac{\partial^2 U_m}{\partial w^2} = \frac{1}{2}b(-2+\lambda(-1+\varphi)+\varphi) \leq 0$; and $\frac{\partial^2 U_m}{\partial \theta^2} = \frac{-8bi+2\gamma^2(\lambda(-1+\varphi)+\varphi)}{4b} \leq 0.$

The Hessian matrix is given by:

$$|H| = \begin{bmatrix} \frac{1}{2}b(-2+\lambda(-1+\varphi)+\varphi) & -\frac{1}{2}\gamma(1+\lambda)(-1+\varphi) \\ -\frac{1}{2}\gamma(1+\lambda)(-1+\varphi) & \frac{-8bi+2\gamma^2(\lambda(-1+\varphi)+\varphi)}{4b} \end{bmatrix} \tag{A.3}$$

The utility function is concave, if $|H| \geq 0, -\frac{\gamma^2}{4} + bi(2+\lambda-(1+\lambda)\varphi) \geq 0.$