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GREEN E-COMMERCE SUPPLY CHAIN ANALYSIS CONSIDERING DELIVERY TIME UNDER EPISTEMIC UNCERTAINTY BASED ON CONFIDENCE LEVEL

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Abstract. Due to the growth of e-commerce and increasing demand for eco-friendly consumption, the green e-commerce supply chain has received significant attention recently. Additionally, the delivery time of products can significantly impact market demand in the online channel. However, due to incomplete historical data, epistemic uncertainty will inevitably arise when estimating the demand for green products. Therefore, by applying uncertainty theory, we propose an uncertain demand function based on greenness and delivery time, thus introducing delivery time into an uncertain green e-commerce supply chain comprising an e-commerce platform and a green manufacturer. Based on the above, chance-constrained models considering the confidence level associated with members' risk attitude are constructed and solved for five scenarios, including the integrated scenario, the green manufacturer-dominant scenarios under the wholesale sales model and the platform sales model, as well as the cost-sharing scenarios under both sales models. The results show that the increasing cost parameter of green investment and the increasing maximum cost of delivery negatively affect the behavioral performance of the supply chain. Moreover, the choice of sales models by the e-commerce platform and the manufacturer is related to their attitude to risk.

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1. Introduction

In recent decades, the global economy has improved significantly, leading to significant changes in people's lifestyles. However, this progress has come at a cost, as large amounts of greenhouse gases have been emitted into the air, leading to social and environmental consequences such as floods and heavy rains. Governments in many countries are enacting regulations to reduce greenhouse gas emissions, and consumers are now recognizing the importance of using eco-friendly products. It is for these reasons that more and more manufacturers are adopting green initiatives [20]. Many companies are taking collective responsibility and striving to project a positive corporate image through sustainable practices. For example, at the Panasonic Green Ideas Forum 2010 held at Panasonic Headquarters, eco-conservation and green issues were identified as its top innovation objectives. Furthermore, as more and more consumers express concern for the environment and interest in purchasing green products, the impact of consumer awareness on environmentally-friendly manufacturing should not be

Keywords. Green e-commerce supply chain, delivery time, epistemic uncertainty, uncertainty theory, confidence level.

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underestimated. More investment in green technology is required by green companies, which leads to higher production costs. With this in mind, companies are looking for more cost-effective ways to operate [36].

Since the outbreak of the COVID-19 epidemic in 2020, offline businesses such as shopping malls, restaurants and tourism have faced severe challenges, while e-commerce has shown strong resilience [11]. Chiang *et al.* [2] point out that as consumer habits continue to evolve and shift towards green products and online shopping, manufacturers are responding by gradually shifting their sales of eco-friendly products from offline channels to online platforms. This has led to the emergence of a green e-commerce supply chain (GECSC) between e-commerce platforms (EP) and green manufacturers (GM). In the GECSC, the e-commerce sales model plays a crucial role in determining the decisions and profits of each participant. Therefore, the choice of the appropriate sales model is of great importance. In practice, two main options for e-commerce sales models are observed – the wholesale sales model (WSM) and the platform sales model (PSM). In WSM, the EP buys wholesale products from upstream manufacturers and sells them to end-users, with the manufacturer relying on the EP's high web traffic to drive sales. In PSM, the platform acts as a marketplace, and the upstream manufacturers sell their products directly to end consumers but are required to pay a percentage of the platform fee to the EP for each product they sell. Tmall is a well-known example of the PSM, while Jingdong is an example of the WSM. The main difference between the two e-commerce models is the trade-off between gaining pricing power and gaining marketing advantages on the EP [29].

Online shopping is growing rapidly in countries such as India (31.9%), China (27.3%), and the United States (14.0%) [19]. In today's online shopping experience, the delivery time is considered a critical factor in determining logistics service quality and has a significant impact on customer satisfaction, confidence and demand. A survey conducted by Dotcom Distribution revealed that 87% of online shoppers consider the speed of delivery to be a critical factor in deciding whether to shop online. Surprisingly, the survey also found that delivery time was considered more important than price *(mhlnews.com)* [17]. Specifically, 67% of online shoppers said that they would be willing to pay extra for same-day delivery [33]. However, a shorter delivery time can lead to higher logistics costs, while a longer delivery time can reduce customer adoption and loyalty towards online channels. Therefore, managing delivery time in the online channel is essential to remain competitive.

Due to the rapidly changing market and increasing competition, the market environment faced by members of the supply chain is uncertain and risky. Especially for some new green products without sufficient sample data or green electronic products with short life cycles, it is difficult to accurately estimate their probability distributions and can only rely on domain experts to predict and estimate the parameters based on their own experience. However, Liu [12] briefly pointed out that the discrepancy between the estimated and actual values is so large that probability theory may not be useful in such cases. To deal with this type of epistemic uncertainty due to lack of data and inadequate subjective perception, Liu [12] proposed that it can be represented by uncertain variables. Furthermore, most of the current literature uses expected value to maximize the supply chain members' profits, which offers an average value under epistemic uncertainty to facilitate analytical decision-making, but it is only suitable for risk-neutral decision-makers and vulnerable to extreme events [3]. Therefore, this paper introduces a decision rule based on confidence level to capture firms' risk attitude in their decision-making and to reduce the influence of the extreme values of low probability, thereby enhancing the rationality of optimal decision-making to some degree. The confidence level is an expression of an individual's risk appetite when making decisions, with a higher level indicating greater risk-averse and a lower level indicating a greater willingness to take risks. In particular, if the confidence level is 1, the individual is entirely risk aversion, whereas if the confidence level is 0, the individual is entirely risk-seeking.

This paper considers the delivery time and applies uncertainty theory to the pricing problem of a GECSC consisting of a GM and an EP. Due to the epistemic uncertainty caused by market fluctuations, green product upgrades, and changes in consumer psychology, we set the parameters of market potential, consumer sensitivity to price, greenness and delivery time as uncertain variables. Furthermore, to characterize the risk appetite of the GM and the EP in their decision-making process, we maximize the potential profit at a specified confidence level and build several models, namely the integrated scenario, the GM-dominant scenario under WSM and PSM, and the cost-sharing scenario under both models. Optimum solutions are then obtained for each model

to examine the sales model preferences of GECSC members and the effect of cost-sharing on the uncertain models. The main innovations of this paper are as follows. (1) First introduce delivery time into the GECSC under epistemic uncertainty. (2) Propose an uncertain demand function based on greenness and delivery time. (3) Build chance-constrained models considering the confidence level associated with members' risk attitude.

The rest of the paper is organized as follows. Section 2 briefly reviews the relevant literature. Section 3 describes the problem and provides the symbols. In Section 4, five models are built and their corresponding equilibrium solutions are obtained. A numerical example is presented in Section 5 to validate the results. Finally, Section 6 presents conclusions and recommendations for future research.

2. Literature review

Our review covers four main areas of the literature. The first area focuses on the green product sales channels. The second category concentrates on the e-commerce sales model. The third category concerns the delivery time. The last one is the green supply chain under epistemic uncertainty. In the following, we provide a brief review of the four categories of literature mentioned above.

2.1. Green product sales channels

As environmental pollution worsens, consumer awareness of environmental protection continues to grow, driving a steady increase in demand for green products. As a result, more and more companies are adopting strategies such as green production and multi-channel sales to gain a competitive edge and expand their markets. In recent years, several researchers and practitioners have conducted extensive research on the marketing of green products through various channels, providing a wealth of valuable insights.

On the one hand, there are studies related to the sale of green products only through traditional offline channels. Liu *et al.* [15] investigated the effect of manufacturers' competitive intensity on product greenness and retail prices in a two-echelon supply chain under corporate social responsibility (CSR), revealing the impact of competing manufacturers' investments in green products on the performance of supply chain members. Song *et al.* [26] examined the effects of consumer fairness concerns on the game equilibrium of a green supply chain consisting of a single conventional manufacturer, a green manufacturer, and a retailer. In addition, Wu *et al.* [32] considered the pricing strategies of the green supply chain under both blockchain technology and capital constraints.

On the other hand, with consumers' increasing reliance on online shopping, manufacturers are gradually shifting the sale of green products from offline to online. As a result, scholars have conducted studies on the sale of green products based on EP. Zhou and Duan [39] studied the impact of consumers' reference to green effects and environmental awareness on sales models, green product design and pricing by developing a programmatic model of a GECSC consisting of a GM and an EP. Wang *et al.* [30] investigated the decision making and coordination of GECSC with GM's fairness concerns in PSM, taking into account product greenness and EP's services, where EP is the decision maker. Meanwhile, Mondal and Giri [19] analyzed return policies and exchange offers in the GECSC, considering the price of the products, the level of greenness and the services of the EP.

2.2. E-commerce sales model

The emergence of EP has not only produced significant changes in the way of business, but also reduced operating costs to a certain extent. Many scholars have compared and analyzed WSM and PSM, aiming to find the choice of sales model applicable to different conditions. Hagiu [6] clarified for the first time the difference between the two sales models and pointed out the various factors affecting the choice of sales model.

Several studies have examined the issue of sales model choice by considering partial order fulfillment costs. For example, Hagiu and Wright [7] analyzed the impact of the relative importance of the private information of independent suppliers and intermediaries, as well as spillovers between products, on the choice of sales model considering these costs. Zhang and Ma [38] investigated whether suppliers and platforms could establish market channels by introducing logistics service strategies. The study found that the level of logistics services has a

greater impact on consumers' channel choice than the selling price of the product. Liu *et al.* [16] explored the impact of e-commerce sales models and logistics choices on supply chain performance, taking into account carbon emissions and logistics levels. Additionally, Tian *et al.* [28] examined the impact of upstream competition and order fulfillment costs on the selection of online intermediary channel model.

There are also studies that consider order fulfillment costs to be zero or treat them as non-critical. Tan and Carrillo [27] examined the benefits of the PSM in digital goods markets by comparing it with the WSM for vertically differentiated products. Kwark *et al.* [9] showed that quality dimensions of online review information can homogenize the differences in consumers' perceived utility. The availability of such information is beneficial for wholesale retailers, but detrimental for platform retailers. Moreover, Yang [36] investigated a dual-channel supply chain consisting of an EP and a GM and theoretically analyzed the green investment strategies of e-commerce firms and their interaction with the e-commerce sales model selection strategies of supply chain members from a profit maximization perspective. Their results suggest that intermediaries can mitigate competitive price pressure in online markets.

2.3. Delivery time

Delivery time is a crucial factor that can enhance responsiveness, significantly influence market demand through the online channel, and strengthen a company's competitiveness. On-time delivery has a direct impact on customer repurchasing intent and brand recognition. Given the importance of delivery time, research on delivery time has become one of the hotspots in supply chain research.

Several scholars have studied rapid delivery management methods. He *et al.* [8] examined the sharing of logistics services and competition in a two-channel e-commerce supply chain involving a manufacturer and a retailer. Momen and Torabi [18] developed a price and delivery time related demand function for an omnichannel retailer, considering both demand certainty and uncertainty to provide integrated fulfillment services to this retailer, examining the dynamic competition between traditional, online and OC retail business models. Xu *et al.* [35] considered a supply chain comprising a producer and an EP, where the producer produces and sells products through its offline channels in accordance with a cap-and-trade policy, and the EP works under PSM or WSM and provides logistics services for online sales. Xu *et al.* [34] explored a manufacturer's decisions regarding production and delivery time. Specifically, they considered a scenario where the manufacturer sold products through an EP operating under PSM. Additionally, Xu *et al.* [33] analyzed the coordination of supply chain decision making and delivery time decisions for EP. The study revealed that the effectiveness of delivery cost sharing contracts in coordinating supply chains is contingent on customer sensitivity to delivery time as well as the EP's power.

In addition, some studies assume that firms promise delivery time to consumers. So and Song [25] first proposed the use of a uniform promised delivery time in their model. Within the promised delivery time, firms can guarantee to fulfill most customers' orders. In order to maximize average net profit in the service industry, an optimization model is developed to formulate optimal price, promised delivery time and capacity expansion decisions, where demand is a price and delivery time sensitive log-linear demand function. Niu *et al.* [21] studied the logistics sharing problem of two competing e-commerce firms in two scenarios, one without and one with promised delivery time. Wen and Wang [31] analyzed a make-to-order supply chain with a contract manufacturer (CM) and an original equipment manufacturer (OEM). In this three-stage Stackelberg game model, the CM committed to delivery time while the OEM determined the product's quality level and selling price.

2.4. Green supply chain under epistemic uncertainty

The above work tends to focus on deterministic demand. However, the market environment facing the members of the supply chain is often uncertain. In general, uncertainty is divided into two categories: inherent uncertainty and epistemic uncertainty, where the former arises from the inherent randomness of things and is commonly addressed by probability theory, while the latter arises from the uncertainty due to the inaccuracy or imperfection of the data and information itself.

It is difficult to accurately obtain the probability distribution function when there is insufficient product sample data, which means that mathematical and statistical methods based on probability theory have many limitations in dealing with epistemic uncertainty. To address this issue, Liu [12] proposed uncertainty theory in 2007, suggesting the application of uncertain variables to describe it. Recently, several researchers have used uncertainty theory in green supply chain pricing under epistemic uncertainty. For example, Chen [1] analyzed the green supply chain under uncertain costs and demand, comprising one manufacturer and two heterogeneous retailers. Their study showed that increased sales efforts by the retailers led to higher profits for both centralized and decentralized supply chain. Sang [22] investigated the pricing and environmental decision problem in an uncertain environment with risk-averse retailers. Wang and Song [29] examined the pricing strategy of a dual-channel supply chain under epistemic uncertainty, taking into account green investment and sales effort.

Most of the above literature uses the traditional expected utility decision rule to maximize the profits of supply chain members, but in the actual decision-making process, supply chain members tend to have certain risk attitudes. Therefore, some scholars have used confidence levels to quantify risk attitudes to conduct research on green supply chains. Gao and Zhao [4] further studied the pricing problem of a green product supply chain considering extended warranty services under epistemic uncertainty by assuming that both the manufacturer and the retailer aim to maximize profits under the confidence level. Additionally, considering the risk attitudes of decision makers in reality, Shen *et al.* [24] construct a chance-constrained model to study the pricing and coordination problems of the green product supply chain in an uncertain environment. Later, Shen *et al.* [23] extend various risk attitude models to study the impact of government intervention on the green supply chain.

2.5. Research gap

The existing literature has extensively examined GECSC and its e-commerce sales model, taking into account greenness or delivery time. In contrast to the above literature, our paper establishes chance-constrained models under epistemic uncertainty, revealing the effects of different confidence levels and other key parameters, such as the cost of green investment and the maximum delivery cost, on the GECSC. It also examines the impact of cost-sharing contracts on the supply chain. The chance-constrained models consider high-probability events with uncertain variables while minimizing the impact of low-probability extreme events on the optimal solution. This results in a more robust decision-making framework, better reflecting the risk preferences and experiences of decision-makers. Moreover, when probability distributions are unavailable, we adopt uncertainty theory to characterize variables, which offers a new method for modeling such problems. Table 1 summarizes the differences between our paper and its highly relevant studies.

3. Problem description

We consider a GECSC consisting of an EP and a GM selling green products through the EP. The EP has two sales models – the wholesale sales model and the platform sales model. In the WSM, the GM invests in greenness and production costs and distributes the green product to EP at the wholesale price. The EP acts as a traditional distributor and takes care of the logistics of delivering the green product to the end-user. The GM determines the products' wholesale price and greenness, while the EP determines the delivery time and retail price. In the PSM, the GM invests in both product greenness and logistics services and determines to distribute products through the EP. In this model, the GM commits to compensating a commission for every product unit sold. The GM decides on the level of product greenness, the delivery time and the selling price. To facilitate our analysis, the notation used in this paper is presented in Table 2. Additionally, the structures of the GECSC under each of the sales models are depicted in Figure 1.

In order to establish the model, we make the following main assumptions.

Assumption 3.1. Our paper excludes horizontal competition and only focuses on the case of an EP and a GM. In the GECSC, the GM has a dominant position.

TABLE 1. Comparison with highly relevant studies.

Key related studies	Price and green sensitivity	E-commerce supply chain	Uncertain demand function	E-commerce sales model selection	Others
Zhou and Duan [39]	✓	✓	×	✓	Reference greenness effect
Mondal and Giri [19]	✓	✓	×	×	Service level; Return policy
Zhang and Ma [38]	×	✓	×	✓	Logistics service sharing
Liu *et al.* [16]	✓	✓	×	✓	Logistics levels
Yang [36]	✓	✓	×	✓	Cap-and-trade regulation
He *et al.* [8]	×	✓	×	×	Logistics service sharing and competition
Xu *et al.* [35]	×	✓	×	✓	Delivery time; Cross-channel effect; Blockchain technology
Xu *et al.* [34]	×	✓	×	×	Delivery time; Cap-and-trade regulation
Gao and Zhao [4]	✓	×	✓	×	Extended warranty
Shen *et al.* [23]	✓	×	✓	×	Government intervention
This paper	✓	✓	✓	✓	Delivery time

TABLE 2. Summary of symbols.

Symbol	Meaning
d	Market demand of the product
c	Unit manufacturing cost of the product
w	Wholesale price of the product
p	Selling price of the product
γ	Total market potential
η_1	Retail price sensitivity of demand
η_2	Greenness sensitivity of demand
η_3	Delivery time sensitivity of demand
I	The cost parameter of green investment
θ	Greenness of the product
$I\theta^2$	The investment cost of greenness
r_0	The maximum cost of delivery
r_1	The cost savings from a one-unit delay in delivery time
L	Delivery time of the product
$(r_0 - r_1 L)^2$	The investment cost of delivery time
ρ	Unit commission paid to the EP

Assumption 3.2. The additional processing cost associated with green products compared to ordinary products is related to the investment in green technology that improves the environmental performance of the product. According to Yang *et al.* [37], Mondal and Giri [19] and Wang *et al.* [30], the investment in green technology can be expressed as a quadratic function of the greenness of the product $I\theta^2$, where I is the green investment cost parameter.

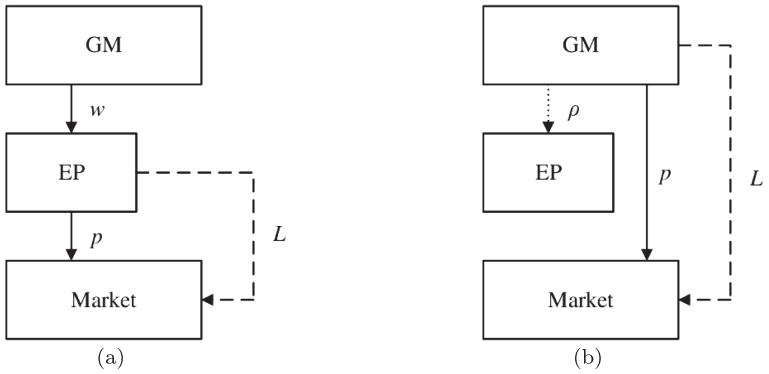

FIGURE 1. The structures of the GECSC in two e-commerce sales models. (a) The structure of the GECSC in the WSM. (b) The structure of the GECSC in the PSM.

Assumption 3.3. Delivery time significantly affects customer preference for online channels, with shorter delivery time increasing online demand and longer delivery time negatively affecting online demand. Members of the supply chain should increase their investment to decrease the delivery time, so the delivery cost is a decreasing function of delivery time, assuming that the investment cost is a quadratic function of delivery time $(r_0 - r_1 L)^2$, where r_0 and r_1 are dependent cost parameters of delivery time and $r_0/r_1 > L$ which follows from [10, 33–35].

Assumption 3.4. In any market, market demand is adversely affected by sale price and delivery time, and market demand is positively affected by greenness. Our study considers uncertain demand, which is linearly influenced by the product's selling price, greenness, and delivery time. In particular, the market demand function d is denoted by

$$d = \gamma - \eta_1 p + \eta_2 \theta - \eta_3 L. \tag{3.1}$$

Here, γ indicates the total market potential, p denotes the selling price, θ stands for the product greenness, and L indicates the delivery time. And η_1, η_2, η_3 respectively represent the sensitive parameters of retail price, greenness and delivery time of demand where $\eta_1 > \eta_2$ [4]. Due to market fluctuations and updates of green products, there is a bias in forecasting customer demand, and consumer psychology is constantly changing, which leads to difficulties in accurately capturing consumer sensitivity to price, greenness and delivery time, and thus lack of historical data to estimate the probability distribution function. Therefore, we assume that the uncertain variables γ, η_1, η_2 and η_3 are independent and positive, and their corresponding uncertainty distributions Ψ, Φ_1, Φ_2 and Φ_3 are all regular. This linear form of demand function is more common in the previous literature, such as Yang *et al.* [37], Mondal and Giri [19] and Wang *et al.* [30].

Assumption 3.5. This paper considers the commission paid by the GM to the EP as an exogenous variable in the PSM, which has a strong basis in practice, for EP like Tmall, Jingdong, Amazon and eBay, where the commission is set before the manufacturer enters the e-platform. In addition, such EP charge varying commissions based on the category of green products.

Assumption 3.6. It is assumed that the EP and the GM have the same understanding of uncertain demand, which can be understood as supply chain players are subject to expert risk estimation of uncertain information. As the EP is closer to the market, its assessments of uncertain demand tend to be more precise and specialized. Assume the EP agrees to collaborate with the GM and share its assessments and insights into its risk attitude. This assumption is plausible because numerous researchers have shown that the traditional model of competition between companies is being replaced by a new model of competition between supply chains [5, 13]. Achieving

competitive advantage in the market increasingly requires a high level of collaboration between upstream and downstream supply chain players. Therefore, we assume that the GM's risk attitude is guided by the EP's risk attitude.

For simplicity, the GM and the EP are denoted by m and e and both have risky attitude and seek to maximize their profit with a given confidence level α. Based on these assumptions, in the WSM, the GM's profit function is

$$\pi_m^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) = (w - c)d - I\theta^2, \tag{3.2}$$

and the EP's profit function is

$$\pi_e^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) = (p - w)d - (r_0 - r_1 L)^2. \tag{3.3}$$

In the PSM, the manufacturer's profit function is

$$\pi_m^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) = (p - \rho - c)d - (r_0 - r_1 L)^2 - I\theta^2, \tag{3.4}$$

and the EP's profit function is

$$\pi_e^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) = \rho d. \tag{3.5}$$

Then the total profit function of the supply chain under both models is

$$\pi^I(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) = (p - c)d - (r_0 - r_1 L)^2 - I\theta^2. \tag{3.6}$$

In order to guarantee the profitability of supply chain members, then $d > 0, p > w, w > c$. Obviously, we can conclude that $\pi_m^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3)$, $\pi_e^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3)$, $\pi_m^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3)$, $\pi_e^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3)$ and $\pi^I(p, \theta, L; \gamma, \eta_1, \eta_2, \eta_3)$ are uncertain variables.

The GM's attitude towards risk when making decisions is represented by the confidence level α, which ranges from 0 to 1. A higher value of α implies greater risk aversion of the GM. Then, the GM's profit can be represented as π_0^m that belongs to $\{\pi_0^m | \mathcal{M}\{\pi_m^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^m\} \geq \alpha\}$, which is a set of profits that the GM can accept in the WSM under confidence level α. The PSM is similar to the above expression. Hence, the GM's optimal profit Π_m^{WSM} and Π_m^{PSM} under α in both models can be expressed as

$$\Pi_m^{\mathrm{WSM}} = \max\{\pi_0^m | \mathcal{M}\{\pi_m^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^m\} \geq \alpha\}, \tag{3.7}$$

and

$$\Pi_m^{\mathrm{PSM}} = \max\{\pi_0^m | \mathcal{M}\{\pi_m^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^m\} \geq \alpha\}. \tag{3.8}$$

Then, the maximum profits of the EP and the entire supply chain under α can be expressed as follows,

$$\Pi_e^{\mathrm{WSM}} = \max\{\pi_0^e | \mathcal{M}\{\pi_e^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^e\} \geq \alpha\}, \tag{3.9}$$

$$\Pi_e^{\mathrm{PSM}} = \max\{\pi_0^e | \mathcal{M}\{\pi_e^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^e\} \geq \alpha\}, \tag{3.10}$$

and

$$\Pi^I = \max\{\pi_0^I | \mathcal{M}\{\pi^I(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^I\} \geq \alpha\}. \tag{3.11}$$

4. Model analysis

In this section, five scenarios will be considered: the integrated scenario and the GM-dominant scenario under WSM, the GM-dominant scenario under PSM, as well as the cost-sharing scenario under both models. We then examine the optimum solutions and evaluate the different strategies adopted by the GECSC in each case.

4.1. The integrated scenario

This subsection presents a integrated scenario as a benchmark. In this model, GECSC's members make decisions with the objective of maximizing system profit at a given confidence level. Next, we establish and present the model for integrated scenario as shown below,

$$\max_{(p,\theta,L)} \max\{\pi_0^I | \mathcal{M}\{\pi^I(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^I\} \geq \alpha\}. \tag{4.1}$$

We transform Model (4.1) into the following equivalent form by applying uncertainty theory,

$$\max_{(p,\theta,L)} (p-c)\big(\Psi^{-1}(1-\alpha) - \Phi_1^{-1}(\alpha)p + \Phi_2^{-1}(1-\alpha)\theta - \Phi_3^{-1}(\alpha)L\big) - I\theta^2 - (r_0 - r_1 L)^2, \tag{4.2}$$

where $\Psi^{-1}(1-\alpha)$ represents the total market potential of GM and EP under confidence level α, $\Phi_1^{-1}(\alpha)$ signifies the consumer's price sensitivity with respect to the confidence level α, $\Phi_2^{-1}(1-\alpha)$ represents the consumer's green sensitivity under confidence level α and $\Phi_3^{-1}(\alpha)$ denotes the delivery time sensitivity of consumer under confidence level α.

Proposition 4.1. *The optimal selling price, the greenness and the delivery time of product are shown as follows,*

$$p^* = \frac{2Ir_1A}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B} + c, \tag{4.3}$$

$$\theta^* = \frac{\Phi_2^{-1}(1-\alpha)r_1A}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B}, \tag{4.4}$$

$$L^* = \frac{-I\Phi_3^{-1}(\alpha)A}{r_1((\Phi_2^{-1}(1-\alpha))^2 r_1^2) + B)} + \frac{r_0}{r_1}, \tag{4.5}$$

and the GECSC's optimal profit under confidence level α is

$$\Pi_I^* = -\frac{IA^2}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B}, \tag{4.6}$$

where

$$A = r_0\Phi_3^{-1}(\alpha) - r_1\Psi^{-1}(1-\alpha) + cr_1\Phi_1^{-1}(\alpha), \tag{4.7}$$

$$B = I\big(\Phi_3^{-1}(\alpha)\big)^2 - 4Ir_1^2\Phi_1^{-1}(\alpha). \tag{4.8}$$

Proposition 4.2. *The retail price p^*, the greenness θ^* of the product and the GECSC's profit Π_I^* decrease with regard to the cost parameter of green investment I while the delivery time L^* of the product increases with regard to the cost parameter of green investment I.*

Proposition 4.2 states that as the cost rate of greenness investment I increases, the product's optimal level of greenness will reduce. Consequently, consumers' willingness to buy may decrease, leading to a reduction in the market demand for the product. Thus, the member of GECSC will invest less in delivery time, resulting in longer delivery time. As a result, the member of GECSC reduces the retail price as a strategy to attract consumers. This may result in reduced profit for the GECSC.

Proposition 4.3. *The selling price p^*, the greenness θ^* of product and the GECSC's profit Π_I^* decrease with respect to the maximum cost of delivery r_0 while the delivery time L^* of the product increases with respect to the maximum cost of delivery r_0.*

Proposition 4.3 indicates that as the maximum cost of delivery r_0 increases, the willingness of supply chain members to optimize product delivery time decreases, resulting in a longer product delivery time which means that online products take longer to deliver to consumers, and some demand will be shifted or even lost due to the inability to meet consumer demand for online consumption, so in order to win back consumers, the selling price will be forced down and the profit will be reduced. The GM will also reduce his green investment and therefore become greenless.

4.2. The GM-dominant scenario under WSM

In this subsection, we focus on the EP acting as a traditional retailer, wholesaling products from the upstream manufacturer, independently setting the retail price to sell the products, and providing the appropriate logistics to deliver green products to customers. Then, we can develop the model for the decentralized channel under WSM with respect to the confidence level α as follows,

$$\begin{cases} \max\limits_{(w,\theta)} \max\{\pi_0^m | \mathcal{M}\{\pi_m^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^m\} \geq \alpha\}, \\ \text{subject to} \\ \max\limits_{(p,L)} \max\{\pi_0^e | \mathcal{M}\{\pi_e^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^e\} \geq \alpha\}. \end{cases} \tag{4.9}$$

We transform Model (4.9) into the following equivalent form by using uncertainty theory,

$$\begin{cases} \max\limits_{(w,\theta)} (w-c)\big(\Psi^{-1}(1-\alpha) - \Phi_1^{-1}(\alpha)p + \Phi_2^{-1}(1-\alpha)\theta - \Phi_3^{-1}(\alpha)L\big) - I\theta^2, \\ \text{subject to} \\ \max\limits_{(p,L)} (p-w)\big(\Psi^{-1}(1-\alpha) - \Phi_1^{-1}(\alpha)p + \Phi_2^{-1}(1-\alpha)\theta - \Phi_3^{-1}(\alpha)L\big) - (r_0 - r_1 L)^2. \end{cases} \tag{4.10}$$

Proposition 4.4. *The GM's best greenness and wholesale price are displayed as follows,*

$$w^{\mathrm{WSM}} = \frac{-BA}{\Phi_1^{-1}(\alpha) r_1 \big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + 2B\big)} + c, \tag{4.11}$$

$$\theta^{\mathrm{WSM}} = \frac{\Phi_2^{-1}(1-\alpha)\, \mathrm{r}_1\, A}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + 2B}, \tag{4.12}$$

and the GM's optimal profit under confidence level α is

$$\Pi_m^{\mathrm{WSM}} = -\frac{IA^2}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + 2B}, \tag{4.13}$$

where A and B are represented as equations (4.7) and (4.8), respectively.

Proposition 4.5. *The EP's best retail price and delivery time are shown below,*

$$p^{\mathrm{WSM}} = \frac{2I\Phi_1^{-1}(\alpha) r_1^2 A - BA}{\Phi_1^{-1}(\alpha) r_1 \big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + 2B\big)} + c, \tag{4.14}$$

$$L^{\mathrm{WSM}} = \frac{-I\Phi_3^{-1}(\alpha) A}{r_1 \big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + 2B\big)} + \frac{r_0}{r_1}, \tag{4.15}$$

and the optimal profit of EP and GECSC under confidence level α are

$$\Pi_e^{\mathrm{WSM}} = \frac{-IBA^2}{\big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + 2B\big)^2}, \tag{4.16}$$

$$\Pi_I^{\mathrm{WSM}} = -\frac{IA^2\big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + 3B\big)}{\big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + 2B\big)^2}, \tag{4.17}$$

where A and B are represented as equations (4.7) and (4.8), respectively.

Proposition 4.6. *The selling price p^{WSM}, the greenness θ^{WSM}, the wholesale price w^{WSM} of the product and the profit of GM, EP and GECSC $\Pi_m^{\mathrm{WSM}}, \Pi_e^{\mathrm{WSM}}, \Pi_I^{\mathrm{WSM}}$ reduce with regard to the cost parameter of green investment I while the delivery time L^{WSM} of the product increases with regard to the cost parameter of green investment I.*

Proposition 4.6 suggests that under WSM, as the cost rate of greenness investment I increases, the greenness improvements of the product will reduce. To encourage EP to purchase these products, the GM will reduce the wholesale price, which may lead to reduced profit for the GM and reduced demand from environmentally sensitive consumers. As a result, the EP will have to reduce the retail price to attract customers, which may reduce profit for the EP and the supply chain. For these reasons, low profit is not enough of an incentive for EP to over-invest in the product's delivery time.

Proposition 4.7. *The selling price p^{WSM}, the greenness θ^{WSM}, the wholesale price w^{WSM} of the product and the profit of GM, EP and GECSC $\Pi_m^{\mathrm{WSM}}, \Pi_e^{\mathrm{WSM}}, \Pi_I^{\mathrm{WSM}}$ reduce with regard to the maximum cost of delivery r_0 while the delivery time L^{WSM} of the product increases with regard to the maximum cost of delivery r_0.*

Proposition 4.7 shows that under WSM, as the maximum cost of delivery r_0 increases, the EP's willingness to optimize the delivery time of the product decreases, resulting in a longer waiting time for green products to reach consumers. This inevitably reduces consumer demand, leading to the retail price and the EP's profit will be decreased. Reduced demand also makes GM and the supply chain less profitable. Low profit is not enough of an incentive for GM to invest too much in green products, and for these reasons, products become less green and the GM will reduce wholesale price to encourage EP to buy these products.

4.3. The GM-dominant scenario under PSM

In this subsection, we discuss a scenario where EP acts as a third-party platform to sell products for the GM. The GM invests in the greenness of the products, chooses to sell their products through a contracted EP, and agrees to compensate the EP with a commission for each unit of product sold. The GM provides an appropriate delivery service to deliver the green products to environmentally sensitive consumers and the EP has no pricing power in the process. Then, we can develop the model for the decentralized channel under PSM with respect to the confidence level α as follows,

$$\begin{cases} \max\limits_{(\theta,L,p)} \max\{\pi_0^m | \mathcal{M}\{\pi_m^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^m\} \geq \alpha\}, \\ \text{subject to} \\ \max \max\{\pi_0^e | \mathcal{M}\{\pi_e^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^e\} \geq \alpha\}. \end{cases} \tag{4.18}$$

We transform Model (4.18) into the following equivalent form by using uncertainty theory,

$$\begin{cases} \max\limits_{(p,\theta,L)} (p - \rho - c)\big(\Psi^{-1}(1-\alpha) - \Phi_1^{-1}(\alpha)p + \Phi_2^{-1}(1-\alpha)\theta - \Phi_3^{-1}(\alpha)L\big) - I\theta^2 \\ \qquad -(r_0 - r_1 L)^2, \\ \text{subject to} \\ \max \rho\big(\Psi^{-1}(1-\alpha) - \Phi_1^{-1}(\alpha)p + \Phi_2^{-1}(1-\alpha)\theta - \Phi_3^{-1}(\alpha)L\big). \end{cases} \tag{4.19}$$

Proposition 4.8. *The GM's optimal greenness level, retail price and delivery time are shown as follows,*

$$\theta^{\mathrm{PSM}} = \frac{r_1 \Phi_2^{-1}(1-\alpha)\left(\rho r_1 \Phi_1^{-1}(\alpha) + A\right)}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B}, \tag{4.20}$$

$$p^{\mathrm{PSM}} = \frac{2Ir_1\big(\rho r_1 \Phi_1^{-1}(\alpha) + A\big)}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B} + (\rho + c), \tag{4.21}$$

$$L^{\mathrm{PSM}} = -\frac{I\Phi_3^{-1}(\alpha)\left(\rho r_1\Phi_1^{-1}(\alpha) + A\right)}{r_1((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B)} + \frac{r_0}{r_1}, \tag{4.22}$$

and the optimal profit of GM, EP and GECSC under confidence level α are

$$\Pi_e^{\mathrm{PSM}} = \frac{2I\rho r_1\Phi_1^{-1}(\alpha)\left(\rho r_1\Phi_1^{-1}(\alpha) + A\right)}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B}, \tag{4.23}$$

$$\Pi_m^{\mathrm{PSM}} = -\frac{I\left(\rho r_1\Phi_1^{-1}(\alpha) + A\right)^2}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B}, \tag{4.24}$$

$$\Pi_I^{\mathrm{PSM}} = \frac{I\left((\rho r_1\Phi_1^{-1}(\alpha))^2 - A^2\right)}{(\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B}, \tag{4.25}$$

where A and B are represented as equations (4.7) and (4.8), respectively.

Proposition 4.9. *The retail price p^{PSM}, the greenness θ^{PSM} of the product and the profit of GM, EP and GECSC $\Pi_m^{\mathrm{PSM}}, \Pi_e^{\mathrm{PSM}}, \Pi_I^{\mathrm{PSM}}$ reduce in terms of the cost parameter of green investment I while the delivery time L^{PSM} of the product increases in terms of the cost parameter of green investment I.*

Proposition 4.9 suggests that under PSM, as the cost rate of greenness investment I increases, the GM's willingness to optimize the greenness level of the product decreases, leading to a lower optimal greenness of the product. Also, as the GM's capital is limited, an increase in the cost rate of greenness investment will reduce the GM's investment in product delivery time, which in turn will increase the product delivery time. The reduction in product greenness and delivery efficiency will ultimately lead to a loss of market share and therefore, in order to attract consumers back, the selling price will be forced down and the profit for the whole supply chain and each member will be reduced.

Proposition 4.10. *The greenness θ^{PSM}, the retail price p^{PSM} of the product and the profit of GM, EP and GECSC $\Pi_m^{\mathrm{PSM}}, \Pi_e^{\mathrm{PSM}}, \Pi_I^{\mathrm{PSM}}$ reduce with regard to the maximum cost of delivery r_0 while the delivery time L^{PSM} of the product increases with regard to the maximum cost of delivery r_0.*

Proposition 4.10 suggests that under PSM, as the maximum cost of delivery r_0 increases, the GM's willingness to optimize the delivery time of the product decreases, resulting in a longer waiting time for green products to reach consumers. Also, as GM's capital is limited, an increase in the fixed investment of reducing delivery time will reduce GM's investment in product greenness, and thus reduce greenness. The reduction in product delivery efficiency and greenness level will ultimately lead to a loss of online consumer demand and therefore, in order to win back consumers, the selling price will be forced down and the profit for the whole supply chain and each member will be reduced.

4.4. The cost-sharing scenario under WSM or PSM

In this subsection, we assume EP joins greenness investment, implying that the members of the GECSC share the green cost. The cost-sharing contract is set under α. We discuss the participation of the EP in green investment under two different sales models, WSM and PSM. First, we give the decision sequence as shown in Figure 2, then we denote the profit equation for the GECSC's members and finally, the equilibrium solutions for the two scenarios are obtained.

To foster a closer relationship, the GM and EP split the eco-friendly cost together. Per the agreement, the green cost is split between the GM and EP, where the GM covers a proportion of μ percent and the EP covers $1-\mu$ percent. Here, $0 \le \mu < 1$. Specifically, the cost share of the GM is $\mu I\theta^2$ and the cost share of the EP is $(1-\mu)I\theta^2$.

In the WSM, the GM's and EP's profit are represented as

$$\pi_m^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) = (w-c)d - \mu I\theta^2, \tag{4.26}$$

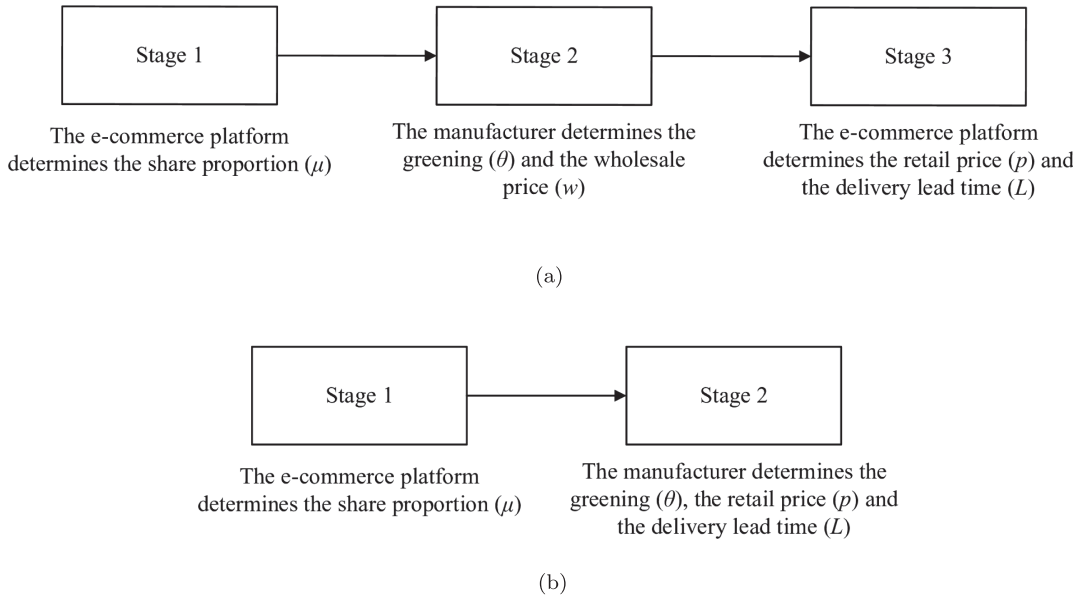

FIGURE 2. The decision diagram of the GECSC in two e-commerce sales models. (a) The decision diagram of the GECSC in the WSM. (b) The decision diagram of the GECSC in the PSM.

and

$$\pi_e^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) = (p - w)d - (r_0 - r_1 L)^2 - (1 - \mu)I\theta^2. \tag{4.27}$$

Thus, the GM's and EP's profit under confidence level α are as follows,

$$\Pi_m^{\mathrm{WSM}} = \max\{\pi_0^m | \mathcal{M}\{\pi_m^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^m\} \geq \alpha\}, \tag{4.28}$$

and

$$\Pi_e^{\mathrm{WSM}} = \max\{\pi_0^e | \mathcal{M}\{\pi_e^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^e\} \geq \alpha\}. \tag{4.29}$$

After that, the model for constructing a cost-sharing case is as follows,

$$\begin{cases} \max\limits_{(\mu)} \max\{\pi_0^e | \mathcal{M}\{\pi_e^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^e\} \geq \alpha\}, \\ \text{subject to} \\ \max\limits_{(w,\theta)} \max\{\pi_0^m | \mathcal{M}\{\pi_m^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^m\} \geq \alpha\}, \\ \text{subject to} \\ \max\limits_{(p,L)} \max\{\pi_0^e | \mathcal{M}\{\pi_e^{\mathrm{WSM}}(\theta, L, w, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^e\} \geq \alpha\}. \end{cases} \tag{4.30}$$

Converting Model (4.30) to its equivalent form by using uncertainty theory,

$$\begin{cases} \max\limits_{(\mu)} (p-w)\big(\Psi^{-1}(1-\alpha)-\Phi_1^{-1}(\alpha)p+\Phi_2^{-1}(1-\alpha)\theta-\Phi_3^{-1}(\alpha)L\big)-(r_0-r_1L)^2 \\ \qquad -(1-\mu)I\theta^2, \\ \text{subject to} \\ \max\limits_{(w,\theta)} (w-c)\big(\Psi^{-1}(1-\alpha)-\Phi_1^{-1}(\alpha)p+\Phi_2^{-1}(1-\alpha)\theta-\Phi_3^{-1}(\alpha)L\big)-\mu I\theta^2, \\ \text{subject to} \\ \max\limits_{(p,L)} (p-w)\big(\Psi^{-1}(1-\alpha)-\Phi_1^{-1}(\alpha)p+\Phi_2^{-1}(1-\alpha)\theta-\Phi_3^{-1}(\alpha)L\big)-(r_0-r_1L)^2 \\ \qquad -(1-\mu)I\theta^2. \end{cases} \tag{4.31}$$

Proposition 4.11. *The GM's best greenness and wholesale price are displayed as follows,*

$$\theta^{\mathrm{WSMcs}} = \frac{2r_1\Phi_2^{-1}(1-\alpha)A}{3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B}, \tag{4.32}$$

$$w^{\mathrm{WSMcs}} = \frac{\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)\big(2cr_1\Phi_1^{-1}(\alpha)-A\big)+4cr_1^2\Phi_1^{-1}(\alpha)(\Phi_2^{-1}(1-\alpha))^2}{3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B}, \tag{4.33}$$

and the GM's optimal profit under confidence level α is

$$\Pi_m^{\mathrm{WSMcs}} = \frac{IA^2\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)}{-2B\big(3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)}. \tag{4.34}$$

Proposition 4.12. *The EP's optimal sharing proportion, delivery time and retail price are shown as follows,*

$$u^{\mathrm{WSMcs}} = \frac{(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B}{4B}, \tag{4.35}$$

$$\begin{aligned} L^{\mathrm{WSMcs}} = {} & \frac{I\Phi_3^{-1}(\alpha)\big((\Phi_2^{-1}(1-\alpha))^2+4I(\Phi_3^{-1}(\alpha))^2\big)\big(Ir_0\Phi_3^{-1}(\alpha)-A\big)}{-2r_1B\big(3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)} \\ & + \frac{4Ir_1D}{-2r_1B\big(3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)}, \end{aligned} \tag{4.36}$$

$$\begin{aligned} p^{\mathrm{WSMcs}} = {} & \frac{IC\big(2cr_1\Phi_1^{-1}(\alpha)-A\big)}{-2r_1B\Phi_1^{-1}(\alpha)\big(3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)} \\ & + \frac{4cr_1^3\Phi_1^{-1}(\alpha)\Phi_2^{-1}(1-\alpha))^2B}{-2r_1B\Phi_1^{-1}(\alpha)\big(3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)} \\ & + \frac{8cIr_1^3\Phi_2^{-1}(1-\alpha))^2\big((-\Phi_2^{-1}(1-\alpha))^2r_1^2+2B\big)}{-2r_1B\Phi_1^{-1}(\alpha)\big(3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)}, \end{aligned} \tag{4.37}$$

and the EP's and the GECSC's optimal profit under confidence level α are

$$\Pi_e^{\mathrm{WSMcs}} = \frac{IA^2\big((\Phi_2^{-1}(1-\alpha))^2r_1^2-4B\big)}{4B\big(3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)}, \tag{4.38}$$

$$\Pi_I^{\mathrm{WSMcs}} = \frac{IA^2\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+12B\big)}{-4B\big(3(\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)}, \tag{4.39}$$

where A, B are respectively shown in equations (4.7) and (4.8) and C, D are represented as follows,

$$\begin{aligned} C &= 4I\big(\Phi_3^{-1}(\alpha)\big)^4 - 40Ir_1^2\Phi_1^{-1}(\alpha)\big(\Phi_3^{-1}(\alpha)\big)^2 + 96Ir_1^4\big(\Phi_2^{-1}(1-\alpha)\big)^2 \\ &\quad - 6r_1^4\Phi_1^{-1}(\alpha)\big(\Phi_2^{-1}(1-\alpha)\big)^2 + r_1^2\big(\Phi_2^{-1}(1-\alpha)\big)^2\big(\Phi_3^{-1}(\alpha)\big)^2, \end{aligned} \tag{4.40}$$

$$\begin{aligned} D &= 4cr_1\Phi_3^{-1}(\alpha)\big(\Phi_2^{-1}(1-\alpha)\big)^2 + 32Ir_0r_1^2\big(\Phi_2^{-1}(1-\alpha)\big)^2 \\ &\quad - 6r_0r_1^2\Phi_1^{-1}(\alpha)\big(\Phi_2^{-1}(1-\alpha)\big)^2 - 12Ir_0\Phi_1^{-1}(\alpha)\big(\Phi_3^{-1}(\alpha)\big)^2 \\ &\quad - 4Ir_1\Psi^{-1}(1-\alpha)\Phi_1^{-1}(\alpha)\Phi_3^{-1}(\alpha) + r_0\big(\Phi_3^{-1}(\alpha)\big)^2\big(\Phi_2^{-1}(1-\alpha)\big)^2. \end{aligned} \tag{4.41}$$

In the PSM, the GM's and the EP's profit are expressed as

$$\pi_m^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) = (p - \rho - c)d - (r_0 - r_1 L)^2 - \mu I\theta^2, \tag{4.42}$$

and

$$\pi_e^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) = \rho d - (1-\mu)I\theta^2. \tag{4.43}$$

Thus, the profit of the GM and the EP under confidence level α are as follows,

$$\Pi_m^{\mathrm{PSM}} = \max\big\{\pi_0^m | \mathcal{M}\big\{\pi_m^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^m\big\} \geq \alpha\big\}, \tag{4.44}$$

and

$$\Pi_e^{\mathrm{PSM}} = \max\big\{\pi_0^e | \mathcal{M}\big\{\pi_e^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^e\big\} \geq \alpha\big\}. \tag{4.45}$$

After that, the model for constructing a cost-sharing case is as follows,

$$\begin{cases} \max\limits_{(\mu)} \max\big\{\pi_0^e | \mathcal{M}\big\{\pi_e^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^e\big\} \geq \alpha\big\}, \\ \text{subject to} \\ \max\limits_{(p,\theta,L)} \max\big\{\pi_0^m | \mathcal{M}\big\{\pi_m^{\mathrm{PSM}}(\theta, L, p; \gamma, \eta_1, \eta_2, \eta_3) \geq \pi_0^m\big\} \geq \alpha\big\}. \end{cases} \tag{4.46}$$

We transform Model (4.46) into the following equivalent form by using uncertainty theory,

$$\begin{cases} \max\limits_{(\mu)} \rho\big(\Psi^{-1}(1-\alpha) - \Phi_1^{-1}(\alpha)p + \Phi_2^{-1}(1-\alpha)\theta - \Phi_3^{-1}(\alpha)L\big) - (1-\mu)I\theta^2, \\ \text{subject to} \\ \max\limits_{(p,\theta,L)} (p - \rho - c)\big(\Psi^{-1}(1-\alpha) - \Phi_1^{-1}(\alpha)p + \Phi_2^{-1}(1-\alpha)\theta - \Phi_3^{-1}(\alpha)L\big) - \mu I\theta^2 \\ \qquad -(r_0 - r_1 L)^2. \end{cases} \tag{4.47}$$

Proposition 4.13. *The GM's optimum greenness, delivery time and retail price are as follows,*

$$\theta^{\mathrm{PSMcs}} = \frac{\Phi_2^{-1}(1-\alpha)r_1\big(A - \rho r_1\Phi_1^{-1}(\alpha)\big)}{2\big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B\big)}, \tag{4.48}$$

$$\begin{aligned} L^{\mathrm{PSMcs}} &= \frac{Ir_1\Phi_3^{-1}(\alpha)\big(8I\Phi_1^{-1}(\alpha) - (\Phi_2^{-1}(1-\alpha))^2\big)\big(2r_0\Phi_3^{-1}(\alpha) - \rho r_1\Phi_1^{-1}(\alpha) - A\big)}{-2B\big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B\big)} \\ &\quad + \frac{2I^2(\Phi_3^{-1}(\alpha))^3\big(c\Phi_1^{-1}(\alpha) - \Psi^{-1}(1-\alpha)\big)}{-2B\big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B\big)} \\ &\quad + \frac{2I\Phi_1^{-1}(\alpha)(\Phi_2^{-1}(1-\alpha))^2 r_1^2\big(4r_0 r_1 + \rho\Phi_3^{-1}(\alpha)\big) - 32Ir_0 r_1^3(\Phi_1^{-1}(\alpha))^2}{-2B\big((\Phi_2^{-1}(1-\alpha))^2 r_1^2 + B\big)}, \end{aligned} \tag{4.49}$$

$$
\begin{aligned}
p^{\mathrm{PSMcs}} = & \frac{Ir_1^3\big((\Phi_2^{-1}(1-\alpha))^2+8I\Phi_1^{-1}(\alpha)\big)\big(2cr_1\Phi_1^{-1}(\alpha)+\rho r_1\Phi_1^{-1}(\alpha)-A\big)}{-B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)} \\
& + \frac{I(\rho+c)\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B-2I\Phi_1^{-1}(\alpha)r_1^2\big)}{-B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)} \\
& + \frac{2Ir_1\big(Ir_0(\Phi_3^{-1}(\alpha))^3+Ir_1(\Phi_3^{-1}(\alpha))^2\Psi^{-1}(1-\alpha)\big)}{-B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)} \\
& - \frac{2Icr_1^4\Phi_1^{-1}(\alpha)(\Phi_2^{-1}(1-\alpha))^2}{-B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)},
\end{aligned} \tag{4.50}
$$

and the optimal profit of the GM under confidence level α is

$$
\begin{aligned}
\Pi_m^{\mathrm{PSMcs}} = & \frac{I\big(\rho r_1\Phi_1^{-1}(\alpha)+A\big)^2\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+2B\big)}{-2B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)} \\
& + \frac{2I\rho r_1^3\Phi_1^{-1}(\alpha)(\Phi_2^{-1}(1-\alpha))^2\big(\rho r_1\Phi_1^{-1}(\alpha)+A\big)}{-2B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)}.
\end{aligned} \tag{4.51}
$$

Proposition 4.14. *The EP's optimal sharing proportion is shown below,*

$$
\begin{aligned}
u^{\mathrm{PSMcs}} = & -\frac{\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+2B\big)\big(\rho r_1\Phi_1^{-1}(\alpha)+A\big)}{B\big(\rho r_1\Phi_1^{-1}(\alpha)-A\big)} \\
& - \frac{2\rho r_1^3\Phi_1^{-1}(\alpha)(\Phi_2^{-1}(1-\alpha))^2}{B\big(\rho r_1\Phi_1^{-1}(\alpha)-A\big)},
\end{aligned} \tag{4.52}
$$

and the EP's and the GECSC's optimal profit under confidence level α are

$$
\begin{aligned}
\Pi_e^{\mathrm{PSMcs}} = & -\frac{I(\Phi_2^{-1}(1-\alpha))^2r_1^2\big(\rho r_1\Phi_1^{-1}(\alpha)+A\big)^2}{-4B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)} \\
& + \frac{2I\rho r_1^3(c-2)\Phi_1^{-1}(\alpha)(\Phi_2^{-1}(1-\alpha))^2\big(\rho r_1\Phi_1^{-1}(\alpha)+A\big)}{-4B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)},
\end{aligned} \tag{4.53}
$$

$$
\begin{aligned}
\Pi_I^{\mathrm{PSMcs}} = & \frac{I\big(\rho r_1\Phi_1^{-1}(\alpha)+A\big)^2\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+4B\big)}{-4B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)} \\
& + \frac{2I\rho cr_1^3\Phi_1^{-1}(\alpha)(\Phi_2^{-1}(1-\alpha))^2\big(\rho r_1\Phi_1^{-1}(\alpha)+A\big)}{-4B\big((\Phi_2^{-1}(1-\alpha))^2r_1^2+B\big)}.
\end{aligned} \tag{4.54}
$$

5. Numerical analysis

We conduct a numerical example to illustrate the conclusions drawn in previous sections. Combined with the previous assumptions, to ensure that the equilibrium solutions in different scenarios are all positive, following Chen *et al.* [1], Gao and Zhao [4], Liu *et al.* [14] and Yang [36], suppose that $c=0, I=1, \rho=0.2, r_0=1, r_1=0.9, \gamma=\mathcal{L}(4,6), \eta_1=\mathcal{L}(2,3), \eta_2=\mathcal{L}(0,1), \eta_3=\mathcal{L}(1,2)$, and then we get $\Psi^{-1}(1-\alpha)=6-2\alpha, \Phi_1^{-1}(\alpha)=2+\alpha, \Phi_2^{-1}(1-\alpha)=1-\alpha, \Phi_3^{-1}(\alpha)=1+\alpha$. Figures are drawn to illustrate the effect of the confidence level α on the retail price, wholesale price, greenness, delivery time of product, and to provide a comparison of the profit behavior of different cases.

Figure 3 presents how product's greenness is impacted by the confidence level α. As shown, the common confidence level has a notable effect on the green level. Specifically, the best greenness strictly decreases as

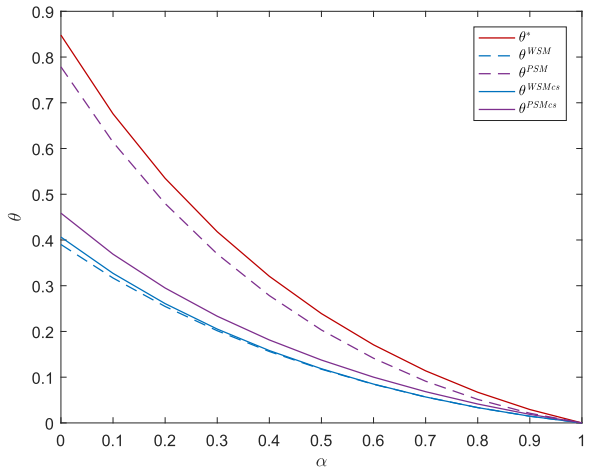

FIGURE 3. The effect of α on greenness.

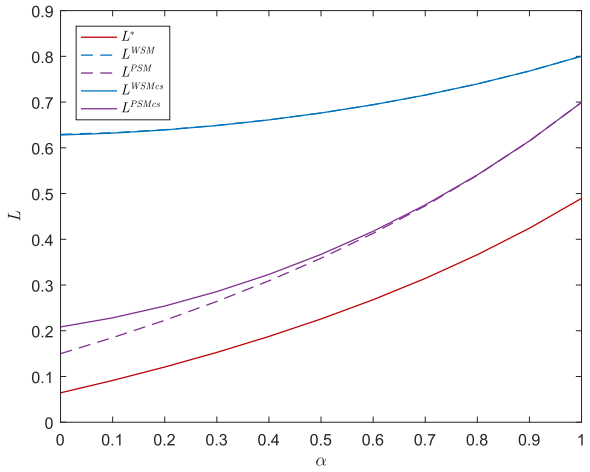

FIGURE 4. The effect of α on delivery time.

α increases. Additionally, regardless of α, the greenness under the integrated scenario is higher than under the GM-dominant scenario under PSM, and higher than under the GM-dominant scenario under WSM, *i.e.* $\theta^* > \theta^{\mathrm{PSM}} > \theta^{\mathrm{WSM}}$, because under the centralized channel, investment in green technology is more flexible and leads to higher profitability for the GECSC by allowing product greenness to be adjusted to market demand. The GM with pricing power under PSM, on the other hand, has the flexibility to adjust product prices according to consumer demand, reducing the cost pressure associated with green production and increasing the overall greenness of the product. The results also show that under PSM, the product is less green in the cost-sharing case than in the decentralized channel case, *i.e.* $\theta^{\mathrm{PSMcs}} < \theta^{\mathrm{PSM}}$, because the EP is unable to ease the pressure on its share of the cost of green investments by raising prices, whereas the GM, which has pricing power, expects the platform to share the costs of greenness. As a result, it may be difficult to reach an agreement on cost sharing, resulting in less investment in green technologies and a reduction in the overall greenness of the product.

Figure 4 shows how the delivery time is impacted by the confidence level α. As shown, the common confidence level has a notable effect on the delivery time. Specifically, the optimal delivery time strictly increases as the

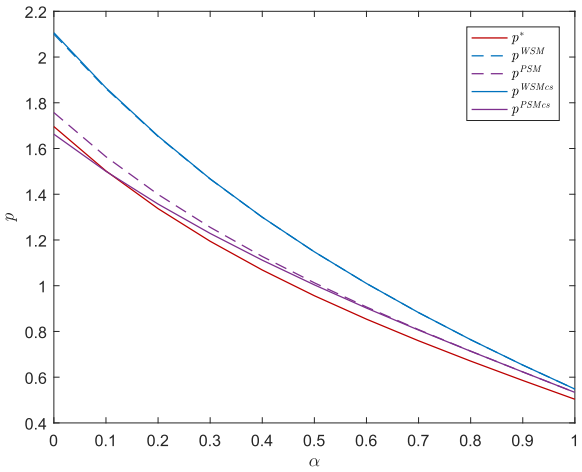

FIGURE 5. The effect of α on retail price.

confidence level increases. Furthermore, the results show that PSM has shorter delivery time than WSM, *i.e.* $L^{\mathrm{PSM}} < L^{\mathrm{WSM}}$. This is because, the GM under PSM holds the decision power of retail price, greenness and delivery time at the same time, which can better balance the relationship between the three. As a result, the delivery efficiency of the PSM is consistently higher than that of the WSM.

Figure 5 illustrates how the retail price is impacted by the confidence level α. As shown, the common confidence level has a notable effect on the retail price. Specifically, the best selling price strictly decreases as α increases. That is because when the risk is higher, members of the supply chain will invest less in the product, thus reducing the overall investment cost, and that less investment leads to less market expansion, thus reducing the retail price. The results show that regardless of α, the selling price in the cost sharing case in WSM p^{WSMcs} is highest, because the EP with pricing power shares part of the cost of greenness and is compensated by the higher price. In PSM, on the other hand, the retail price is lower in the cost sharing case, *i.e.* $p^{\mathrm{PSMcs}} < p^{\mathrm{PSM}}$, because the EP alleviates the cost pressure of the GM by bearing part of the green costs, which in turn reduces the products' price set by the GM.

Figure 6 illustrates how the GM's wholesale price is impacted by the confidence level α. As shown, the common confidence level has a notable effect on the wholesale price of the GM. In both cases, the optimal wholesale price decreases strictly with α. This is because when the risk is higher, GM invests less in the greenness and production of green products, leading to less total investment costs, while lower investment results in less market expansion and therefore lower wholesale prices. Furthermore, the results indicate that EP's sharing of greenness costs has little effect on the optimal wholesale price.

Figure 7 presents how the GECSC's profit is impacted by the confidence level α. As shown, the common confidence level has a notable effect on the GECSC's profit. Specifically, the optimal profit of GECSC strictly decreases as the confidence level increases. Additionally, regardless of the confidence level, the GECSC's profit is higher for the centralized channel case than for the decentralized channel case, *i.e.* $\Pi_I^* > \max\{\Pi_I^{\mathrm{WSM}}, \Pi_I^{\mathrm{PSM}}\}$, because the closer the supply chain members are to each other, the more profitable the GECSC is. Further, the GECSC's profit is higher in the PSM and the corresponding cost sharing case than in the WSM and the corresponding cost sharing case, *i.e.* $\min\{\Pi_I^{\mathrm{PSM}}, \Pi_I^{\mathrm{PSMcs}}\} > \max\{\Pi_I^{\mathrm{WSM}}, \Pi_I^{\mathrm{WSMcs}}\}$. The reason for this is that the GM with pricing power in PSM has the flexibility to adjust retail prices according to consumer demand, allowing the GM to focus on improving product eco-efficiency and supply efficiency while maintaining profitability, which in turn leads to increased market share and higher profits for the entire supply chain. And under PSM, EP's involvement in green investments is detrimental to overall profitability, *i.e.* $\Pi_I^{\mathrm{PSM}} > \Pi_I^{\mathrm{PSMcs}}$.

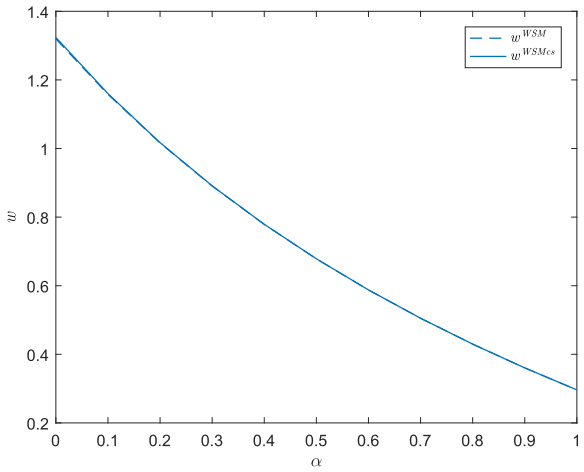

FIGURE 6. The effect of α on the GM's wholesale price.

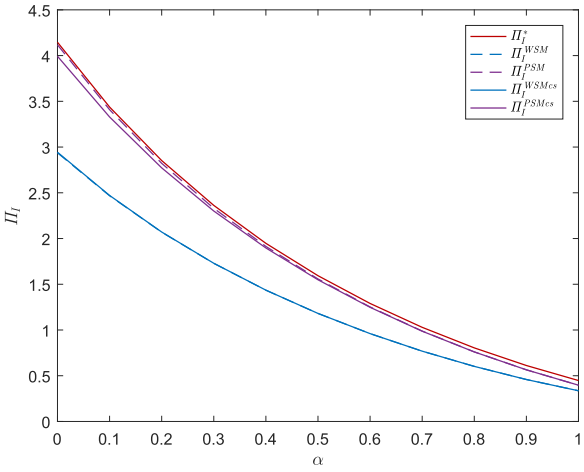

FIGURE 7. The effect of α on the GECSC's profit.

This is because the cost pressure from EP's share of green investments cannot be alleviated by raising prices, but GM, which has pricing power, wants the platform to share in the costs of greenness. The inability of the two parties to reach an agreement reduces the overall profitability of the supply chain.

Figure 8 presents how the GM's profit is impacted by the confidence level α. As shown, the common confidence level has a notable effect on the GM's profit. Specifically, the optimal profit of GM strictly decreases as the confidence level increases. Furthermore, the figure shows that $\Pi_m^{\mathrm{PSM}} > \Pi_m^{\mathrm{WSM}}$ at a lower confidence level, while $\Pi_m^{\mathrm{WSM}} > \Pi_m^{\mathrm{PSM}}$ at a higher confidence level. This is because, in the low-risk case, GM with pricing power in the PSM has the flexibility to adjust market prices according to market demand to ensure his profit. In the high-risk case, GM sells the product to EP at the wholesale price, which delivers the product to consumers, thereby reducing GM's risk to some extent, while allowing GM to fully exploit EP's marketing advantages, allowing GM to focus more on green investments and satisfying consumer demand, thus increasing GM's profit.

Figure 9 shows how the EP's profit is impacted by the confidence level α. As shown, the common confidence level has a notable effect on the EP's profit. Specifically, the optimal profit of EP strictly decreases as the

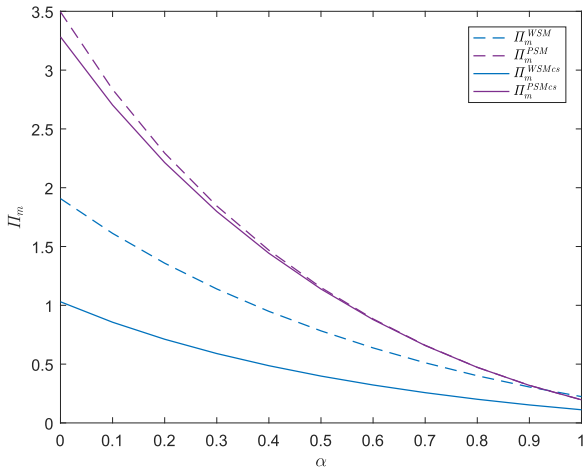

FIGURE 8. The effect of α on the GM's profit.

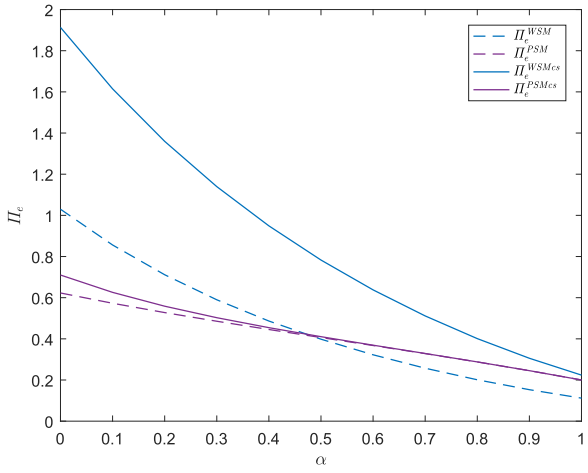

FIGURE 9. The effect of α on the EP's profit.

confidence level increases. Furthermore, the figure shows that $\Pi_e^{\mathrm{WSM}} > \Pi_e^{\mathrm{PSM}}$ at a lower confidence level, while $\Pi_e^{\mathrm{PSM}} > \Pi_e^{\mathrm{WSM}}$ at a higher confidence level. This is because, in the low-risk case, the EP with pricing power in the WSM has the flexibility to adjust market prices according to market demand, thereby ensuring the profit of EP. In the high-risk case, the EP receives a commission from the manufacturer for each unit of green product sold and does not have to bear the cost of product delivery, which reduces the EP's risk to some extent and increases the EP's profit.

6. Conclusions

In this paper, we investigate the pricing strategy of a GECSC consisting of an EP and a GM, considering delivery time and epistemic uncertainty. To obtain optimal greenness, delivery time and pricing decisions, we build five chance-constrained models considering members' risk preferences. We analyze the influence of the

green investment cost parameter and the maximum cost of delivery on the behavioral performance of GECSC members. Finally, a numerical example is provided to validate our conclusions.

This study offers valuable managerial insights on the issues of greenness, delivery time and price in a two-stage GECSC. First, the greenness investment cost parameter and maximum delivery cost negatively affect the optimal greenness, retail price and delivery time, respectively. Second, based on our numerical example, we conclude that a lower confidence level leads to better equilibrium decisions. In other words, when supply chain participants are more optimistic, they tend to benefit more, despite higher retail and wholesale prices. Furthermore, the choice of sales model by the GM and EP depends on their risk appetite. When the confidence level is low, the GM prefers PSM, otherwise, the GM prefers WSM, while the EP's choice is the exact opposite of the GM's. Finally, the greenness, delivery time, retail price, and overall profitability of GECSC remain optimal in the centralized scenario, regardless of changes in confidence level.

This paper examines the GECSC's pricing problem under one confidence level. In future research, the consideration of scenarios with different risk attitudes of supply chain members is a topic that deserves to be explored in depth in cases where the EP is not willing to share its risk attitude assessment and information with the GM. In addition, this paper discusses the pricing problem of GECSC under a single channel. To better reflect market reality, future research should also consider the case where competing manufacturers or retailers open offline channels.

Data availability statement

No new data/codes were created or analyzed in this study.

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Appendix A.

Some basic notions and properties of uncertainty theory for solving pricing problems are presented below.

Let Γ be a nonempty universal set and $\mathcal{L}$ a σ-algebra over Γ. Each element $\Lambda \in \mathcal{L}$ is called an event and is given a number $\mathcal{M}\{\Lambda\}$ to indicate the degree of belief that we believe Λ will occur.

Definition A.1 ([12]). The set function $\mathcal{M}$ is called an uncertain measure if it satisfies

Axiom 1. (Normality Axiom) $\mathcal{M}\{\Gamma\} = 1$ for the universal set Γ;

Axiom 2. (Duality Axiom) $\mathcal{M}\{\Lambda\} + \mathcal{M}\{\Lambda^c\} = 1$ for any event Λ;

Axiom 3. (Subadditivity Axiom) For every countable sequence of events $\Lambda_1, \Lambda_2, \cdots$, we have

$$\mathcal{M}\left\{\bigcup_{i=1}^{\infty} \Lambda_i\right\} \leq \sum_{i=1}^{\infty} \mathcal{M}\{\Lambda_i\}.$$

Definition A.2 ([12]). Suppose that an uncertainty distribution $\Phi(x)$ is a continuous and strictly increasing function with respect to x at which $\Phi(x) \in (0, 1)$, and

$$\lim_{x \to -\infty} \Phi(x) = 0, \quad \lim_{x \to \infty} \Phi(x) = 1.$$

Then, $\Phi(x)$ is regarded to be regular.

Definition A.3 ([12]). Suppose ξ is an uncertain variable with regular uncertainty distribution $\Phi(x)$. Then the inverse function $\Phi^{-1}(\alpha)$ is called the inverse uncertainty distribution of ξ.

Definition A.4 ([12]). The uncertain variables $\xi_1, \xi_2, \cdots, \xi_n$ are said to be independent if

$$\mathcal{M}\left\{\bigcap_{i=1}^{n} (\xi_i \in B_i)\right\} = \bigwedge_{i=1}^{n} \mathcal{M}\{\xi_i \in B_i\}$$

for any Borel sets $B_1, B_2, \cdots, B_n$.

Theorem A.5 ([12]). Let $\xi_1, \xi_2, \cdots, \xi_n$ be uncertain variables, and f be a real-valued measurable function. Then $\xi = f(\xi_1, \xi_2, \cdots, \xi_n)$ is an uncertain variable which is denoted by

$$\xi(\gamma) = f(\xi_1(\gamma), \xi_2(\gamma), \cdots, \xi_n(\gamma)), \qquad \forall \gamma \in \Gamma.$$

Theorem A.6 ([12]). Let $\xi_1, \xi_2, \cdots, \xi_n$ be independent uncertain variables with continuous uncertainty distributions $\Phi_1, \Phi_2, \cdots, \Phi_n$, respectively. If the function $f(x_1, x_2, \cdots, x_n)$ is strictly increasing in terms of $x_1, x_2, \cdots, x_m$ and strictly decreasing in terms of $x_{m+1}, x_{m+2}, \cdots, x_n$, then the uncertain variable

$$\xi = f(\xi_1, \xi_2, \cdots, \xi_n)$$

has an uncertainty distribution

$$\Phi(x) = \sup_{f(x_1, x_2, \cdots, x_n) = x} \left(\min_{1 \le i \le m} \Phi_i(x) \wedge \min_{m+1 \le i \le n} (1 - \Phi_i(x)) \right).$$

Additionally, if $\Phi_1, \Phi_2, \cdots, \Phi_n$ are regular, then ξ follows an inverse uncertainty distribution given by

$$\Phi^{-1}(\alpha) = f\big(\Phi_1^{-1}(\alpha), \cdots, \Phi_m^{-1}(\alpha), \Phi_{m+1}^{-1}(1-\alpha) \cdots, \Phi_n^{-1}(1-\alpha)\big).$$