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Textile and apparel supply chain coordination under ESG related cost-sharing contract based on stochastic demand

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A R T I C L E I N F O

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A B S T R A C T

In recent years, heightened attention has been given to the challenges of sustainable development precipitated by environmental pollution in the Textile and Apparel (TA) industry. The burgeoning demand for fast fashion, often reliant on cheap and environmentally unsustainable textiles, exacerbates this environmental degradation. To facilitate a harmonized and sustainable progression of the entire TA industry, this study employs the Stackelberg game model to investigate the prerequisites for establishing Environmental, Social, and Governance (ESG) related cost-sharing contracts and their consequential effects on supply chain coordination. Specifically, the paper compares four distinct supply chain models under two conditions: whether market demand is stochastic or deterministic. Through this comparative analysis, the study finds that the ESG related cost-sharing contracts bring more profit to the textile and apparel supply chain (TASC) in deterministic and stochastic demand, which effectively mitigates the risks associated with unpredictable demand. Numerical results indicate that the ESG cost-sharing contract significantly improves TASC's ESG performance with customers' sustainable awareness increasing. Furthermore, such contracts are instrumental in enhancing the aggregate ESG environmental performance of the Textile and Apparel Supply Chain (TASC), elevating profits for both manufacturers and retailers and alleviating the impact of fluctuating demand on supply chain participants.

1. Introduction

In recent years, the rapidly expanding textile and apparel (TA) industries have become notorious for being major contributors to global pollution (John and Mishra, 2023; Pal and Gander, 2018). Especially, a growing demand for fast fashion products relying on cheap textile production, frequent cloth consumption, and short-lived garment usage exacerbate environmental pollution. According to a range of estimations, the TA industry produces up to 10% of CO_2 emissions, which is the second largest source of industrial pollution after aviation. On the basis of these environmental impacts, it is urgent and essential to adopt an approach to change the unsustainable practices of the industry. For example, ZARA has taken steps to protect biodiversity, reduce the consumption of water, energy and other resources, avoid waste and combat climate change. More than 200 leading brands in the sportswear, fashion, luxury, and carpeting sectors have adopted the ECONYL recycling system, including Stella McCartney, Gucci, Volcom, Adidas, and Levis (DiVito et al., 2022).

In addition to environmental concerns, the textile and apparel supply chain (TASC) also faces another problem: unstable market demand, especially during the COVID-19 epidemic (Dohale et al., 2023). This impact of uncertainty even continues into the post-epidemic era. Adhikari et al. (2020) given the high volatility in apparel demand and cotton production yield coordination mechanism issues. The holistic depiction of the TASC in different demand scenarios draws scholarly attention. Yaghin (2020) proposed a geometric multivariate demand function in the TA industry to enhance TASC production-marketing planning. Shafiee Roudbari et al. (2023) designed a two-stage stochastic programming for the garment industry in Montreal, Canada based on circular economy strategies. In an attempt to reduce the impact of demand uncertainty, our study aims to incorporate sustainability and environmental concerns into the garment industry.

Currently, the importance of Environmental, Social, and Governance (ESG) for societal and corporate development has surpassed that of CSR (Cucari et al., 2018), and investors have gradually shifted from focusing on corporate financial performance to corporate sustainability performance, especially within these three critical dimensions (Tsang et al., 2023). In 2004, the United Nations Global Compact released a report

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titled, Who Cares Wins. The report formally proposed the concept of ESG which has since gradually been adopted by governments and regulators (Eccles et al., 2020). Corporate ESG performance can improve companies' total factor productivity, financial performance, innovation level, reputation, and more (Avramov et al., 2022). Recent studies have found that, in an asymmetrical information environment, corporate ESG performance allows firms to win the trust of stakeholders such as financial institutions, suppliers, and customers, which reduces business operational costs while improving efficiency (Houston and Shan, 2022). More and more enterprises are opting to introduce ESG into their developmental strategies to promote the harmonization of corporate and social values with high-quality economic development (Tan and Zhu, 2022). Since corporate ESG activities are associated with high input costs and uncertain outputs (which may weaken firms' motivation to implement ESG activities), ESG cost-sharing is a potential cost-saving solution (Sandu et al., 2023). Therefore, this study attempts to depict ESG efforts as a sustainable cost for TASC. It utilizes optimization methods (OM) to find the best decision among the manufacturer and retailer to achieve overall sustainability.

The study proposes an ESG related cost-sharing contract in a two-echelon TASC to coordinate the manufacturer and retailer shift toward achieving sustainability within the TA industry. Specifically, this paper investigates how two different scenarios (whether the market is stochastic or not) affect the supply chain. Based on the Stackelberg game model, we explore how four different cost-sharing contract condition modes (i.e., decentralized decision-making under deterministic demand; ESG cost-sharing contracts under deterministic demand; decentralized decision-making under stochastic demand; and ESG cost-sharing contracts under stochastic demand) influence the supply chain's coordination mechanisms. To explore these different ESG cost-sharing agreement conditions and identify effective incentives for the sustainable development of the TASC as a whole, the purpose of this paper is to explore the following issues:

RQ1. What is the best decision-making strategy for the manufacturer and retailer in the TASC deterministic and stochastic market?

RQ2. Can ESG cost-sharing contracts be reached among TASC participants, and will this improve the sustainable performance and profits of the entire TASC?

RQ3. How do customers' ESG perceptions impact TASC participants' profitability and decision-making in the stochastic market?

The remaining parts of this paper are organized as follows. Part 2 is a literature review. Part 3 gives the notation and assumptions related to the model considered in this paper. Part 4 and Part 5 develop models based on different decisions and give the modeling analysis. Part 6 performs some numerical analysis to verify the effect of the relevant parameters on the model. The final section draws some conclusions.

2. Literature review

This paper is closely related to sustainable supply chain coordination, ESG development in supply chain contract coordination, and supply chain development in the TA industry.

2.1. Supply chain coordination

From sustainability to resilience to digitalization and artificial intelligence, the field of supply chain research is rapidly evolving, providing companies with new tools and strategies to respond to changing market conditions (Saberi et al., 2019). Research questions related to supply chain management are divided into five categories: Inventory Problem (IP), Information Flow (IF) and Coordination and Contract (CC), Network Design (ND), and Performance Evaluation (PE) (Tiwari et al., 2012). Among them, Supply chain coordination is essential to integration and collaboration among supply chain nodes (Terzi and Cavalieri, 2004). As a result, academic and corporate communities are paying more attention to supply chain coordination and contracting issues. Existing studies have shown that the coordination mechanism helps supply chain partners keep up with market fluctuations and enhance supply chain trust and partnership (Xiao et al., 2017).

The existing supply chain coordination contracts discuss, on the one hand, determining contract parameters under specific contract terms and, on the other, the relationship between demand patterns and contract conditions (Tsay et al., 1999; Wu, 2013). For example, Giannoccaro and Pontrandolfo (2004) found that supply chain coordination can be achieved by adjusting the contract parameters in the revenue-sharing contract model to improve all participants' profits and system efficiency. By designing coordination contracts, Bernstein and Federgruen (2005) study under uncertainty by designing a coordination contract for an equilibrium behavior of a decentralized supply chain with competing retailers. Based on the Pareto optimality theory, Zhang et al. (2022) studied the standard double-agent supply chain with supply chain coordination under the objectives of mean variance (MV) and mean marginal risk (MDR). In addition, Li et al. (2022) investigated the coordination mechanism of commercial credit in supply chains oriented to stochastic demand, and analyzed the best operational decisions using a Stackelberg game model.

However, few existing studies integrate the effect of coordination agreements on the supply chain and its participants' performance. Further research is needed to examine the impact of relevant coordination pacts on the performance of the SC and its participants and on increasing the system's operational performance. Thus, this study explores the conditions for ESG cost-sharing contracts and seeks incentives for the overall sustainability of the supply chain apparel industry.

2.2. ESG development in supply chain contract coordination

ESG initially originated from the United Nations Global Compact *Who Cares Wins* in 2004, which formally introduced the concept of ESG to national governments and financial regulators (UNEP, 2004). GRI, SASB, CDP, CDSB, and IIRC then jointly issued a plan to build a unified ESG disclosure standard in 2020, following continuous improvement and development (Afolabi et al., 2022). Countries have introduced many ESG-related policies and regulations over the past decade to encourage reporting financial data by listed companies alongside their ESG performance (Cicchiello et al., 2023). The European Union has developed environmental auditing rules and management systems such as ISO 14001, which have resulted in the most complete and useful environment-related reporting (Neugebauer, 2012). Moreover, according to Mackay et al. (2022), in October 2021, the Canadian Securities Administrators (CSA) would issue a proposal titled Disclosure on Climate-Related Matters, which would introduce mandatory disclosure requirements for corporations (other than investment funds) regarding climate-related matters. Furthermore, a growing number of environmental issues such as carbon emissions, biological diversity, and climate change are integrated into ESG's Environment (Folque et al., 2021; Lambooy et al., 2018; Persakis, 2023). Compared with traditional CSR, ESG pays more attention to environmental issues that are in line with the sustainable development needs of industrial sectors, especially in the energy-intensive TA sector.

ESG rating as a key indicator of management capacities, corporate sustainability, and social commitment has been increasingly used to evaluate corporate non-financial performance (Eccles et al., 2020; Lokuwaduge and Heenetigala, 2017). An increasing number of listed companies disclose their ESG performance by releasing ESG reports, in order to gain the favor from capital market (Camilleri, 2015; Gallucci et al., 2022; Tsang et al., 2023). In this context, the current research focuses on corporate ESG practices and performance. Folque et al. (2021) proposed integrating ESG risks into sustainable investment funds will enhance sustainable development. Tan and Zhu (2022) showed that ESG ratings significantly promote corporate green innovation, alleviate financial constraints, and increase environmental awareness. Persakis (2023) found that the firms will enhance their ESG performance in measuring climate policy uncertainty. ESG ratings and practices can indeed help companies improve total factor productivity, financial performance, innovation level, and reputation. López Sarabia et al. (2021) stated Covid-19 accelerated the garment industries adopt ESG standards. Several ESG rating methods have been introduced to assess TA industries' sustainable performance. Liu et al. (2023) used blockchain technology to assess ESG performance in the TA industry.

In recent years, ESG rating has been gradually applied to evaluate supply chain sustainability. Zeng et al. (2022) combined ESG and financial indicators to assess green supply chain performance. Baid and Jayaraman (2022) amplified the importance of social responsibility ("S" in ESG) in supply chain financing. Bade et al. (2023) leveraged qualitative and quantitative methods based on the grounded theory to investigate the effect of German pharmaceutical corporations' ESG maturity on supply chain security. In today's highly globalized economy, ESG measures are futile unless they explicitly incorporate an individual company's end-to-end operations throughout its entire supply chain (Dai and Tang, 2022). However, Current research mainly focuses on ESG ratings and their effect, and less on ESG-related supply chain practices. We found that the research on corporate social responsibility has been integrated into supply chain coordination to enhance the sustainability of the entire supply chain. Yang et al. (2022) introduced a cost-sharing contract with CSR efforts to a three-tier supply chain. Aflaki and Pedraza-Martinez (2023) proposed a CSR-related revenue-sharing contract to coordinate the general supply chain. These research have certain significance in the supply chain ESG measures.

2.3. Supply chain development in the TA industry

Many industries have been affected by globalization, including the TA industry. Due to the globalization of the economy and the advancement of various technologies, the business and production models utilized in the TA industry have undergone significant development and change. In the said industry, operational management of the supply chain is typically a complex and critical process. In a conventional garment manufacturing supply chain, raw materials are procured from many suppliers, followed by producing goods in one or more manufacturing facilities (Sen, 2008). The goods are then conveyed to intermediate storage facilities, such as warehouses or distribution centers, for packaging, loading, and delivery to retailers or end consumers (Boysen et al., 2021).

However, rapid economic growth has presented the apparel industry with new sustainability challenges. As a result, contemporary apparel supply chains have faced the urgent need to fully integrate sustainability into their operations (Saha et al., 2021). According to the findings of Bruce et al. (2004), many companies have relocated their production bases to countries with lower labor costs to pursue cost efficiency, meet market demand, and optimize productivity.

In addition, the proliferation of consumer preferences has resulted in a surge in the assortment of products and designs accessible on the market, and the phenomenon of fast fashion has experienced and widespread growth (Jeacle, 2015). However, the increased production speed and decreased lifespan of apparel have posed significant challenges for inventory management, shipping, and production planning (Bruce and Daly, 2011). Additionally, Jeacle (2015) found that substantial quantities of water and chemicals are utilized in the textile and apparel manufacturing process, resulting in significant environmental contamination. Due to this rationale, many enterprises are prioritizing their supply chains' environmental consciousness and sustainability. Thus, this study proposes integrating ESG into the TASC while utilizing optimization methods (OM) to address sustainability issues in the TA industry.

In this context, this research makes three significant contributions to complement the current study. Firstly, referred to Raza (2018) in CSR investment depicting, the manufacturer's and retailer's ESG performance is used to represent the TASC's sustainable performance in this study. We introduce the ESG effort to characterize sustainable performance changes, making up for the shortcomings of existing research in characterizing sustainable practices. Furthermore, we extend the study of Yang et al. (2022), ESG cost-sharing contract coordination is introduced to explore its sustainable improvement of the TASC supply chain. Meanwhile, we analyze the optimal decisions of retailers and suppliers under different demand scenarios to verify the coordination effect of the ESG cost-sharing contract. This study expands the research perspective on TASC ESG-related contract coordination under different demand scenarios which enriches the related research on TASC sustainability issues.

Table 1
Notations.

Parameters	
a	Market demand, $a \geq 0$
c	Manufacturing cost for per unit item, $c \geq 0$
b	Price sensitivity coefficient, $b \geq 0$
k	ESG effort sensitivity coefficient, $k \geq 0$
λ	Customer ESG sensitivity coefficient, $\lambda \geq 0$
$C = C(e)$	Product fresh-keeping cost
$\theta = \theta(e)$	ESG performance
$D = D(p, e)$	Deterministic market demand
Accents	
$\tilde{x}$	Parameter, $x \in \mathbb{R}$, when the demand is price-and-ESG dependent stochastic demand
Superscript	
x^{de}	Decisions variables in decentralized scenario
x^{cs}	Decisions variables in ESG cost-sharing contract scenario
x^{*}	Optimal value of a control parameter, $x \in \mathbb{R}$
Subscript	
π_M	Manufacturer profit
π_R	Retailer profit
Decision variables	
Manufacturer	
w	Wholesale price, $w \geq c$
e	ESG effort, $e \geq 0$
β	ESG cost proportion, $0 \leq \beta \leq 1$
Retailer	
m	Retailer margin, $m \leq p$
p	Selling price, $p = w + m$, $w \leq p \leq \frac{a}{b}$
q	Order quantity, $q \geq 0$

3. Research design

3.1. Problem description

The research focuses on the single-selling cycle involving manufacturers and retailers in a TASC. The symbols utilized in this document can be found in Table 1. The retailer orders textiles and apparel (q) from the manufacturer at a wholesale price (w) per unit and then sells it to the end consumer at a retail price (p). In the meantime, the manufacturer makes an effort to its ESG activities that cost an investment (e), which positively impacts market demand. While the retailer generally does not participate in the manufacturer's ESG behaviors, they may assume some of the manufacturer's ESG effort to improve TASC's sustainable performance.

Our research examines the optimal decision-making processes for decentralized TASC decision-making and ESG cost-sharing contracts under two demand scenarios: deterministic demand and stochastic demand. It examines the impact of uncertainty on supply chain coordination and sustainability in both scenarios. It also seeks incentive methods to enhance the overall sustainability of the SC. Fig. 1illustrates the market structure and distribution channels through which products are offered to consumers for the retail model discussed in this paper and a supply chain system diagram to determine whether market demand is

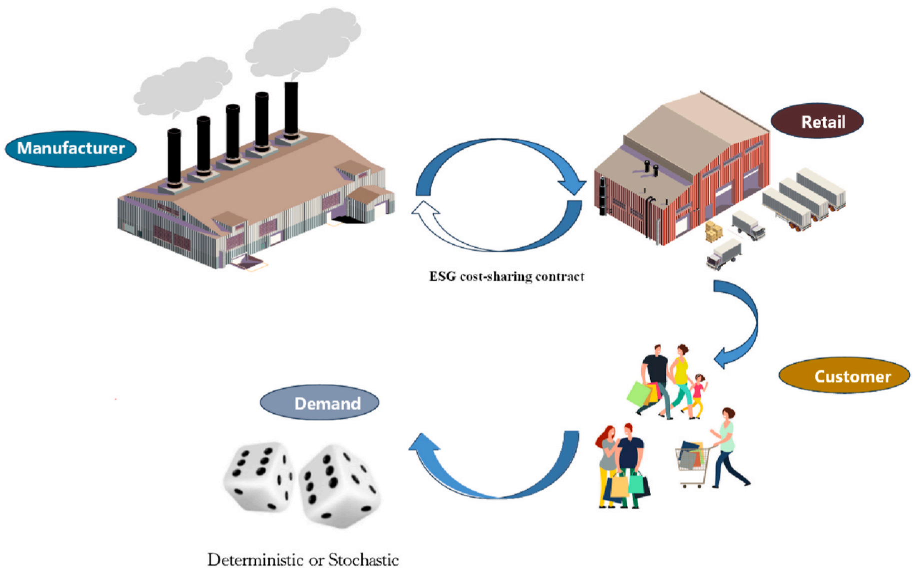


Fig. 1. ESG cost-sharing contracts omnichannel retail model.

random.

3.2. Model assumptions

The following assumptions were considered in order to build a reasonable model and obtain an analytical solution:

Assumption 1. Both the manufacturer and the retailer are rational and risk-neutral.

Assumption 2. There is information symmetry in TASC. This means that players start a single sales period of the game with the same information.

Assumption 3. The market demand is affected by product price and brand social responsibilities, and customers tend to buy low-priced and environment-friendly clothes. Price-and-ESG related deterministic market demand for apparel is developed as $D(p, e) = a - bp + ke\ \left(w \le p \le \frac{a}{b}\right)$, where a is overall apparel market demand, b is product price sensitivity coefficient, and k is ESG effort sensitivity coefficient.

Assumption 4. The ESG effort implies a specific investment cost, denoted as $C(e)$. It is a strictly non-decreasing function of cost. To develop simplified (closed-form) solutions, the ESG cost function is set to $(e) = \frac{1}{2}\lambda e^2$, where λ is the ESG effort coefficient. To ensure the solvability of the model, this coefficient is in a range $\lambda > k^2/2b$.

4. Deterministic demand

When the garment selling period is in price-and-ESG related deterministic demand (D), surplus and safety stocks are not at risk. Thus, once the retailer makes the decision on the selling price (p), the order quantity is equal to the market demand ($q = D$), which is no longer the retailer's decision.

4.1. Decentralized decision-making

Theorem 1. *For the supply chain system discussed in this paper, when the retailer and the manufacturer take decentralized decisions, we got the best wholesale price from the manufacturer* $w^{de*} = \frac{2\lambda(a+bc)-ck^2}{4b\lambda-k^2}$, *and ESG effort* $e^{de*} = \frac{k(a-bc)}{4b\lambda-k^2}$, *while the manufacturer and retailer's optimal profits are* $\pi_R^{de*} = \frac{b\lambda^2(a-bc)^2}{(2b\lambda-k^2)^2}$, $\pi_M^{de*} = \frac{\lambda(a-bc)^2}{2(2b\lambda-k^2)}$ *respectively*.

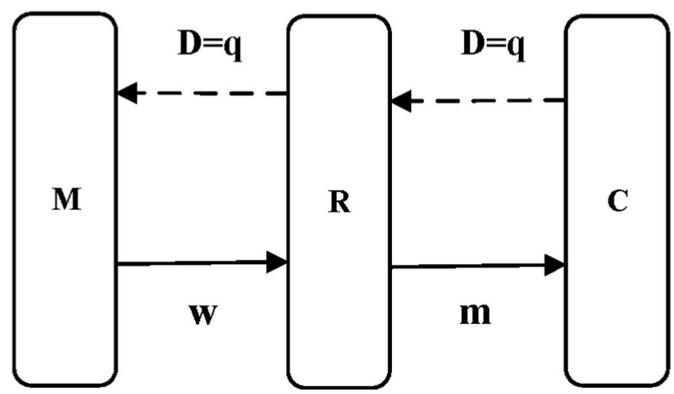


Fig. 2. Decentralized decisions in deterministic demand omnichannel retail model.

In the decentralized decision, the manufacturer as the leader, first decides on the wholesale price (w) and ESG effort (e). In response to the manufacturer's decision, the retailer sets the margin (m) (see Fig.2). Thus, the profit functions of the manufacturer and the retailer are

$$\pi_R(m) = m(a - b(m+w)+ke) \tag{1}$$

$$\pi_M(w,e) = (w-c)(a-b(m+w)+ke) - \frac{1}{2}\lambda e^2 \tag{2}$$

The backward induction method is used to solve the problem. Since $\frac{\partial^2 \pi_R}{\partial m^2} = -2b < 0$, $\pi_R(m)$ is a concave function with the optimal solution. Let $\frac{\partial \pi_R}{\partial m} = 0$, we obtain

$$m(e) = \frac{a - bc + ek}{2b} \tag{3}$$

And then, substituting m into equation (2), we get that $\pi_M = \frac{(w-c)(a-bw+ke)-\lambda e^2}{2}$. The backward induction method is used to solve the problem. The π_M hessian matrix is for w, e is:

$$H = \begin{bmatrix} \frac{\partial^2 \pi_M}{\partial w^2} & \frac{\partial^2 \pi_M}{\partial w \partial e} \\ \frac{\partial^2 \pi_M}{\partial e \partial w} & \frac{\partial^2 \pi_M}{\partial e^2} \end{bmatrix} = \begin{bmatrix} -b & \frac{k}{2} \\ \frac{k}{2} & -\lambda \end{bmatrix}$$

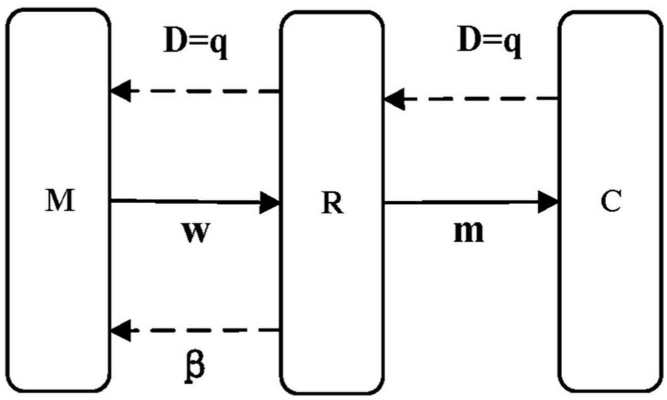


Fig. 3. ESG cost-sharing contract in deterministic demand omnichannel retail model.

From Assumption 4, we can obviously find that the first two principal minors are negative, i.e., $\frac{\partial^2 \pi_M}{\partial w^2} = -b < 0$, $\frac{\partial^2 \pi_M}{\partial e^2} = -\lambda < 0$, i.e., $|H| \geq 0$, so the Hessian matrix is a negative semi-definite matrix. Therefore $\pi_M(w, e)$ is a quasi-concave function with a unique optimal solution. Solving their first-order conditions, we get that

$$w^{de*} = \frac{2\lambda(a+bc) - ck^2}{4b\lambda - k^2} \tag{4}$$

$$e^{de*} = \frac{k(a-bc)}{4b\lambda - k^2} \tag{5}$$

We substitute e^{de*} to equation (3) obtaining that $m^{de*} = \frac{\lambda(a-bc)}{4b\lambda - k^2}$.

The other optimal retail price, manufacturer's profit, and the retailer's profit are $p^{de*} = \frac{\lambda(3a+bc)-ck^2}{4b\lambda-k^2}$, $\pi_R^{de*} = \frac{b\lambda^2(a-bc)^2}{(2b\lambda-k^2)^2}$, $\pi_M^{de*} = \frac{\lambda(a-bc)^2}{2(2b\lambda-k^2)}$ respectively.

4.2. ESG cost-sharing contract

Theorem 2. *For the ESG cost-sharing supply chain system in the TA industry discussed in this paper, when the retailer and the manufacturer take decentralized decisions, we gained the manufacturer's optimal wholesale price* $w^{cs*} = \frac{8b\lambda(a+bc)-k^2(a+5bc)}{2b(8b\lambda-3k^2)}$, *and ESG effort* $e^{cs*} = \frac{2k(a-bc)}{8b\lambda-3k^2}$, *where the manufacturer's ESG cost proportion* $\beta^* = \frac{k^2}{8b\lambda}$. *The maximum gains for the manufacturer and retailer stand at* $\pi_M^{cs*} = \frac{(a-bc)^2(8b\lambda-k^2)}{8(8b\lambda-3k^2)}$ *and* $\pi_R^{cs*} = \frac{(a-bc)^2(8b\lambda+k^2)}{16(8b\lambda-3k^2)}$ *respectively.*

To motivate the garment manufacturer to implement sustainable practices actively, an ESG cost-sharing contract is introduced to coordinate the TASC. It is assumed that the retailer shares β proportion of its ESG cost, $\beta C(e)$, where $0 \leq \beta \leq 1$, and the manufacturer shares $1-\beta$. In the ESG cost-sharing contract, the retailer will decide the proportion (β) at first, and then the manufacturer sets the ESG effort level (e) and wholesale prices (w) (see Fig. 3). The retailer then determines the retail price based on the manufacturer's selection.

Assumption 5. To ensure the meaning of the model, we propose $\lambda > k^2/4b(1-\beta)$ based on assumption 4.

The profit function of the retailer and manufacturer are as follows:

$$\pi_R(p, \beta) = (p-w)(a-bp+ke) - \frac{1}{2}\beta\lambda e^2 \tag{6}$$

$$\pi_M(w, e) = (w-c)(a-bp+ke) - \frac{1}{2}(1-\beta)\lambda e^2 \tag{7}$$

The second derivative of p, $\frac{\partial^2 \pi_R}{\partial p^2} = -2b < 0$. Hence, $\pi_R(p, \beta)$ is a concave function and has a unique optimal solution. Let $\frac{\partial \pi_R}{\partial p} = 0$, the optimal wholesale price function can be obtained as $p(w, e) = \frac{a+bw+ke}{2b}$. And then, substituting $p(w, e)$ to equation (7), we got $\pi_M(w, e) = \frac{(w-c)(a-bw+ke)-\lambda e^2(1-\beta)}{2}$. The $\pi_M(w, e)$ hessian matrix is $H = \begin{bmatrix} \frac{\partial^2 \pi_M}{\partial w^2} & \frac{\partial^2 \pi_M}{\partial w \partial e} \\ \frac{\partial^2 \pi_M}{\partial e \partial w} & \frac{\partial^2 \pi_M}{\partial e^2} \end{bmatrix} = \begin{bmatrix} -b & \frac{k}{2} \\ \frac{k}{2} & -\lambda(1-\beta) \end{bmatrix}$. From Assumption 6, $|H| \geq 0$ which is a positive definite matrix. $\pi_M(w, e)$ is a concave function. Solving their first-order conditions, we get that $w(\beta) = \frac{2\lambda(1-\beta)(a+bc)-ck^2}{4b\lambda(1-\beta)-k^2}$, $e(\beta) = \frac{k(a-bc)}{4b\lambda(1-\beta)-k^2}$.

And then, substituting $p(\beta)$, $w(\beta)$ and $e(\beta)$ to equation (6), we got $\pi_R(\beta) = \frac{\lambda(a-bc)^2[2b\lambda(1-\beta)^2-\beta k^2]}{2[4b\lambda(1-\beta)-k^2]^2}$. Since $\frac{\partial^2 \pi_R}{\partial \beta^2} = -\frac{2bk^2\lambda^2(a-bc)^2[8b\lambda(2\beta+1)-5k^2]}{[4b\lambda(1-\beta)-k^2]^4} \leq 0$, let $\frac{\partial \pi_R}{\partial \beta} = 0$, we get $\beta^* = \frac{k^2}{8b\lambda}$.

The optimal solutions for other parameters are as follows:

$$w^{cs*} = \frac{8b\lambda(a+bc) - k^2(a+5bc)}{2b(8b\lambda - 3k^2)}$$

$$e^{cs*} = \frac{2k(a-bc)}{8b\lambda - 3k^2}$$

$$p^{cs*} = \frac{8b\lambda(3a+bc) - 3k^2(a+3bc)}{4b(8b\lambda - 3k^2)}$$

$$\pi_R^{cs*} = \frac{(a-bc)^2(8b\lambda + k^2)}{16(8b\lambda - 3k^2)}$$

$$\pi_M^{cs*} = \frac{(a-bc)^2(8b\lambda - k^2)}{8(8b\lambda - 3k^2)}$$

Proposition 1. *The ESG cost proportion* β *positively correlates with the ESG effort sensitivity coefficient k and negatively correlates with the customer ESG sensitivity coefficient* λ (Xie et al., 2018).

From Proposition 1, the manufacturer in the case of high ESG costs, retailers only need to bear a low proportion of ESG costs. However, when the consumer ESG sensitivity coefficient is high, the retailer will have to bear a higher proportion of ESG costs. Since the cost-sharing mechanism stimulates the retailer to improve service incentives and thus product quality, the consumer and thus the demand for high-quality products increases significantly, the retailer can share the ESG costs, and even if there is a tiny increase in the quality level of the product, the retailer can ensure profits.

Proposition 2. *The equilibrium value of a general decentralized supply chain compared to the equilibrium value in ESG cost-sharing contract has a value of* $w^{cs*} \geq w^{de*}$, $e^{cs*} \geq e^{de*}$, $p^{cs*} \geq p^{de*}$.

From Proposition 2, it can be observed that in the case of ESG cost-sharing contracts, the manufacturer's investment in the ESG cost-sharing contract situation differs from the corresponding investment in the decentralized decision-making situation. Specifically, manufacturers invest more in ESG in the decentralized decision-making situation because an ESG cost-sharing contract allows the retailer to share some of the ESG costs, reducing the proportion of the manufacturer's investment in ESG. Therefore, for consumers, the cost (price) of purchasing high-quality products under the contract is also higher; consumers are more sensitive to higher-quality products, so consumers' willingness to buy will increase, and thus the demand is expected to increase. As consumers are price sensitive, the elasticity of demand for goods is small, and the negative effect on profits of the decline in demand brought about by price increases is significantly lower than the positive effect of price increases on profits, thus showing a significant increase in the profits of manufacturers and retailers. However, manufacturers and retailers will enter into a contractual agreement only if they are more profitable, which leads to Proposition 3.

Proposition 3. *When demand is fixed, the profits of both the manufacturer and the retailer are compared in the following scenarios of decentralized supply chain and decentralized supply chain under the cost-sharing contract scenario.*

Proposition 3 reveals that in an ESG cost-sharing agreement, both the manufacturer and retailer register superior profits than in a conventional decentralized supply chain, and it is evident that ESG cost-sharing between the manufacturer and the retailer helps the manufacturer to gain higher profits. The main reason is that the ESG cost-sharing decentralized supply chain has an improved overall ESG effort sensitivity coefficient compared to the ordinary decentralized supply chain. The retailer would be willing to take on some of the ESG costs, which makes both parties share the cost, and assume a portion of the manufacturer's ESG effort to enhance the manufacturer's profitability. Thus, the added value of the supply chain products increases, thus increasing overall profitability. Therefore, the profit-sharing principle of the supply chain ensures that both the manufacturer and the retailer can receive the profit enhancement resulting from the cost-sharing contract. This also explains Proposition 2, which explores why the two subjects of the supply chain reach a contractual agreement.

5. Stochastic demand

In price-and-ESG related stochastic demand, $\widetilde{D}(p,e,\xi) = D + \xi$, where $\xi \in \left[\underline{\xi}, \overline{\xi}\right]$ is random demand factors and perceptual independent of the retail price (p) and ESG effort (e). ξ follows a continuous twice differentiable probability $f(\xi)$ and cumulative probability distribution functions $F(\xi)$. In addition, the distribution-free approach rooted in Scarf's rule explores the optimal decisions of two parties (Arrow et al., 1958). The distribution is assumed to be unrecognized, and the mean (μ) and standard deviation (σ) are known.

Unlike deterministic demands, the retailer must determine the order quantity (q). In this scenario, the manufacturer may first determine the ESG effort (e) and the wholesale price (w), and then the retailer decides the retail price (p) and the order quantity (q). To distinguish the stochastic demand analysis, we utilize an accent "$\sim$" in stochastic analyses here.

5.1. Decentralized decision-making

Theorem 3. *In the context of the TA industry with price and ESG-influenced stochastic demand, when both the retailer and manufacturer consider such variable demand, the ideal wholesale price from the manufacturer's perspective is* $\widetilde{w}^{de*} = \frac{2\lambda(a+bc)-ck^2+\lambda\sigma}{4b\lambda-k^2}$, *and ESG effort* $\widetilde{e}^{de*} = \frac{k[2(a-bc)+\sigma]}{2(4b\lambda-k^2)}$, *while the retailer's optimal selling price is* $\widetilde{p}^{de*} = \frac{b\lambda(6a+2bc-\sigma)-k^2(2bc-\sigma)}{2(b\lambda-2k^2)}$, *and the optimal profits for the manufacturer and retailer are* $\widetilde{\pi}_M^{de*} = \frac{(2a-2bc-\sigma)^2}{8(4b\lambda-k^2)}$ *and*

$$\widetilde{\pi}_R^{de*} = \frac{4b^2\lambda^2(a-bc)^2 - 4ab\lambda\sigma\left(7b\lambda-2k^2\right) + b\lambda\sigma^2\left(b\lambda-4k^2\right) - k^4\sigma(2bc-\sigma) - 4b^2c\lambda\sigma\left(b\lambda-2k^2\right)}{4\left(4b\lambda-k^2\right)^2}$$

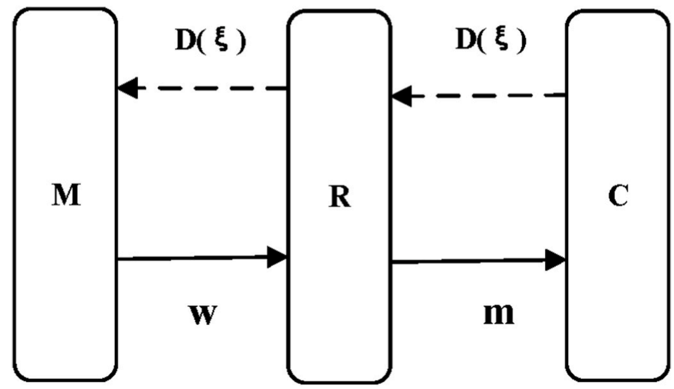


Fig. 4. Decentralized decisions in stochastic demand omnichannel retail model.

respectively.

In decentralized decisions for stochastic demand (see Fig.4), the manufacturer profit function is formulated as

$$\widetilde{\pi}_M(\widetilde{w},\widetilde{e}) = \widetilde{q}(\widetilde{w}-c) - \frac{1}{2}\lambda\widetilde{e}^2 \tag{8}$$

The retailer profit function is that:

$$\widetilde{\pi}_R(\widetilde{q},\widetilde{p}) = \widetilde{p}\min\{\widetilde{q},\widetilde{D}\} - \widetilde{w}\widetilde{q} \tag{9}$$

Since $\min\{\widetilde{q}, \widetilde{D}\} = \widetilde{q} - E[\widetilde{q}-\widetilde{D}]^+$, where $[\widetilde{q}-\widetilde{D}]^+ = \max\{0, \widetilde{q}-\widetilde{D}\}$, equation (9) can be simplified to

$$\widetilde{\pi}_R(\widetilde{q},\widetilde{p}) = (\widetilde{p}-\widetilde{w})\widetilde{q} - \widetilde{p}E[\widetilde{q}-\widetilde{D}]^+ \tag{10}$$

According to the distribution-free rule, the expected order quantity is bounded as:

$$E[\widetilde{q}-\widetilde{D}]^+ \le \frac{\sqrt{\sigma^2+(\widetilde{q}-D)^2}+(\widetilde{q}-D)}{2} \tag{11}$$

Substituting equation (11) to equation (10), the retailer profit function with stochastic demand is:

$$\widetilde{\pi}_R(\widetilde{q},\widetilde{p}) = (\widetilde{p}-\widetilde{w})\widetilde{q} - \widetilde{p}\frac{\sqrt{\sigma^2+(\widetilde{q}-D)^2}+(\widetilde{q}-D)}{2} \tag{12}$$

Let $\frac{\partial\widetilde{\pi}_R}{\partial\widetilde{q}} = 0$, we get $\widetilde{q} = D + \frac{\sigma(2\rho-1)}{2\sqrt{\rho(1-\rho)}}$, $\rho = \frac{\widetilde{p}-\widetilde{w}}{\widetilde{p}}(0 \le \rho \le 1)$. Substituting q to equation (12), we obtain

$$\widetilde{\pi}_R(\widetilde{q},\widetilde{p}) = (\widetilde{p}-\widetilde{w})\widetilde{q} - \sigma\widetilde{p}\sqrt{\rho(1-\rho)} \tag{13}$$

Given $g(\rho) = \sqrt{\rho(1-\rho)}$, since σ, p is greater than zero, it can be seen from equation (13) that the increase of $g(\rho)$ will lead to the minimum retailer's profit. At this point, we consider the worst case of the supply chain profit. Solving $max g(\rho)$, $\rho = \frac{1}{2}$. Therefore, $\widetilde{q} = D$. The revised retailer and the manufacturer profit function would be:

$$\widetilde{\pi}_R(\widetilde{p}) = (\widetilde{p}-\widetilde{w})D - \frac{1}{2}\sigma\widetilde{p} \tag{14}$$

$$\widetilde{\pi}_M(\widetilde{w},\widetilde{e}) = (\widetilde{w}-c)D - \frac{1}{2}\lambda\widetilde{e} \tag{15}$$

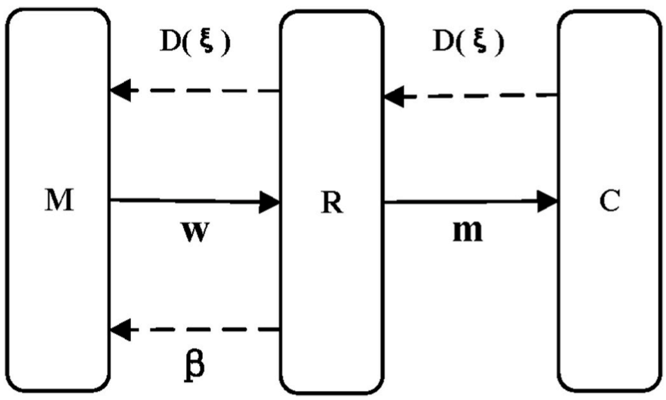


Fig. 5. ESG cost-sharing contract in stochastic demand omnichannel retail model.

Remark 1. $\pi_R \geq \widetilde{\pi}_R$

Next, we reconsider the retailer's profit function and we find the optimal response of the retailer using the first-order optimality condition $\frac{\partial \widetilde{\pi}_R}{\partial \widetilde{p}} = 0$, obtained that

$$\widetilde{p}(\widetilde{w}, \widetilde{e}) = \frac{2(a + b\widetilde{w} + \widetilde{e}k) - \sigma}{4b} \tag{16}$$

we substitute equation (15) to equation (16), obtaining the manufacturer's profit function $\widetilde{\pi}_M(\widetilde{w}, \widetilde{e})$ as follows:

$$\widetilde{\pi}_M(\widetilde{w}, \widetilde{e}) = \frac{1}{4}(w - c)(2a - 2bw - 2ek + \sigma) - \frac{1}{2}\lambda e^2$$

Subsequently, the manufacturer makes an optimal decision about the wholesale price $(\widetilde{p})$ and the ESG effort $\widetilde{e}$. Since its hessian matrix is $H = \begin{bmatrix} \frac{\partial^2 \widetilde{\pi}_M}{\partial \widetilde{w}^2} & \frac{\partial^2 \widetilde{\pi}_M}{\partial \widetilde{w} \partial \widetilde{e}} \\ \frac{\partial^2 \widetilde{\pi}_M}{\partial \widetilde{e} \partial \widetilde{w}} & \frac{\partial^2 \widetilde{\pi}_M}{\partial \widetilde{e}^2} \end{bmatrix} = \begin{bmatrix} b & \frac{k}{2} \\ \frac{k}{2} & \lambda \end{bmatrix}$ and $|H| \geq 0$, $max\ \widetilde{\pi}_M(\widetilde{w}, \widetilde{e})$ could be achieved by the first order optimal conditions $\frac{\partial \widetilde{\pi}_M}{\partial \widetilde{w}} = 0$, $\frac{\partial \widetilde{\pi}_M}{\partial \widetilde{e}} = 0$. We solve them simultaneously, getting that

$$\widetilde{w}^{de*} = \frac{2\lambda(a + bc) - ck^2 + \lambda\sigma}{4b\lambda - k^2}$$

$$\widetilde{e}^{de*} = \frac{k(2a - 2bc + \sigma)}{2\left(4b\lambda - k^2\right)}$$

We substitute $\widetilde{w}^*$ and $\widetilde{e}^*$ to equation (16) and profit function to obtain other optimal decisions and maximum payoffs of the retailer and the manufacturer.

$$\widetilde{p}^{de*} = \frac{b\lambda(6a + 2bc - \sigma) - bk^2(2bc - \sigma)}{2b\left(4b\lambda - 2k^2\right)}$$

$$\widetilde{\pi}_M^{de*} = \frac{(2a - 2bc - \sigma)^2}{8\left(4b\lambda - k^2\right)}$$

5.2. ESG cost-sharing contract

Theorem 4. *In this segment discussing the textile and apparel sector with a supply chain system influenced by price and ESG-related stochastic demand, upon the retailer and manufacturer factoring in such demand, the manufacturer's best wholesale price is pinpointed as* $\widetilde{w}^{cs*} = \frac{8b\lambda(a+bc)-k^2(a+5bc)}{2b(8b\lambda-3k^2)}$, *and ESG effort* $\widetilde{e}^{cs*} = \frac{k(2-2bc-3\sigma)}{8b\lambda-3k^2}$, *where the manufacturer's ESG cost proportion* $\widetilde{\beta}^* = \frac{2k^2(a-bc)-\sigma(32b\lambda-9k^2)}{8b\lambda(2a-2bc-3\sigma)}$. *The maximum gains for the manufacturer and retailer stand at* $\widetilde{\pi}_M^{cs*} = \frac{(a-bc)^2(8b\lambda-k^2)}{8(8b\lambda-3k^2)}$ *and* $\widetilde{\pi}_R^{cs*} = \frac{(a-bc)^2(8b\lambda+k^2)}{16(8b\lambda-3k^2)}$ *respectively.*

With reference to Section 4.2 and in combination with the distribution-free discussion given in Section 5.1, which is assumed retailers will share the $\widetilde{\beta}$ proportion of ESG investment cost with the manufacturer (see Fig. 5), where $0 \leq \widetilde{\beta} \leq 1$. The profit equations for the retailer and manufacturer are detailed below:

$$\widetilde{\pi}_R(\widetilde{p}) = (\widetilde{p} - \widetilde{w})(a - b\widetilde{p} + k\widetilde{e}) - \frac{1}{2}\sigma\widetilde{p} - \frac{1}{2}\widetilde{\beta}\lambda\widetilde{e} \tag{17}$$

$$\widetilde{\pi}_M(\widetilde{w}, \widetilde{e}) = (\widetilde{w} - c)(a - b\widetilde{p} + k\widetilde{e}) - \frac{1}{2}(1 - \widetilde{\beta})\lambda\widetilde{e} \tag{18}$$

The price, $\widetilde{p}$, that maximizing retailer revenue, $\widetilde{\pi}_R$ is gained using the first order optimal condition, $\frac{\partial \widetilde{\pi}_R}{\partial \widetilde{p}} = 0$, which derives the optimal price equation (19).

$$\widetilde{p}(\widetilde{w}, \widetilde{e}, \widetilde{\beta}) = \frac{2(a + b\widetilde{w} + \widetilde{e}k) - \sigma}{4b} \tag{19}$$

The price $\widetilde{p}$ is substituted into the manufacturer's profit function equation (18) to obtain the optimal decision of wholesale price and ESG effort.

$$\widetilde{w}(\beta) = \frac{\lambda(2a + 2bc + \sigma)(1 - \beta) - ck^2}{4b\lambda(1 - \beta) - k^2}$$

$$\widetilde{e}(\beta) = \frac{k(2a - 2bc + \sigma)}{2\left(b\lambda(1 - \beta) - k^2\right)}$$

Substituting $\widetilde{w}(\beta)$, $\widetilde{e}(\beta)$ to equation (19), we get that $\widetilde{p}\left(\widetilde{\beta}\right) = \frac{3ab\lambda(\beta-1)+b^2c\lambda(\beta-1)+k^2\left(bc-\frac{1}{2}\sigma\right)-\frac{1}{2}b\lambda\sigma(\beta+1)}{b\left(4b\beta\lambda-4b\lambda+k^2\right)}$. Given that, $max\ \widetilde{\pi}_R(\widetilde{\beta})$ .We solve it with the optimal first-order condition, $\frac{\partial \widetilde{\pi}_R}{\partial \widetilde{\beta}} = 0$.

$$\widetilde{\beta}^* = \frac{2k^2(a - bc) - \sigma\left(32b\lambda - 9k^2\right)}{8b\lambda(2a - 2bc - 3\sigma)}$$

The optimal decision and payoff are as follows:

$$\widetilde{p}^{cs*} = \frac{8b\lambda(6a + 2bc - \sigma) - 3k^2(2a + 6bc + 5\sigma)}{8b\left(8b\lambda - 3k^2\right)}$$

$$\widetilde{w}^{cs*} = \frac{2b\lambda(8a + 8bc + k\sigma) - k^2(2a + 10bc + 9\sigma)}{6b\left(2b\lambda - k^2\right)}$$

$$\widetilde{\pi}_R^{de*} = \frac{4b^2\lambda^2(a - bc)^2 - 4ab\lambda\sigma\left(7b\lambda - 2k^2\right) + b\lambda\sigma^2\left(b\lambda - 4k^2\right) - k^4\sigma(2bc - \sigma) - 4b^2c\lambda\sigma\left(b\lambda - 2k^2\right)}{4\left(4b\lambda - k^2\right)^2}$$

Table 2
The optimal strategies for Deterministic demand and Stochastic demand.

Variable	Deterministic market demand		Stochastic market demand	
	Decentralized decisions	ESG cost-sharing contract	Decentralized decisions	ESG cost-sharing contract
p^*	$\frac{\lambda(3a+bc)-ck^2}{4b\lambda-k^2}$	$\frac{8b\lambda(3a+bc)-3k^2(a+3bc)}{4b(8b\lambda-3k^2)}$	$\frac{b\lambda(6a+2bc-\sigma)-bk^2(2bc-\sigma)}{2b(4b\lambda-2k^2)}$	$\frac{8b\lambda(6a+2bc-\sigma)-3k^2(2a+6bc+5\sigma)}{8b(8b\lambda-3k^2)}$
e^*	$\frac{k(a-bc)}{4b\lambda-k^2}$	$\frac{2k(a-bc)}{8b\lambda-3k^2}$	$\frac{k(2a-2bc+\sigma)}{2(4b\lambda-k^2)}$	$\frac{k(2a-2bc-3\sigma)}{8b\lambda-3k^2}$
w^*	$\frac{2\lambda(a+bc)-ck^2}{4b\lambda-k^2}$	$\frac{8b\lambda(a+bc)-k^2(a+5bc)}{2(8b\lambda-3k^2)}$	$\frac{2\lambda(a+bc)-ck^2+\lambda\sigma}{4b\lambda-k^2}$	$\frac{2b\lambda(8a+8bc+k\sigma)-k^2(2a+10bc+9\sigma)}{6b(2b\lambda-k^2)}$
β^*	–	$\frac{k^2}{8b\lambda}$	–	$\frac{2k^2(a-bc)-\sigma(32b\lambda-9k^2)}{8b\lambda(2a-2bc-3\sigma)}$
π_M^*	$\frac{\lambda(a-bc)^2}{2(2b\lambda-k^2)}$	$\frac{(a-bc)^2(8b\lambda-k^2)}{8(8b\lambda-3k^2)}$	$\frac{(2a-2bc-\sigma)^2}{8(4b\lambda-k^2)}$	$\frac{(2a-2bc+\sigma)(8b(a-bc\lambda)+k^2(bc-a))+8(8b\lambda\sigma-9k^2\sigma)}{80b(3k^2-b\lambda)}$
π_R^*	$\frac{b\lambda^2(a-bc)^2}{(2b\lambda-k^2)^2}$	$\frac{(a-bc)^2(8b\lambda+k^2)}{16(8b\lambda-3k^2)}$	$\frac{4b^2\lambda^2(a-bc)^2-4ab\lambda\sigma(7b\lambda-2k^2)+b\lambda\sigma^2(b\lambda-4k^2)-k^4\sigma(2bc-\sigma)-4b^2c\lambda\sigma(b\lambda-2k^2)}{4(4b\lambda-k^2)^2}$	$\frac{32ab\lambda(a-2bc-7\sigma)+32b^2c\lambda(bc-\sigma)+8b(\lambda\sigma^2-ack^2)+4k^2(9a+15bc\sigma)+33k^2\sigma^2}{8b(b\lambda-3k^2)}$

$$e^{cs*} = \frac{k(2a-2bc-3\sigma)}{8b\lambda-3k^2}$$

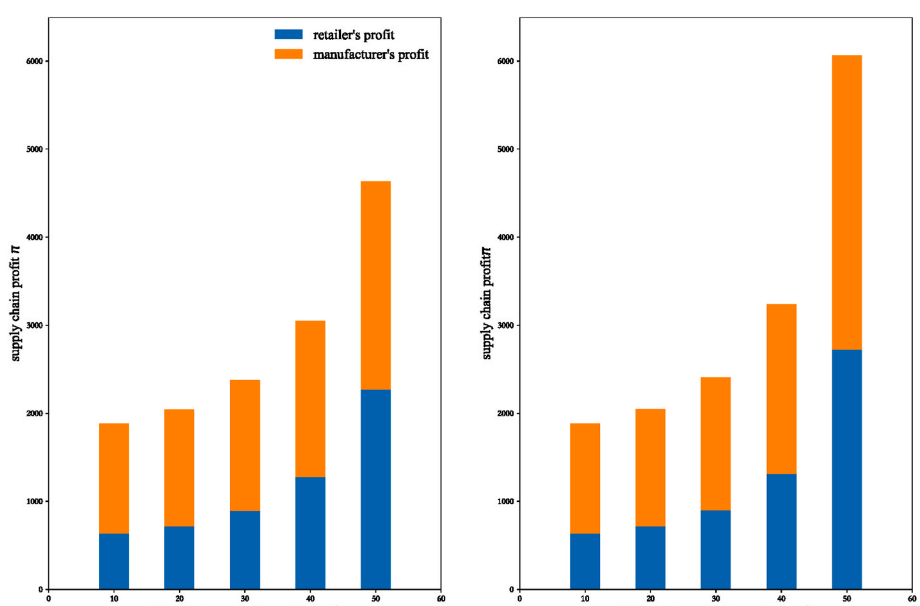
$$\widetilde{\pi}_R^{cs*} = \frac{32ab\lambda(a-2bc-7\sigma)+32b^2c\lambda(bc-\sigma)+8b\left(\lambda\sigma^2-ack^2\right)+4k^2(9a+15bc\sigma)+33k^2\sigma^2}{8b\left(b\lambda-3k^2\right)}$$

$$\widetilde{\pi}_M^{cs*} = \frac{(2a-2bc+\sigma)\left(8b(a-bc\lambda)+k^2(bc-a)\right)+8\left(8b\lambda\sigma-9k^2\sigma\right)}{80b\left(3k^2-b\lambda\right)}$$

Proposition 4. *When demand is stochastic, the ESG cost ratio $\widetilde{\beta}$ is positively related to the ESG effort sensitivity coefficient k and negatively related to the customer ESG sensitivity coefficient λ.*

From Proposition 4, when demand is random, the retailer will only have to bear a low proportion of the high ESG costs of the manufacturer. However, when consumers' ESG sensitivity coefficients are high, the retailer will have to bear a higher proportion of ESG costs (Ghosh and Shah, 2015). Since the cost-sharing mechanism stimulates retailers to improve their service incentives and hence product quality and consumers' demand for higher-quality products increases significantly, the retailer can share in the ESG costs, and even if there is a tiny improvement in the quality level of the product, the retailer can still ensure its profitability.

Proposition 5. *Under stochastic demand, the profit earned by the manufacturer under the ESG cost-sharing decision is less than that earned under the decentralized decision, i.e., $\widetilde{\pi}_M^{de*} \geq \widetilde{\pi}_M^{cs*}$.*



(a) Decentralized decision-making in deterministic demand (b) ESG cost-sharing contract in deterministic demand

Fig. 6. The effect of k on TASC profit in deterministic demand.

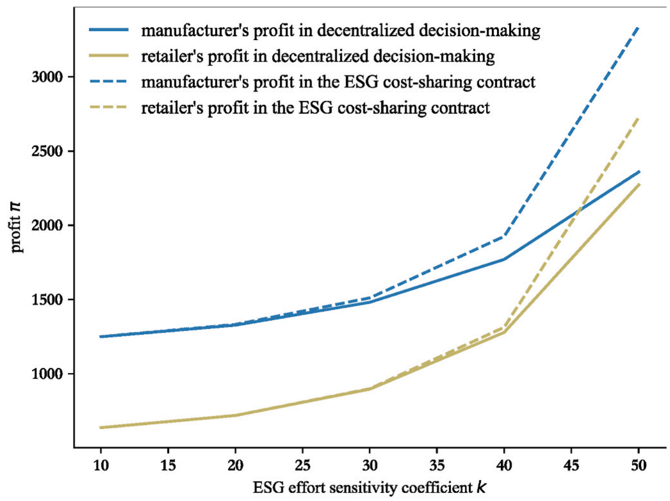


Fig. 7. The effect of k on manufacturer and retailer profit in deterministic demand.

Proposition 6. *Whether it is decentralized decisions or ESG cost-sharing contracts, the optimal value under deterministic market demand is larger than the optimal value under stochastic market demand* (Cohen et al., 2022).

Proof. *By backward induction* (Gong et al., 2022), *the optimal solutions in deterministic demand and stochastic demand are shown in* Table 2. *Taking the manufacturer's profit as an example, when the decentralized decision is chosen, with the certainty of market demand, and the manufacturer's profit is* $\pi_M^{de*} = \frac{\lambda(a-bc)^2}{8(2b\lambda-k^2)}$, *However when market demand is random, manufacturer's profit is* $\widetilde{\pi}_M^{de*} = \frac{(2a-2bc-\sigma)^2}{8(4b\lambda-k^2)}$, *since* $8(2b\lambda - k^2) < 8(4b\lambda - k^2)$, *so* $\frac{\lambda(a-bc)^2}{8(2b\lambda-k^2)} > \frac{(2a-2bc-\sigma)^2}{8(4b\lambda-k^2)}$. *The proof of the retailer's profit comparison under ESG cost-sharing controls follows in the same way.*

From Proposition 5, the introduction of ESG cost-sharing contracts reduces the impact of the stochastic nature of market demand on the supply chain, improving both product quality and the profitability of manufacturers and retailers (Wang et al., 2020).

6. Numerical analysis

Considering the complexity of the optimal solution expressions obtained from the previous analysis, the numerical experiment is used to analyze the model further numerically. We mainly study the effect of the ESG effort sensitivity coefficient (k) on the profitability and decision variables in deterministic and stochastic demand scenarios respectively.

6.1. Deterministic demand

In deterministic demand, the demand function is known as seen in Assumption 3. The illustrative example uses data for input parameters from Philips (2005) and a relevant supply chain in the apparel industry (John and Mishra, 2023), and customizes it to the present TASC context. According to John and Mishra (2023) methodology for quantifying three-tier integrated supply chain systems in the textile industry, and based on John and Mishra (2023) approach to quantifying a three-tier integrated supply chain system in the textile industry, the selection of what appears to be the maximum capacity based on the optimal solution of the model as well as application of pessimistic evaluation to avoid parameter overestimation using the Dombi operation as an example (Dombi, 1982). In addition, this paper's source of parameter assignment also refers to Chang and Lin (2015), who considered production management using minimum, algebraic product or Einstein product operation to eliminate the error caused by parameter selection. Therefore, the basic parameters of this research are $a = 1000$, $b = 50$, $c = 60$, $\lambda = 26$, and $k \in [0, 50]$ based on Assumptions 4 and 5.

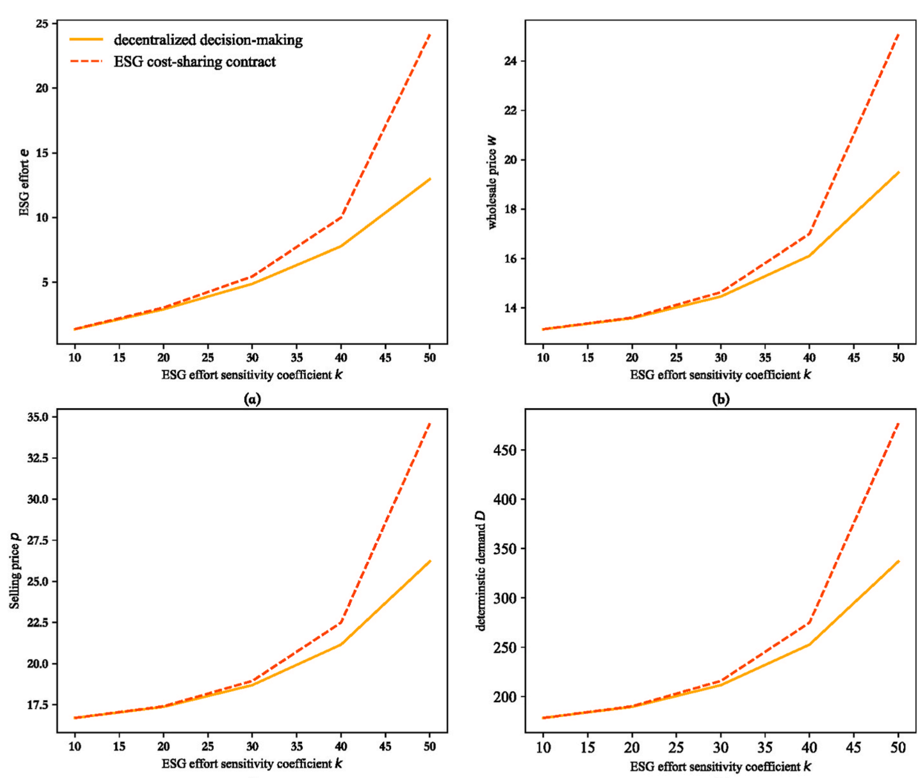


Fig. 8. The effect of k on decision variables in deterministic demand.

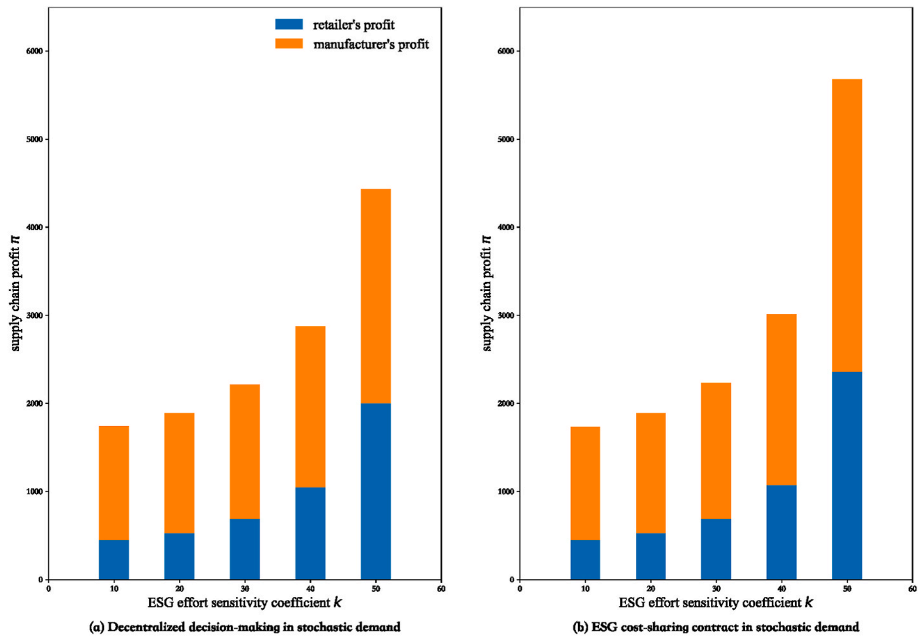


Fig. 9. The effect of k on TASC profit in stochastic demand.

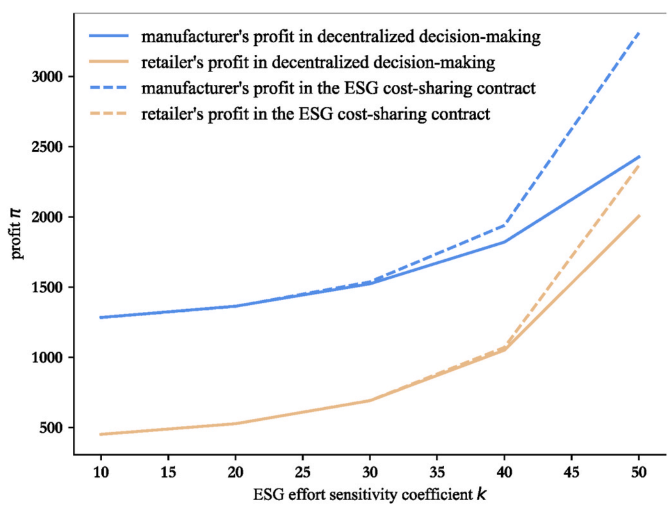


Fig. 10. The effect of k on manufacturer and retailer profit in stochastic demand.

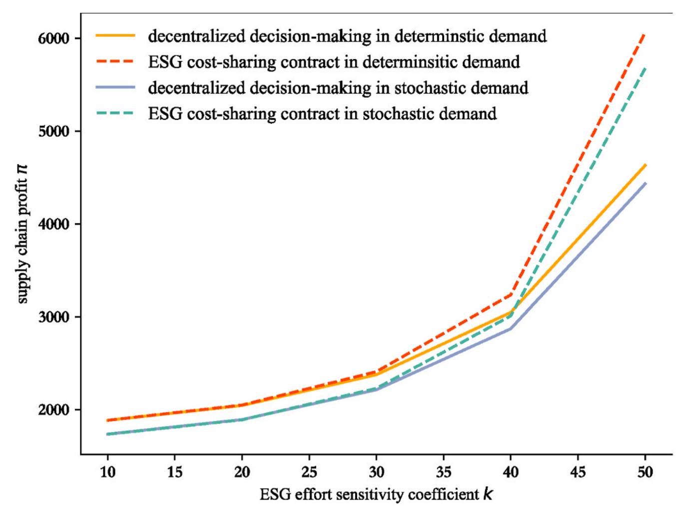


Fig. 11. TASC profit in deterministic and stochastic demand.

6.1.1. The effect of the ESG effort sensitivity coefficient (k) on the profitability

As seen in Fig. 6, increasing the ESG effort sensitivity coefficient (k) leads to a higher overall TASC profit in both two situations, in which the profit in the ESG cost-sharing contract is obviously higher than in decentralized decision-making. Therefore, it is evident that the ESG cost-sharing contract brings greater profits to the entire supply chain. Specifically, the manufacturer's and retailer's profitability are both improved through the ESG cost-sharing contract as shown in Fig. 7. When the sensitivity coefficient reaches a certain level, the increasing trend becomes obvious. In consequence, the ESG-sharing contract will be concluded among TASC participants in a deterministic demand market for profit purposes.

6.1.2. The effect of the ESG effort sensitivity coefficient (k) on the decision variables

It can be seen from Fig. 8 that the ESG effort sensitivity coefficient (k) has positive effects on the decision variables and demand. As the TA product becomes more sensitive to ESG efforts, the ESG effort (e), whole price (w), and selling price (p) will increase seen in Fig. 8(a)~(c). Increasing the ESG effort sensitivity coefficient (k) will lead to higher investment in ESG efforts, which in turn increases product cost, thus the wholesale and selling price improved. Furthermore, it is observed that the value of decision variables (e,w,p) in the ESG cost-sharing contract is higher than in decentralized decision-making, the gap will continue to widen with TA products being more sensitive to ESG effort. In this way, the demand for the ESG cost-sharing contract also has greater improvement, as shown in Fig. 8(d). Therefore, it is concluded that although the wholesale and selling price will increase in the ESG cost-sharing contract, the market demand will increase, corresponding to the profit increase as well.

6.2. Stochastic demand

In the scenario of stochastic demand, only the mean value (μ) and variance (σ) are known, while the demand distribution information is unknown. In this context, we give $\mu = 0$ and $\sigma = 20$ for numerical analysis.

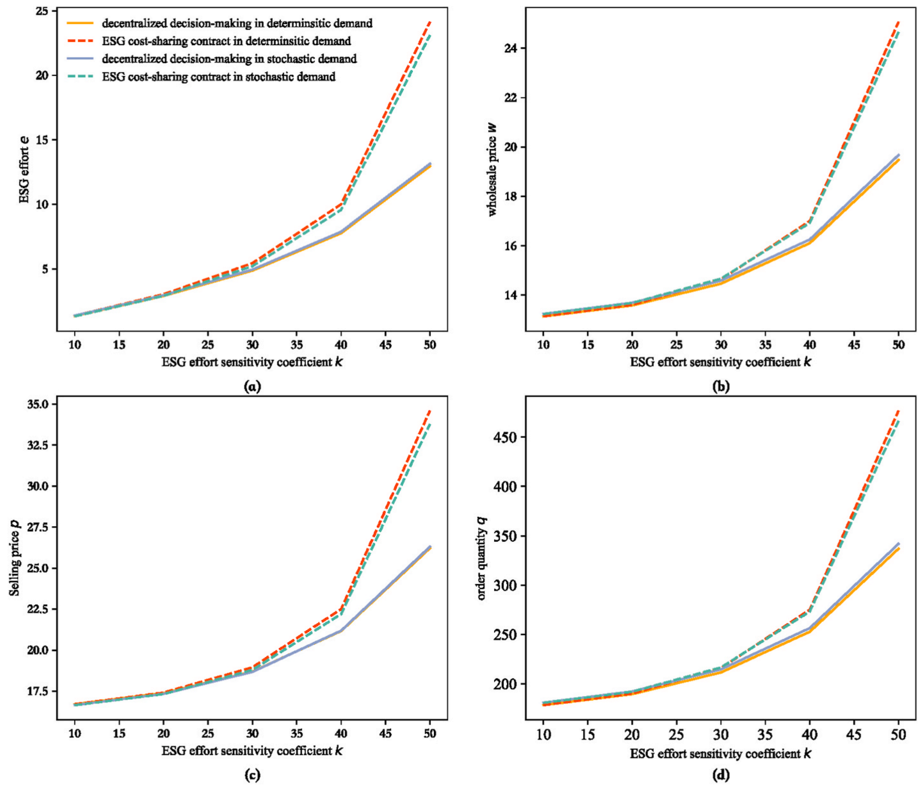


Fig. 12. The effect of k on decision variables in stochastic demand.

6.2.1. *The effect of the ESG effort sensitivity coefficient (k) on the profitability*

From Figs. 9 and 10, the profitability-impacted trend performance under the stochastic demand scenario is the same as deterministic demand (seen in Figs. 6 and 7). As the ESG effort sensitivity coefficient increases, revenues for the manufacturer, retailer, and TASC as a whole are growing. Also in a stochastic market, implementing an ESG cost-sharing contract can lead to greater profits compared to decentralized decision-making. Notably, when the ESG cost-sharing contract brought in stochastic demand TASC, the entire supply chain's profit is even higher than in the decentralized decision-making situation where demand is determined (see Fig.11). Therefore, the ESG-sharing contract is very effective in reducing uncertainty in the stochastic market.

6.2.2. *The effect of the ESG effort sensitivity coefficient (k) on the decision variables*

According to the numerical results in Fig. 12, it is found that the decision variables (e, w, p, q) and stochastic demand increase as the ESG effort sensitivity coefficient increases in the stochastic demand market. Compared with the decentralized decision-making situation, the entire decision variables are higher in the ESG cost-sharing contract in the stochastic demand market, which has the same trend as deterministic demand. It is worth noting that as the sensitivity factor of ESG efforts becomes higher, especially when its value reaches a certain level, the ESG cost-sharing contract will bring a huge increase in the number of orders seen in Fig. 12(d). Therefore, as customers pay more attention to the sustainability of corporations and products in the stochastic market, the ESG cost-sharing contract is a great way for the manufacturer and retailer to increase their ESG performance and lead to higher market share.

7. Conclusions

This paper examines supply chain systems in two scenarios to determine whether market demand is stochastic. Comparing four models (i.e., decentralized decision-making under deterministic demand, ESG cost-sharing contract under deterministic demand, decentralized decision-making under stochastic demand, and ESG cost-sharing contracts under deterministic demand), we explore the conditions for reaching a cost-sharing contract and its impact on the supply chain coordination mechanism based on the Stackelberg game model. We also explore the conditions for ESG cost-sharing contracts and seek incentives for the overall sustainability of the supply chain apparel industry.

The analyses of model and numerical results demonstrate that the ESG cost-sharing contract is more beneficial to individual members than the standard decentralized supply chain. When suppliers and retailers independently determine the cost-sharing ratio, they will seek to maximize their benefits while maintaining stability to reduce the total cost of the products. The ESG cost-sharing contract will compel suppliers to make greater ESG efforts, thereby increasing the margins of both manufacturers and retailers. The ESG efforts and SC profits of the ESG cost-sharing contract are greater than those of the retailer-provided cost-sharing contract. Therefore, retailers and suppliers should pay close attention to the positive effects of cost-sharing, as it not only significantly increases consumers' willingness to consume due to an increase in ESG effort but also increases consumers' aggregate demand to a certain extent, which, under the combined effect of the two factors above, significantly increases the sales revenues of both retailers and suppliers, resulting in an increase in profits for both parties.

7.1. *Theoretical contribution*

In this paper, we investigate the conditions for reaching a cost-sharing contract and its effect on the SC coordination mechanism based on the Stackelberg game model.

Firstly, in the existing supply chain coordination contracts studies, on the one hand, determining contract parameters under specific contract terms and, on the other, the relationship between demand patterns and contract conditions (Tsay et al., 1999; Wu, 2013). Among those, Hosseini-Motlagh et al. (2022) discussed the instability of short-term coordination strategy and studied the evolutionary behavior of supply chain members to supply chain coordination. However, supply chain coordination protocols also have an important effect on supply chain participants and supply chain performance (Gunasekaran et al., 2004). In this vein, this paper examines how cost-sharing contracts promote the strategic decisions of SC participants in the TA industry and effectively reduce the risks associated with unpredictable demand.

Secondly, more and more companies are opting for ESG disclosure, which has emerged as a measure of corporate environmental performance (Camilleri, 2015). However, most of the existing studies introduce the development of ESG (Lokuwaduge and Heenetigala, 2017; Tsang et al., 2023) and focuses on the relationship between ESG disclosure and financial returns (Zhou et al., 2022). Nevertheless, ESG disclosure can be used as a corporate strategy to address sustainability issues firms face (Tan and Zhu, 2022), but only some studies have focused on this issue. In order to address this research gap, this study explores the conditions for ESG cost-sharing contracts and seeks incentives for the overall sustainability of the supply chain apparel industry.

Thirdly, unlike existing studies, there has been much discussion about the technical assistance industry, the environmental problems or development challenges facing the technical assistance industry and the mode of operation (Caniato et al., 2012; Farahani et al., 2022). For instance, John and Mishra (2023) found that the TA industry is primarily responsible for environmental pollution, and found that investment in green technology and waste minimization technology can reduce the damage caused by environmental pollution. However, rapid economic growth has presented the apparel industry with new sustainability challenges. As a result, contemporary TASC have faced the urgent need to integrate sustainability into their operations fully (Saha et al., 2021). In order to make up for the gap in previous research, our paper examines the optimal decision-making processes for decentralized TASC decision-making and ESG cost-sharing contracts.

7.2. Practical contribution

This study addresses the critical research needed to develop a body of knowledge on how a meaningful shift toward sustainability within the TA industry can be achieved. Specifically, this paper investigates how two different scenarios (whether the market is stochastic or not) affect the supply chain. On the basis of the Stackelberg game model, we explore how four different cost-sharing contract condition modes influence the supply chain's coordination mechanisms. This study finds that the existence of ESG cost-sharing contracts can reduce the supply chain risk caused by random demand to supply chain participants and give relevant suggestions in order to achieve the sustainable development of the TA industry. For example, in the TA industry's current environmentally challenging environment for consumers, suppliers and retailers should collaborate to increase ESG investment and improve corporate ESG performance to gain a better reputation and build a green image to attract consumers. In addition, governments should play a role in promoting sustainable supply chain development in the textile and apparel industry by increasing penalties against environmentally damaging companies.

7.3. Limitation and future research

Supply chain contract coordination is an essential topic in SC management research. However, although there has been much research in this area, there are still some research deficiencies and areas that need further exploration, for example, First, coordination mechanisms in complex environments. Many existing studies are focused on relatively simplified models and environments. More in-depth research is needed for a multi-level, multi-participant, or complex supply chain environment with different types of uncertainties. Second, behavioral factors and coordination: many existing studies are based on rational economic participant models. However, in practice, the decisions of supply chain participants may be affected by various behavioral biases. In-depth research on how these behavioral biases affect the design and effect of supply chain contracts still needs to be completed. Third, dynamic coordination mechanism: Most existing supply chain contract coordination studies assume a stable market environment; however, market conditions, demand, and supply are often dynamic. How to design a dynamic contract mechanism that can adapt to these changes is still an open problem. With the deepening of research and enhancing practical application demand, these areas are expected to get more research attention.

CRediT authorship contribution statement

Linze Li: Writing – original draft. **Xuexin Liu:** Conceptualization. **Man Hu:** Writing – review & editing, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix

Proposition 1

Proof

Since $\beta^* = \frac{k^2}{8b\lambda}$*, the partial derivatives of* λ *and* k*, respectively,* $\frac{\partial \beta^*}{\partial \lambda} = \frac{-k^2}{8b\lambda^2} < 0, \frac{\partial \beta^*}{\partial k} = \frac{k}{4b\lambda} > 0.$

Thus, the proposition is proved.

Proposition 2

Proof

$w^{de^*} = \frac{2\lambda(a+bc)-ck^2}{4b\lambda-k^2}$*, and ESG effort* $e^{de^*} = \frac{k(a-bc)}{4b\lambda-k^2}$*,* $p^{de^*} = \frac{\lambda(4a+bc)-ck^2}{4b\lambda-k^2}$.

$w^{cs*} = \frac{8b\lambda(a+bc)-k^2(a+5bc)}{2b(8b\lambda-3k^2)}$, and ESG effort $e^{cs*} = \frac{2k(a-bc)}{8b\lambda-3k^2}$, $p^{cs*} = \frac{8b\lambda(3a+bc)-3k^2(a+3bc)}{4b(8b\lambda-3k^2)}$.
Since $w^{cs*} - w^{de*} = \frac{k^4(a-bc)}{2b(4b\lambda-k^2)(8b\lambda-3k^2)} \geq 0$, $e^{cs*} - e^{de*} = \frac{k^3(a-bc)}{(4b\lambda-k^2)(8b\lambda-3k^2)} \geq 0$, $p^{cs*} - p^{de*} = \frac{3k^4(a-bc)}{4b(4b\lambda-k^2)(8b\lambda-3k^2)} \geq 0$.
Thus, the proposition is proved.

Proposition 3

Proof

Since $\pi_R^{de*} = \frac{\lambda(a-bc)^2}{4(2b\lambda-k^2)}$, $\pi_M^{de*} = \frac{\lambda(a-bc)^2}{8(2b\lambda-k^2)}$, $\pi_R^{cs*} = \frac{(a-bc)^2(8b\lambda+k^2)}{16(8b\lambda-3k^2)}$, $\pi_M^{cs*} = \frac{(a-bc)^2(8b\lambda-k^2)}{8(8b\lambda-3k^2)}$.
If $\frac{(a-bc)^2(8b\lambda+k^2)}{16(8b\lambda-3k^2)} \geq \frac{\lambda(a-bc)^2}{4(2b\lambda-k^2)}$, i.e., $(8b\lambda + K^2)(2b\lambda - K^2) \geq 4(8b\lambda - 3K^2)$, which gives $k^4 \geq 0$, the condition holds. Then we have $\pi_R^{cs*} \geq \pi_R^{de*}$.
If $\frac{(a-bc)^2(8b\lambda-k^2)}{8(8b\lambda-3k^2)} \geq \frac{\lambda(a-bc)^2}{8(2b\lambda-k^2)}$, i.e., $(8b\lambda - k^2)(2b\lambda - k^2) \geq \lambda(8b\lambda - 3k^2)$, It follows that $k^4 \geq 0$, the condition holds. Then we have $\pi_M^{cs*} \geq \pi_M^{de*}$.
Thus, the proposition is proved.

Proposition 4

Proof

Since $\widetilde{\beta}^* = \frac{2k^2(a-bc)-\sigma(32b\lambda-9k^2)}{8b\lambda(2a-2bc-3\sigma)}$, the partial derivatives of λ and k, respectively,

$$\frac{\partial\widetilde{\beta}^*}{\partial\lambda} = \frac{-2k^2(a-bc)-\sigma qk^2}{8b\lambda^2(2a-2bc-3\sigma)}, \frac{\partial\widetilde{\beta}^*}{\partial k} = \frac{4k(a-bc)+18\sigma k}{8b\lambda(2a-2bc-3\sigma)}$$

From $e^{cs*} = \frac{k(2-2bc-3\sigma)}{8b\lambda-3k^2}$, and $e \geq 0$, we can get $2 - 2bc - 3\sigma > 0$, so $\frac{\partial\widetilde{\beta}^*}{\partial\lambda} < 0$, $\frac{\partial\widetilde{\beta}^*}{\partial k} > 0$.
Thus, the proposition is proved.

Proposition 5

Proof

Since $\widetilde{\pi}_M^{de*} = \frac{(2a-2bc-\sigma)^2}{8(4b\lambda-k^2)}$, $\widetilde{\pi}_M^{cs*} = \frac{(2a-2bc+\sigma)(8b(a-bc\lambda)+k^2(bc-a))+8(8b\lambda\sigma-9k^2\sigma)}{80b(3k^2-b\lambda)}$.
And $\frac{(2a-2bc-\sigma)^2}{8(4b\lambda-k^2)} \geq \frac{(2a-2bc+\sigma)(8b(a-bc\lambda)+k^2(bc-a))+8(8b\lambda\sigma-9k^2\sigma)}{80b(3k^2-b\lambda)}$.
Then we have $\widetilde{\pi}_M^{de*} \geq \widetilde{\pi}_M^{cs*}$.

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