SUPPLY CHAIN COORDINATION CONSIDERING E-TAILER’S
PROMOTION EFFORT AND LOGISTICS PROVIDER’S
SERVICE EFFORT

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Abstract. Promoting the sale of green agriculture products through online platforms has become the main focus of agricultural industries. In a supply chain consisting of an e-tailer and third-party logistics (TPL), both the promotion effort of the e-tailer and the logistics service effort of TPL can affect the demand. Considering that logistics service contracts may be provided by the e-tailer or TPL, this study defines two different timing sequences. Three types of contracts, i.e., fixed-price, revenue-sharing, and cost-sharing contracts, are used to coordinate the supply chain. The game models under different timing sequences and different contract scenarios are established and solved. The promotion effort and logistics service effort under different scenarios are compared theoretically and numerically. The results indicate that both the promotion effort and logistics service effort change with timing sequences and contract types. The timing sequences depending on the contract provider significantly affect the performance of the supply chain. The cost-sharing contract provided by the TPL can motivate the e-tailer to apply the largest effort, and vice versa. The cost-sharing contract provided by the e-tailer can achieve the largest demand that is optimal for both the e-tailer and supply chain. However, the optimal contract for the TPL is conditional.

1. Introduction. The sudden outbreak of the COVID-19 in December 2019 affected the global economy and slowed the sales of commodities such as green agriculture products that primarily rely on offline channels. Due to the difficulty in preservation, promoting the sale of green agriculture products through online platforms has become the main focus of all agriculture industry. Therefore, e-tailer (online retailer) corporations used this opportunity to incorporate the entire sector online (Majumdar et al. [30]; Lvanov [28]). Meanwhile, the Caring for Agriculture...
Project (CAP) was proposed by the government of China to mitigate this challenge, and it was widely welcomed by farmers. The project involves selling green agriculture products at low prices through live broadcasting on online platforms and delivering them to consumers through convenient logistics methods, which are generally provided by third-party logistics (TPL) suppliers. Hereafter, we use the TPL to denote the third-party logistics suppliers for concision. This results in considerable benefits to farmers, promotes economic development, reduces circulation, and lowers logistics costs and carbon emissions (Das and Roy [8]).

In practice, online sales involve multiple participants, including e-tailers and the TPLs. Both the e-tailer and TPL can apply efforts to increase consumption experience and market demand (Li et al. [22]; Xu et al. [42]). The green sale efforts of e-tailers mainly include advertising, discounts, and free logistics (Alizadeh-basban and Taleizadeh [1]). Green logistics service efforts of the TPLs mainly include increasing the service quality and shortening the delivery time. Additionally, the TPL can provide logistics service environmentally friendly, such as using electric cars (Bai et al. [3]; Das et al. [9]; Das et al. [10]). It is noted that both the efforts of the e-tailer and TPL will incur some cost of efforts. Therefore, as rational economic entities, both the e-tailer and TPL just apply effort according to their own interests, which is often not optimal for the supply chain. Thus, it is necessary to study the contract coordination mechanism between the e-tailer and TPL to improve the performance of the supply chain and achieve low-carbon sale and delivery.

The research of this paper is carried out under the framework of Stackelberg game. As independent economic entities, the e-tailer and TPL constitute a typical game relationship. The logistics contract is used to achieve the payment from the e-tailer to the TPL. Therefore, the contract provider wants using the contract to encourage the other party to exert effort. The contract provider first designs the contract, and the contract receiver decides his own effort after accepting the contract. Thus, the contract provider needs to consider the possible responses of the contract receiver when designing the contract. It can be seen that the e-tailer and TPL constitute a Stackelberg game.

Note that the design of the coordination contract of the supply chain must consider the different power structures between the e-tailer and TPL; that is, who will provide the logistics service contract. The existing studies rarely consider the problem of different providers of logistics contract and the coordination of the e-tailer supply chain at the same time. The difference in providers of logistics contracts determines the different timing sequences of the e-tailer supply chain and significantly affects supply chain coordination. However, research on related problems in the existing literature is insufficient. In this study, depending on different contract providers, two different timing sequences are considered.

Note that under online sales, the promotion effort and the logistics service effort will affect the sales simultaneously. However, so far, few papers have studied the optimal decision-making of these two types of efforts in the supply chain and their effect on supply chain performance. This study fills this gap.

This paper studies the design issue of three types of contracts (fixed-price contract, revenue-sharing contract, and cost-sharing contract) under two types of decision-making timing sequences (the timing sequence when the e-tailer provides contract and the timing sequence when the TPL provides contract).

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1 https://www.technologyreview.com/2020/05/06/1001186/china-rural-live-streaming-during-cornavirus-pandemic/
Specifically, we address the following research questions:

1) How do the e-tailer make promotion effort and the TPL make logistics service effort under different contract scenarios?

2) How do different timing sequences affect the promotion effort, logistics service effort and market demand?

3) Which type of contract under different timing sequence scenarios is optimal for the e-tailer and TPL?

First, we establish game models of the fixed-price contract under different timing sequences, and obtain analytical solutions of promotion effort, logistics effort and logistics price by solving the models. Second, the revenue-sharing contract and cost-sharing contract are designed to coordinate the e-tailer supply chain and the impact of main parameters on coordination effect is discussed. Third, the promotion effort, logistics effort and market demand under different contracts with different timing sequences are compared theoretically, and which type of contract is the optimal for the e-tailer or TPL is determined. Finally, the impact of logistics marginal effort cost coefficient on optimal results is examined, and the expected utility of the e-tailer, TPL and supply chain are compared through numerical experiments.

This paper’s main contributions are as follows. (1) This study simultaneously considers the promotion effort of the e-tailer and the logistics service effort of TPL while most existing literature only considers one kind of effort. The interaction of these two types of effort has a significant effect on supply chain coordination. (2) Considering the logistics contract can be offered by the e-tailer or TPL, two different timing sequences based on different contract providers are defined, and the effects of timing sequences on the supply chain are investigated. (3) The fixed-price, revenue-sharing and cost-sharing contracts are used to coordinate the supply chain, and the coordination effect of different types of contract under different timing sequences are analyzed.

The remainder of this paper is organized as follows. Section 2 presents a literature review, which comprehensively analyzes the previous research results and provides references for this research. Section 3 describes and assumes supply chain models and symbols. Section 4 provides the optimal results under the fixed-price, revenue-sharing and cost-sharing contracts and sensitive analysis theoretically. Section 5 compares the results of different contracts under different timing sequences numerically. Section 6 presents the conclusion of this article and future research considerations.

2. Literature review. The literature related to our work mainly belongs to four streams: green supply chain and e-tailer channel, TPL service effort, e-tailer promotion effort and incentive for effort.

2.1. E-tailer green supply chain. In today highly competitive environment, green supply chains are increasingly gaining interest. More customers are accepting environmentally friendly products and are willing to spend more money on these products (Zi et al. [53]; Das et al. [11]; Demirel et al. [12]). Therefore, many retailers have begun selling green products to satisfy customer demands (Cao and Zhang [7]).

The research on greenness determination and pricing of green product under dual-channel has attracted enough attention. Jamali and Rasti-barzoki [20] investigated the problem of determining the greenness of green products in the competition with non-green products and found the greenness of the product could be higher
in the centralized mode. Gao et al. [14] studied the impact of green degree on the product prices of the dual-channel and argued that a growing green standard could increase the environmental benefits. Heydari et al. [17] discussed the manufacture’s determination of product greenness in a three-tier dual channel supply chain and found the transitional triad could increase green level of the product. Zhang et al. [49] investigated the issue of determining the product green level under two-stage pricing strategies of a dual-channel supply chain and argued that an increased greening level could enhance the performance of the supply chain. The above studies focused on the determination of green efforts of manufacturers in the e-tailer green supply chain. However, in online sales channel, both the promotion effort of the e-tailer and logistics effort of the TPL also have important impacts on the market demand of green products. The efforts of the e-tailer and TPL have been ignored in existing research. This paper attempts to fill this gap.

There are also several studies focusing on the greenness determination and pricing of green product in dual-channel supply chain by considering demand uncertainties. Rahmani and Yavari [35] studied the decision-making of product greenness in a dual-channel green supply chain by considering demand disruptions and found demand disruption increased the market size which can bring more enhancements to the greening level of green products. Aslani and Heydari [2] examined the determination of product greenness in a green dual-channel supply chain by considering channel disruption and argued the transshipment contract between the two channels could coordinate the supply chain. Yang et al. [46] studied the decision of product green level in dual-channel under fuzzy uncertainties and argued that demand uncertainty made the manufacturer to turn to online channel. Although the above literature studied the impact of uncertainty on the green supply chain, it rarely considered the attitude of decision makers to uncertainty. In fact, the attitude of decision-makers towards uncertainty will significantly affect the decision-making and coordination of the e-tailer supply chain. Lotfi et al. [26] established a robust optimization model for sustainable and resilient closed-loop supply chain to handle uncertainties. The authors argued that the risk aversion of decision-makers had an important influence in network design. This paper considers the TPL’s risk aversion behavior to demand uncertainty, and studies the contract design and coordination of the e-tailer green supply chain.

Research on online sales of green agriculture products has also received some attention. Fecke et al. [13] examined the willingness of German farmers to accept e-commerce and argued that e-tailers of agriculture products need to pay more attention to trust, service quality and timely delivery. Robina-Ramírez et al. [36] investigated attributes which influence the intention to online buy and sell agriculture products in Spain. Cang and Wang [5] studied the online shopping willingness of fresh agriculture products and found logistics service quality had a significant impact on consumers. The above research studied the online channel sales willingness of green agriculture products based on questionnaire surveys. This paper investigates the contract design under the e-tailer green supply chain. In particular, the current study enriches this domain by designing contracts to coordinate the supply chain composed of an e-tailer and a TPL that are both encouraged to exert green efforts.

2.2. **TPL service effort.** Logistics services always play an important role in enhancing market demand regardless of online or offline channels. With the rapid development of online sales, service level becomes particularly important (Wu et
al. [39]; Ma et al. [29]). For consumers, the main difference between online shopping and brick-and-mortar stores is the manner in which the products reach users. Under online sales, logistics services provided by the TPL deliver goods to consumers rapidly and with high quality. Therefore, logistics services are defined as an effective means of competition among e-retailers.

The TPL's freshness-keeping efforts play a key role in the freshness of fresh products. Cai et al. [4] studied the optimal decisions of a fresh product supply chain with a TPL and found that the existence of the TPL had a significant impact on the supply chain performance. Wu et al. [40] investigated determinations of logistics service effort and price by considering the power structure and found power structure had a significant impact on the decisions of the logistics service level. Yu and Xiao [47] investigated cold-chain service level decisions of the TPL in a fresh agriculture products supply chain and argued that the cold-chain service level increased with the price sensitivity as well as the service sensitivity. Furthermore, Yu et al. [48] examined cold-chain service level decisions by considering competing retailers and found vertical integration mode made the TPL to increase service level. Shen et al. [37] considered the speed of logistics as the TPL service effort and argued that the transportation mode was important to short life cycle products. The above studies all affirmed the important role of TPL logistics efforts in the distribution of fresh products.

The TPL's efforts are also important to the supply chain of non-fresh products. Yan and Sun [43] studied the collection effort of the TPL for closed-loop supply chain and used a target rebate-punish contract to incentive the TPL to exert effort. Jamali and Rasti-Barzoki [21] studied the impact of TPL service efforts on a sustainable supply chain and argued that TPL service efforts could reduce delivery time and carbon emissions. Huang et al. [19] investigated the effect of the TPL service effort in reducing quality risk of logistics service and showed the TPL service effort could achieve high-quality delivery. Lou et al. [27] discussed the influence of logistics service outsourcing choices on a retailer-led supply chain and found the TPL service effort could benefit the retailer. Gong et al. [16] considered the information technology investment as the TPL service effort and indicated the TPL IT investment depended on the different logistics outsourcing contract structures. The above studies all designed incentive mechanism for the TPL service effort through contracts. Considering an e-tailer supply chain, this paper not only considers the logistics effort of the TPL but also the promotion effort of the e-tailer, and try to encourage the TPL effort and the e-tailer effort through contracts separately.

The above studies all investigated logistics efforts under the offline supply chains. However, with the continuous development of the Internet, online channels are becoming increasingly popular in the retail industry. Thus, studying the decision-making problems of the logistics service effort in online supply chains is necessary.

Recently, the decision-making of logistics service effort in e-tailer supply chains has attracted the attention of scholars. Xu et al. [42] developed game-theoretic models to study the purchasing strategy problems faced by an e-retailer who sell products online under different logistics distribution systems. The results showed that the sensitivity of demand to logistics services had an important impact on the logistics strategies of the e-tailer. Qin et al. [33] analyzed the strategic and economic effects of logistics service sharing and observed that the logistics service level had an important impact on logistics service sharing in an e-tailer platform. It can be seen few scholars studied the green service efforts of logistics under the
2.3. **E-tailer promotion effort.** There are many studies focusing on the effect of promotion efforts on supply chain decision-making and performance. For online sales, the promotion efforts of e-tailers are key to gaining market share (Pu et al. [32]).

The promotion effort of the e-tailer has a positive impact on product demand in online channels. Liu et al. [24] investigated the impact of information sharing on the e-tailer service level and found high demand information sharing could guide the e-tailer to improve service level. Hou et al. [18] analyzed the impact of investments in delivery service by considering competing e-tailers and argued that the competition could induce the e-tailer to invest more in delivery service. Liu et al. [23] studied the decisions of the e-tailer advertising effort in an online fresh product supply chain and argued that the advertising effort was reduced in the decentralized mode. Pu et al. [32] analyzed the effects of sales effort in a dual-channel supply chain and indicated that under deterministic demand, the sales effort was reduced under the decentralized scenario. Zhou et al. [51] discussed the service strategies for a dual-channel supply chain with free riding and service-cost sharing and showed that e-tailer promotion efforts were realized through cost sharing with offline retailers. Yang and Tang [45] studied the freshness-keeping effort of the e-tailer under different sale modes of fresh product and demonstrated that the higher the consumers' sensitivity to freshness, the higher the e-tailer effort to maintain freshness. Zhou and Ye [52] examined the advertising effort of the e-tailer on emission reduction in a dual-channel supply chain and found the advertising effort of the e-tailer increased in a single-channel supply chain. In this study, promotion efforts are considered. Additionally, the interaction between promotion and logistics efforts in the supply chain is investigated. The effect of these two types of efforts on supply chain performance is revealed.

Thus far, few literature has considered both promotion and logistics efforts. Qin et al. [34] studied the determination of promotion effort of the e-tailer and logistics effort of the TPL in a retailer supply chain where the market is affected by the two types service efforts. Our model is similar, except for two important aspects. On one hand, we considered two different decision-making timing sequences: the logistics service contract may be provided by the e-tailer or the TPL. On the other hand, we introduced a revenue- and cost-sharing contracts to coordinate the supply chain and investigate their effect on supply chain performance.

2.4. **Incentive efforts through contract.** Contract design and coordination is an important topic in supply chain management. It provides incentives for all members and solves the problem of profit and loss distribution among the parties in the supply chain.

Research on incentives for the efforts of TPL in the supply chain receives increasing interest from scholars. Wu et al. [40] designed incentive mechanisms to coordinate the fresh product outsourcing logistics channels with power structures and showed incentive mechanisms could achieve full channel coordination. Shen et al. [37] examined the revenue sharing and logistics cost sharing contracts for channel
coordination on short life cycle products and argued that a suitable logistics contract was important for the TPL. Huang et al. [19] proposed a contract to inspire the TPL to exert effort based on delivery quality and showed the cooperative bargaining contract could motivate the TPL to apply effort and achieve high-quality delivery. Lou et al. [27] found a variable cost sharing contract was beneficial to the retailer but was harmful to the logistics service provider in a retailer-led supply chain. Gong et al. [16] used the fixed-price, contingent-price, profit-sharing and revenue-sharing contracts to motivate the TPL to invest in IT for the logistics outsourcing supply chain. The above research showed that the revenue sharing and cost sharing contracts were effective in motivating the TPL to apply effort. This paper investigates the validity of these contracts on motivating not only the TPL effort but also the e-tailer effort in an e-tailer supply chain.

Incentives for the efforts of e-tailers in the supply chain have received significant interest from scholars. Zhou et al. [51] and Pu et al. [32] studied free-riding of an online manufacture on sales effort of an offline store and used cost-sharing contracts to coordinate the dual-channel supply chain. Yang and Tang [45] investigated the coordination of fresh product supply chain under online-to-offline mode and found that the two-part tariff contract could coordinate the channel. Zhou and Ye [52] designed a cooperative advertising contract to coordinate the dual-channel supply chain and showed that it could benefit the manufacture. Qin et al. [34] examined the coordination contract of service effort for the e-tailer supply chain with competing TPLs and demonstrated a multilateral side-payment contract could increase the e-tailer service level. The differences between this paper and the above studies are that this paper stimulates the promotion effort of the e-tailer and the logistics service effort of the TPL simultaneously by considering two timing sequences.

Timing sequence is an important topic in supply chain coordination. Liu et al. [25] studied option contracts of supplier-led and retailer-led supply chains and argued that both the supplier-led supply chain and the retailer-led supply chain could be coordinated under the same conditions. Yang et al. [44] considered two types of timing sequences corresponding to pull and push supply chains and showed that the optimal order quantity in pull was higher than that in push. Matsui [31] studied the optimal timing for bargaining between a manufacturer and a retailer and thought that the manufacturer should pay attention to the price formation mode. Remarkably, few studies considered the problem of decision-making timing sequences when studying the incentives for members’ efforts in the supply chain. This study fills this gap. We study the timing sequences of supply chain decision-making in an e-tailer environment. Considering that both the promotion and logistics efforts can affect the market demand, the optimal green efforts of both parties and the price of logistics services are provided under the two timing sequences that depend on the different logistics contract providers. In this study, a fixed-price contract is first investigated. A revenue-sharing contract and a cost-sharing contract are introduced to coordinate the e-tailer supply chain, respectively.

In Table 1, we compare the model constructed in this study with those in existing studies. Differences and similarities between the reviewed literature and this study were observed.

3. Problem statement. Online platforms that sell products online have increased over the last decade. Selling green agriculture products has always been a challenge owing to the difficulty in preservation. The sudden outbreak of the COVID-19 has
further worsened the sales of green agriculture products and caused difficulties for farmers.

Therefore, this paper considers an e-tailer supply chain of green agriculture products and studies the coordination problems of the e-tailer supply chain. This section gives model assumptions and defines two types of timing sequences. Section 3.1 is the basic assumptions and section 3.2 is two types of timing sequences.

3.1. Basic assumptions. The research object is a supply chain composed of an e-tailer and a TPL. The e-tailer sells green agriculture products through an online platform. When a consumer places an order, the e-tailer entrusts the TPL to complete the delivery of the goods and comprehend the shopping behavior of consumers.

Assumption 1. The e-tailer can perform promotion efforts during the online sales process, and the TPL perform logistics service effort during the logistics distribution process. The efforts of both parties will positively increase the demand for green agriculture products.

Assumption 2. The e-tailers’ promotion efforts and logistics service efforts both generate costs. These costs are not related to the actual quantity sold, that is, the promotion and logistics efforts are regarded as one-time investments.

Assumption 3. The sales price of the products is exogenous, that is, it is determined by the market.

Assumption 4. All decision-making information is jointly owned by the e-tailer and the TPL; that is, there is no information asymmetry between the two parties.

Assumption 5. According to the Principal-agent theory, the e-tailer as a principal is risk-neutral, and the TPL as an agent is risk-averse.

Considering the existing market demand function of goods (Cao and Fan [6]), the demand function in this study is expressed as follows:

\[ D = D_0 - \alpha p_1 + \beta e_1 + \gamma e_2 + \varepsilon, \] (1)
where $p_1$ is the unit price of green agriculture products. The $e_1$ and $e_2$ represent the promotion effort of the e-tailer and the logistics service effort of the TPL, respectively. The $\alpha$, $\beta$, and $\gamma$ represent the marginal effect coefficients of green agriculture products price, promotion effort, and logistics service effort on demand, respectively. The $\varepsilon$ is a random factor affecting market demand and $\varepsilon \sim N(0, \sigma^2)$. The $D_0$ is the market size of green agriculture products, which is assumed to be sufficiently large to ensure that market demand will not be negative. The demand model proposed here is general and applicable to common scenarios. Obviously, the COVID-19 makes the promotion effort of the e-tailer and the logistics service effort of the TPL are key to the sale of green agriculture products.

The cost functions of the promotion and logistics efforts are assumed to be $k_1e_1^2/2$ and $k_2e_2^2/2$, respectively. The $k_1$ and $k_2$ represent the effort cost coefficient of the e-tailer and TPL, respectively. A larger $k_1$ or $k_2$ indicates that the same effort level requires a higher effort cost.

3.2. Two types of timing sequences. The logistics service contract is key to the supply chain under the online sales model. The supply chain has two scenarios of e-tailers and TPL providing logistics contracts. Based on the differences between logistics service contract providers, this study considers two types of decision-making timing sequences. This study defines Timing Sequence 1 as when the e-tailer provides the logistics contract and Timing Sequence 2 as when the TPL provides the logistics contract. The two types of timing sequences are shown in Figure 1 and Figure 2, respectively.

![Figure 1. Timing sequence when the e-tailer provides the logistics contract.](image)

![Figure 2. Timing sequence when the TPL provides the logistics contract.](image)

(1) **Timing sequence 1**

$T_0$: The E-tailer determines the unit price of the logistics service $p_2$ and provides the logistics contract to the TPL.

$T_1$: The TPL decides whether to accept the contract. When it accepts the contract, the TPL determines the logistics service effort $e_2$. 

$T_2$: As the sales season approaches, the e-tailer decides the promotion effort $e_1$.

$T_3$: Market demand is realized, and the e-tailer provides payment to the TPL according to the contract.

(2) Timing sequence 2

$T_0$: The TPL determines the unit price of the logistics service $p_2$ and provides the logistics contract to the e-tailer. Additionally, the TPL determines logistics service effort $e_2$.

$T_1$: The e-tailer decides whether to accept the contract. When the contract is accepted, the e-tailer decides the promotion effort $e_1$.

$T_2$: Market demand is realized, and the e-tailer provides payment to the TPL according to the contract.

In the supply chain, both promotion effort and logistics service effort can improve consumers’ consumption experience and increase market demand. However, in the absence of a corresponding contract coordination mechanism, both parties will seek to maximize their interests, which will damage the interests of the entire supply chain. Therefore, studying the coordination contract between the e-tailer and TPL to coordinate the supply chain and achieve Pareto improvement is important. In the following, the fixed-price, revenue-sharing, and cost-sharing contracts are investigated sequentially, and the coordination results are analyzed.

| Variables | Meanings |
|-----------|----------|
| $c_1$     | The unit cost of the e-tailer |
| $c_2$     | The unit cost of the TPL |
| $D_0$     | The market size of green agriculture products |
| $k_1$     | The effort cost coefficient of the e-tailer |
| $k_2$     | The effort cost coefficient of the TPL |
| $p_1$     | The unit price of green agriculture products |
| $\alpha$  | The marginal effect coefficient of product price on demand |
| $\beta$   | The marginal effect coefficient of promotion effort on demand |
| $\gamma$  | The marginal effect coefficient of logistics effort on demand |
| $\varepsilon$ | The random factor affecting market demand, $\varepsilon \sim N(0, \sigma^2)$ |
| $\theta$  | The proportion of logistics effort costs shared by the e-tailer, $0 < \theta < 1$ |
| $\varphi$ | The revenue-sharing proportion of the e-tailer, $0 < \varphi < 1$ |

Subscript

$i$ | The subscript $i$ denotes the $i$th type contract. That is, $i = 1, 2, 3$ denotes the fixed-price, revenue-sharing and cost-sharing contracts

$j$ | The subscript $j$ represents the $j$th decision-maker. That is, $j = 1, 2$ denotes the e-tailer and TPL

Decision variables

$e_{ij}$ | The effort level of the $j$th decision-maker in the $i$th type contract provided by the e-tailer

$e'_{ij}$ | The effort level of the $j$th decision-maker in the $i$th type contract provided by the TPL

$p_{i2}$ | The price of the logistics service in the $i$th type contract provided by the e-tailer

$p'_{i2}$ | The price of the logistics service in the $i$th type contract provided by the TPL

Table 2. Notations and descriptions used in the paper.
For ease of expression, double subscripts of variables are introduced. The first subscript \( i \) is used to represent the \( i \)th type contract and the second subscript \( j \) is used to represent the \( j \)th decision-maker. The detailed definitions can be found in Table 2.

4. Optimal contracts. Considering that the e-tailer is risk-neutral, its expected utility and expected profit are equivalent; that is, the e-tailer maximizes the expected profit:

\[
U_1 = E\{[(1 - \varphi)p_1 - p_2 - c_1]D - \frac{k_1}{2}e_1^2 - \frac{k_2\theta}{2}e_2^2\}
\]

\[
= [(1 - \varphi)p_1 - p_2 - c_1](A + \beta e_1 + \gamma e_2) - \frac{k_1}{2}e_1^2 - \frac{k_2\theta}{2}e_2^2. \tag{2}
\]

where \( c_1 \) is the unit cost of the e-tailer and \( A = D_0 - \alpha p_1 \). The \( \varphi \) represents the revenue-sharing proportion of the e-tailer and \( 0 < \varphi < 1 \). The \( \theta \) represents the proportion of logistics costs shared by the e-tailer and \( 0 < \theta < 1 \).

The profit of the TPL is

\[
\Pi_1 = (\varphi p_1 + p_2 - c_2)(A + \beta e_1 + \gamma e_2) - \frac{k_2(1 - \theta)}{2}e_2^2 - \frac{l}{2}(p_2 - c_2)^2\sigma^2. \tag{3}
\]

where \( c_2 \) is the logistics unit cost of the TPL. Without loss of generality, \( p_1 > c_1 + c_2 \) is assumed.

Considering that the TPL is risk-averse and has the characteristics of constant absolute risk aversion, this study assumes that the TPL maximizes the expected utility:

\[
U_2 = (\varphi p_1 + p_2 - c_2)(A + \beta e_1 + \gamma e_2) - \frac{k_2(1 - \theta)}{2}e_2^2 - \frac{l}{2}(p_2 - c_2)^2\sigma^2. \tag{4}
\]

where \( l \) is the constant absolute risk aversion of the TPL.

For ease of expression, we let \( U_{ij} \) represents the expected utility of the \( j \)th decision-maker in the \( i \)th type contract provided by the e-tailer and \( U'_{ij} \) represents the expected utility of the \( j \)th decision-maker in the \( i \)th type contract provided by the TPL.

4.1. Fixed-price contract. Under the fixed-price contract scenario, the e-tailer pays logistics expenses to the TPL according to the unit price of the logistics service. At this time, \( \theta = 0 \) and \( \varphi = 0 \). As independent decision-making entities, both the e-tailer and TPL aim to maximize their own expected utility.

4.1.1. Contract provided by the e-tailer. When the fixed-price contract is provided by the e-tailer, the expected utility function of the e-tailer is

\[
U_{11} = E\{(p_1 - p_{12} - c_1)D - \frac{k_1}{2}e_{11}^2\}
\]

\[
= (p_1 - p_{12} - c_1)(A + \beta e_{11} + \gamma e_{12}) - \frac{k_1}{2}e_{11}^2. \tag{5}
\]

The expected utility function of the TPL is

\[
U_{12} = (p_{12} - c_2)(A + \beta e_{11} + \gamma e_{12}) - \frac{k_2}{2}e_{12}^2 - \frac{l}{2}(p_{12} - c_2)^2\sigma^2. \tag{6}
\]
Using Timing Sequence 1 (Figure 1), the reverse order method is used to solve the model. First, the expected utility function of the e-tailer $U_{11}$ is used to determine $e_{11}$. For $\partial U_{11}/\partial e_{11} = -k_1 < 0$, $U_{11}$ is observed to be concave with respect to $e_{11}$. Therefore, using $\partial U_{11}/\partial e_{11} = \beta (p_1 - p_{12} - c_1) - k_1 e_{11} = 0$, we can obtain $e_{11} = (p_1 - p_{12} - c_1)/\beta/k_1$. Subsequently, we introduce $e_{11}$ into $U_{12}$ and rewrite the expected utility function of the TPL: $U_{12} = (p_{12} - c_2)(k_1 + \beta^2 (p_1 - p_{12} - c_1) + k_1 e_{12})/k_1 - k_2 e_{12}^2/2 - l(p_{12} - c_2)^2$. The expected utility function of the TPL is used to determine $e_{12}$. For $\partial U_{12}/\partial e_{12} = -k_2 < 0$, $U_{12}$ can be observed to be concave with respect to $e_{12}$. Therefore, using $\partial U_{12}/\partial e_{12} = \gamma (p_{12} - c_2) - k_2 e_{12} = 0$, we can obtain $e_{12} = (p_2 - c_2)\gamma/k_2$.

Subsequently, we introduce $e_{12}$ and $e_{11}$ into $U_{11}$ to obtain the expected profit function of the e-tailer: $U_{11} = (p_1 - p_{12} - c_1)[2k_1 k_2 A + k_2 \beta^2 (p_1 - p_{12} - c_1) + 2k_1 \gamma^2 (p_1 - p_{12} - c_1)]/(2k_1 k_2)$. $U_{11}$ is used to solve the optimal $p_{12}^*$. $U_{11}$ is concave with respect to $p_{12}$. Thus, using $\partial U_{11}/\partial p_{12} = A + \beta^2 (p_1 - p_{12} - c_1)/k_1 + \gamma e_{12} - \beta^2 (p_{12} - c_2) = 0$, we have $p_{12}^* = [k_1 k_2 A + k_2 \beta^2 (p_1 - c_1) - k_1 \gamma^2 (c_2 - c_1 + p_1)]/(k_2 \beta^2 - 2k_1 \gamma^2)$.

When we determine $p_{12}^*$, the other optimal results can be obtained using back substitution. Thus, we have Proposition 1 in which $B = p_1 - c_1 - c_2$.

**Proposition 1.** When the fixed-price logistics contract is provided by the e-tailer, the promotion effort and the logistics service effort are $e_{11}^* = -\beta (k_2 A + \gamma^2)/(k_2 \beta^2 - 2k_1 \gamma^2)$ and $e_{12}^* = \gamma [k_1 k_2 A + (k_2 \beta^2 - k_1 \gamma^2)B]/[k_2 (k_2 \beta^2 - 2k_1 \gamma^2)]$, respectively, and the market demand of green agriculture products is $D_1^* = -k_1 \gamma^2 (k_2 A + \gamma^2 B)/[k_2 (k_2 \beta^2 - 2k_1 \gamma^2)]$.

Considering that the promotion effort cannot be negative, we let $k_2 \beta^2 - 2k_1 \gamma^2 < 0$. Considering that the logistics service effort cannot be negative, we let $k_1 k_2 A + (k_2 \beta^2 - k_1 \gamma^2)B < 0$. Clearly, $k_2 \beta^2 - k_1 \gamma^2 < 0$, i.e., $k_1/k_2 > (\beta/\gamma)^2$. When the logistics service effort is more cost-effective than the promotion effort, the e-tailer will encourage the TPL to apply much effort.

From $\partial e_{11}^*/\partial \beta = (k_2 A + \gamma^2 B)(k_2 \beta^2 + 2k_1 \gamma^2)/(k_2 \beta^2 - 2k_1 \gamma^2) > 0$, we can consider that $\beta$ has a positive effect on $e_{11}^*$, that is, the larger the marginal effect of the promotion effort on the demand, the more willing the e-tailer is to apply effort. For $\partial e_{11}^*/\partial \gamma = -\beta (k_2 \beta^2 - k_1 \gamma^2)/\gamma^2 > 0$, we know that $\gamma$ has a negative effect on $e_{11}^*$; that is, the larger the marginal effect of the logistics service effort on the demand, the more unwilling the e-tailer is to apply effort.

For $\partial e_{12}^*/\partial \beta^2 = -\gamma (k_1 \gamma^2 B + k_1 k_2 A)/(k_2 \beta^2 - 2k_1 \gamma^2)^2 < 0$, we know that $\beta$ has a negative effect on $e_{12}^*$; that is, the larger the marginal effect of the promotion effort on the demand, the less willing the TPL is to apply effort. For $\partial e_{12}^*/\partial \gamma = [(2k_1 \gamma^2 + k_2 \beta^2)k_1 k_2 A + k_2 \beta^2 B(k_2 \beta^2 - k_1 \gamma^2) - 4k_1^2 \gamma^4 B]/(k_2 \beta^2 - 2k_1 \gamma^2)^2 > 0$, $\gamma$ can be observed to have a negative effect on $e_{12}^*$; that is, the greater the marginal effect of the logistics service effort on the demand, the less willing the TPL is to apply effort.

For $\partial D_1^*/\partial \beta^2 = k_1 \gamma^2 (k_2 A + \gamma^2 B)/(2k_1 \gamma^2 - k_2 \beta^2)^2 > 0$, we know that $\beta$ has a positive effect on $D_1^*$, that is, the larger the marginal effect of the promotion effort on the demand, the greater the market demand is. For $\partial D_1^*/\partial \gamma^2 = [2k_1^2 \gamma^4 B - k_2 \beta^2 (2k_1 \gamma^2 B + k_1 k_2 A)]/[k_2 (k_2 \gamma^2 - k_2 \beta^2)^2] > 0$, we know that $\gamma$ has a positive effect on $D_1^*$; that is, the greater the marginal effect of the logistics service effort on the demand, the greater the market demand is.

**4.1.2.** Contract provided by the TPL. When the fixed-price contract is provided by the TPL, the expected utility function of the e-tailer is
\[ U'_{11} = E[(p_1 - p_1') - c_1)]D - \frac{k_1^2}{2} e_{11}' \]
\[ = (p_1 - p_1') - c_1)(A + \beta e_{11} + \gamma e_{12}) - \frac{k_1^2}{2} e_{11}'. \]

The expected utility function of the TPL is
\[ U'_{12} = (p_1' - c_2)(A + \beta e_{11}' + \gamma e_{12}') - \frac{k_2}{2} e_{12}' - l(p_1' - c_2)^2 \sigma^2. \]

According to Timing Sequence 2 (Figure 2), the reverse order method is used to solve the above model. First, the expected utility function of the e-tailer \( U'_{11} \) is used to determine \( e_{11}' \). For \( \partial U_{11}'/\partial e_{11}' = -k_1 < 0 \), we can observe that \( U'_{11} \) is concave with respect to \( e_{11} \). Therefore, using \( \partial U_{11}'/\partial e_{11} = \beta(p_1 - p_1' - c_1 - k_1 e_{11}) = 0 \), we obtain \( e_{11}' = (p_1 - p_1' - c_1)/\beta \).

Subsequently, we introduce \( e_{11}' \) into \( U'_{12} \) to obtain the expected utility function of the TPL: \( U'_{12} = p_1' - c_2[k_1 A + \beta^2(p_1 - p_1' - c_1) + k_1 \gamma e_{12}^{'2}]/(k_1 - 2k_2 e_{12}^{'2}/2 - (p_1' - c_2)^2 \sigma^2). \)

Let \( H_1 \) be the Hessian matrix of \( U'_{12}(p_{11}'^2, e_{12}') \), that is
\[ H_1 = \begin{pmatrix}
\frac{\partial^2 U'_{12}}{\partial p_{11}'^2} & \frac{\partial^2 U'_{12}}{\partial p_{12}'^2} \\
\frac{\partial^2 U'_{12}}{\partial e_{12}'^2} & \frac{\partial^2 U'_{12}}{\partial p_{12}' \partial e_{12}'}
\end{pmatrix}
\]

A sufficient condition for an optimal solution of the TPL utility function is that \( H_1 \) is negative. This can be easily verified when \( 2k_2 \beta^2 + 2k_1 k_2 \sigma^2 > k_1 \gamma^2 \), \( H_1 \) is negative. The expected utility function of the e-tailer \( U'_{12} \) is used to determine \( e_{12}' \) and \( p_{12}' \). For \( \partial U_{12}'/\partial e_{12}^{'2} = -k_2 < 0 \) and \( \partial U_{12}'/\partial p_{12}^{'2} = -2 \beta^2/k_1 < 0 \), we can observe that \( U'_{12} \) is concave with respect to \( e_{12} \) and \( p_{12}' \). Using \( \partial U_{12}'/\partial e_{12}^{'2} = \gamma(p_1' - c_2) - k_2 e_{12}^{'2} = 0 \), we obtain \( e_{12}' = (p_1' - c_2)/\gamma/k_2 \). Using \( \partial U_{12}'/\partial p_{12}^{'2} = \gamma[A - (2\beta^2/k_1 + 2\sigma^2)p_{12}^{'2}]/(k_1 + \gamma e_{12}^{'2} + 2\sigma^2 c) = 0 \), we obtain \( p_{12}' = [k_1 k_2 A + k_2 \beta^2(p_1 - c_1 + c_2) + (2k_1 k_2 \sigma^2 - k_1 \gamma^2) c]/(2k_2 \beta^2 + 2k_1 k_2 \sigma^2 - k_1 \gamma^2). \)

When we determine \( p_{12}' \), the other optimal results can be obtained using back substitution. Thus, Proposition 2 is obtained.

**Proposition 2.** When the fixed-price logistics contract is provided by the TPL, the promotion effort and the logistics service effort are \( e_{11}^* = (k_2 \beta^2 - k_1 \gamma^2 + 2k_1 k_2 \sigma^2 B - k_1 k_2 A)/(k_1 k_2 \beta^2 - k_1 \gamma^2) \) and \( e_{12}^* = (\gamma^2 B + k_1 A)/2(k_2 \beta^2 + k_1 k_2 \sigma^2 - k_1 \gamma^2) \), respectively, and the market demand of green agriculture products is \( D^*_1 = (k_2 \beta^2 + 2k_1 k_2 \sigma^2)(k_1 A + \beta^2 B)/(2k_1 k_2 \beta^2 + k_1 k_2 \sigma^2 - k_1 \gamma^2) \).

Considering that the promotion effort cannot be negative, we let \( k_2 \beta^2 B - k_1 \gamma^2 B + 2k_1 k_2 \sigma^2 B - k_1 k_2 A > 0 \). For \( \partial e_{11}'/\partial \beta^2 = (k_1 k_2 \beta^2 - k_1 \gamma^2 + 2k_1 k_2 \sigma^2) + k_1 k_2 A(k_1 \gamma^2 - 2k_1 k_2 \sigma^2 + 2k_2 \beta^2) + k_1 \gamma B(k_1 \gamma^2 - k_2 \beta^2) + 2k_2 \beta^2 B + 2k_1 k_2 \sigma^2 - k_1 \gamma^2) > 0 \), we observe that \( \beta \) has a positive effect on \( e_{11}' \); that is, the larger the marginal effect of the promotion effort on the demand, the more willing the e-tailer is to apply effort. For \( \partial e_{11}'/\partial \gamma^2 = -\beta(k_2 \beta^2 B + k_1 k_2 A)/(2k_2 \beta^2 + 2k_1 k_2 \sigma^2 - k_1 \gamma^2) < 0 \), we observe that \( \gamma \) has a negative effect on \( e_{11}' \); that is, the greater the marginal effect of the logistics service effort on the demand, the more unwilling the e-tailer is to apply effort.

For \( \partial e_{12}'/\partial \beta^2 = \gamma[(k_2 k_1 k_2 \sigma^2 - k_1 \gamma^2)B - 2k_1 k_2 A]/(2k_2 \beta^2 + 2k_1 k_2 \sigma^2 - k_1 \gamma^2) \), we observe that \( \partial e_{12}'/\partial \beta^2 > 0 \) when \( B < k_1 k_2 A/(2k_1 k_2 \sigma^2 - k_1 \gamma^2) \); that is, \( \beta \) has
a positive effect on $e_{12}$. The larger the marginal effect of the promotion effort on the demand, the more willing the TPL is to apply effort. For $\partial e_{12} / \partial \gamma = (\beta^2 B + k_1 A)(2k_2 \beta^2 + k_1 k_2 \sigma^2 + k_1 \gamma^2)/(2k_2 \beta^2 + k_1 k_2 \sigma^2 - k_1 \gamma^2)^2 > 0$, we observe that $\gamma$ has a positive effect on $e_{12}$; that is, the larger the marginal effect of the logistics service effort on demand, the more willing the TPL is to apply effort.

Considering $\partial D_1^* / \partial \beta^2 = [(2k_1 k_2 \sigma^2 B + 2k_2 \beta^2 B - k_1 k_2 A)(2k_1 k_2 \sigma^2 + k_1 \gamma^2) + 2k_2 \beta^2 k_2 \beta^2 B]/(k_1 (2k_2 \beta^2 + k_1 k_2 \sigma^2 - k_1 \gamma^2)^2) > 0$, we observe that $\beta$ has a positive effect on $D_1^*$; that is, the larger the marginal effect of the promotion effort on the demand, the greater the market demand is. For $\partial D_1^* / \partial \gamma^2 = (k_1 A + \gamma^2 B)(2k_2 \beta^2 + k_1 k_2 \sigma^2)/(2k_2 \beta^2 + k_1 k_2 \sigma^2 - k_1 \gamma^2)^2 > 0$, we observe that $\gamma$ has a positive effect on $D_1^*$; that is, the larger the marginal effect of the logistics service effort on demand, the greater the market demand is.

By comparing $p_{12}^*$ and $p_{12}^*$, we can obtain $p_{12}^* > p_{12}^*$ when $B \leq k_1 k_2 A(k_2 \beta^2 + k_1 \gamma^2 + 2k_1 k_2 \sigma^2)/(2k_1 k_2 \sigma^2(k_1 \gamma^2 - k_2 \beta^2))$. Considering the relationship between $e_{11}$, $e_{12}$, $D_1$, and $p_{12}$, we obtain $e_{11}^* > e_{11}^*$, $e_{12}^* < e_{12}^*$, and $D_1^* < D_1^*$. These demonstrate that when $B$ is lower than a threshold value, the e-tailer is more willing to apply effort if it provides the fixed-price logistics contract. Similarly, the TPL is more willing to apply effort when it provides the fixed-price logistics contract. In addition, we observe that the market demand of green agriculture products under the fixed-price contract provided by the e-tailer is smaller than that under the fixed-price contract provided by the TPL.

4.2. Revenue-sharing contract. To encourage the TPL to exert more effort in the distribution process of green agriculture products, the e-tailer may consider sharing its revenue with the TPL (Wei et al. [38]; Zhang et al. [50]). This section introduces a revenue-sharing contract and investigates its effect on the supply chain.

4.2.1. Contract provided by the e-tailer. In this contractual scenario, the expected utility function of the e-tailer is

$$U_{21} = E\{[(1 - \varphi)p_1 - p_{22} - c_1]D - \frac{k_1}{2} e_{21}^2\}$$

$$= [(1 - \varphi)p_1 - p_{22} - c_1](A + \beta e_{21} + \gamma e_{22}) - \frac{k_1}{2} e_{21}^2. \quad (9)$$

The expected utility function of the TPL is

$$U_{22} = (p_1 \varphi + p_{22} - c_2)(A + \beta e_{21} + \gamma e_{22}) - k_2 e_{22}^2/2 - l (p_1 \varphi + p_{22} - c_2)^2 \sigma^2. \quad (10)$$

Using Timing Sequence 1 (Figure 1) and a similar solving process and method as in Section 4.1, we can obtain Proposition 3.

**Proposition 3.** When the revenue-sharing logistics contract is provided by the e-tailer, the promotion effort and the logistics service effort are $e_{21}^* = -\beta(k_2 A + \gamma^2 B)/(k_2 \beta^2 - 2k_1 \gamma^2)$ and $e_{22}^* = \gamma[k_1 k_2 A + (k_2 \beta^2 - k_1 \gamma^2)B]/|k_2(k_2 \beta^2 - 2k_1 \gamma^2)|$, respectively, and the market demand of green agriculture products is $D_2^* = -k_1 \gamma^2(k_2 A + \gamma^2 B)/(k_2 \beta^2 - 2k_1 \gamma^2)$.

We observe that the optimal results in Proposition 3 are the same as optimal results in Proposition 1. This indicates that the coordination effect of the revenue-sharing contract on the supply chain and that of the fixed-price contract are the same. This is an interesting observation. This means that the fixed-price logistics
service contract achieves revenue sharing between the e-tailer and the TPL, and it is reasonable.

Note that $p_{12}' = k_1k_2A + k_2\beta^2(p_1 - c_1) - k_1\gamma^2(c_2 - c_1 + p_1)/(k_2\beta^2 - 2k_1\gamma^2)$ and $p_{22}^* = [k_1k_2A + (k_1\gamma^2 - k_2\beta^2)(p_1\varphi - p_1 + c_1) + k_1\gamma^2(\varphi p_1 - c_2)]/(k_2\beta^2 - 2k_1\gamma^2)$; therefore, we obtain $\varphi p_1 + p_{22}' = p_{12}'$. That is, the sum of the sharing and unit prices of the logistics service under the revenue-sharing contract provided by the e-tailer is equal to the unit price of the logistics service under the fixed-price contract provided by the e-tailer. Thus, the fixed-price contract can be considered a type of revenue-sharing contract, and the revenue sharing behavior is realized through the logistics service price, $p_2$. Therefore, the promotion and logistics efforts under the two contracts are the same.

Note that $p_{22}'$ is linear with respect to $\varphi$. As the revenue-sharing proportion of the e-tailer increases, the logistics service price linearly increases or decreases. In particular, the logistics service price may be lower than zero under certain conditions, which will be discussed in numerical experiments.

4.2.2. Contract provided by the TPL. In this contractual scenario, the expected utility function of the e-tailer is

$$U_{21} = E\{[(1 - \varphi)p_1 - p_{22}' - c_1]D - \frac{k_1}{2}e_{21}'\}$$

$$= [(1 - \varphi)p_1 - p_{22}' - c_1](A + \beta e_{21}' + \gamma e_{22}') - \frac{k_1}{2}e_{21}'. \quad (11)$$

The expected utility function of the TPL is

$$U_{22}' = (\varphi p_1 + p_{22}' - c_2)(A + \beta e_{21}' + \gamma e_{22}') - \frac{k_2}{2}e_{22}' - l(\varphi p_1 + p_{22}' - c_2)^2\sigma^2. \quad (12)$$

Using Timing Sequence 2 (Figure 2) and a similar solving process and method as in Section 4.2, we can obtain Proposition 4.

**Proposition 4.** When the revenue-sharing logistics contract is provided by the TPL, the promotion effort and the logistics service effort are $e_{21}' = \beta(2k_2\beta^2 - k_1\gamma^2 + 2k_1k_2\sigma^2)B - k_1k_2A/[2k_1(k_2\beta^2 + k_1k_2\sigma^2) - k_1\gamma^2]$ and $e_{22}' = \gamma(\beta^2B + k_1A)/[2(k_2\beta^2 + k_1k_2\sigma^2) - k_1\gamma^2]$, respectively, and the market demand of green agriculture products is $D_A^* = (k_1k_2\beta^2 + k_1k_2\sigma^2)(k_1A + k_1k_2\sigma^2)/2(k_1k_2\beta^2 - 2k_1k_2\sigma^2 - k_1\gamma^2)$.

We observe that the optimal results in Proposition 4 are the same as the optimal results in Proposition 2. The reason is similar. Note that $p_{12}' = k_1k_2A + k_3\beta^2(p_1 - c_1 + c_2) + (2k_1k_2\sigma^2 - k_1\gamma^2)c_2/(2k_2\beta^2 + 2k_1k_2\sigma^2 - k_1\gamma^2)$ and $p_{22}^* = [k_1k_2A - k_2\beta^2(\varphi p_1 - p_1 + c_1) + (k_1\gamma^2 - 2k_1k_2\sigma^2 - k_2\beta^2)(\varphi p_1 - c_2)]/(2k_2\beta^2 + 2k_1k_2\sigma^2 - k_1\gamma^2)$; therefore, we obtain $\varphi p_1 + p_{22}' = p_{12}'$. That is, the sum of the sharing and unit prices of the logistics services under the revenue-sharing contract provided by the TPL is equal to the unit price of the logistics service under the fixed-price contract provided by the TPL. Therefore, the market demand under the two contracts is the same.

In summary, the revenue-sharing contract cannot coordinate the supply chain more effectively than the fixed-price contract, regardless of contract providers. The next section introduces a cost-sharing contract to coordinate the supply chain.
4.3. Cost-sharing contract. To encourage the TPL to exert more effort in the distribution process of green agriculture products, the e-tailer may consider sharing the logistics cost of the TPL (Xing and Liu [41]; Ghosh and Shah [15]). This section introduces a cost-sharing contract and investigates its effect on the supply chain.

4.3.1. Contract provided by the e-tailer. In this contractual scenario, the expected utility function of the e-tailer is

\[ U_{31} = E[(p_1 - p_{32} - c_1)D - \frac{k_1}{2} e_{31}^2 - \frac{k_2}{2} \theta e_{32}^2] \]

\[ = (p_1 - p_{32} - c_1)(A + \beta e_{31} + \gamma e_{32}) - \frac{k_1}{2} e_{31}^2 - \frac{k_2}{2} \theta e_{32}^2. \]  

(13)

The expected utility function of the e-tailer is

\[ U_{32} = (p_{32} - c_2)(A + \beta e_{31} + \gamma e_{32}) - \frac{k_2(1 - \theta)}{2} e_{32}^2 - l(p_{32} - c_2)^2 \sigma^2. \]  

(14)

Using Timing Sequence 1 and a similar solving process and method as in Section 4.1, we can obtain Proposition 5.

Proposition 5. When the cost-sharing logistics contract is provided by the e-tailer, the promotion effort and the logistics service effort are

\[ e_{31}^* = -\beta \frac{\theta}{k_2[k_2 \beta^2 m_2^2 + k_1 \gamma^2(\theta - 2)] - k_1 \gamma^2 B} \]

\[ e_{32}^* = \gamma \frac{m[k_1 k_2 A + k_2 \beta^2 B]}{[k_2[k_2 \beta^2 m_2^2 + k_1 \gamma^2(\theta - 2)]]}, \]

respectively, and the market demand of green agriculture products is

\[ D_3 = -\gamma^2 (k_1 k_2 A + \theta k_2 \beta^2 B + k_1 \gamma^2)/[k_2[m^2 k_2 \beta^2 + (\theta - 2)k_2 \gamma^2]]. \]

4.3.2. Contract provided by the TPL. In this contractual scenario, the expected utility function of the e-tailer is

\[ U'_{31} = E[(p_1 - p'_{32} - c_1)D - \frac{k_1}{2} e'_{31}^2 - \frac{k_2}{2} \theta e'_{32}^2] \]

\[ = (p_1 - p'_{32} - c_1)(A + \beta e'_{31} + \gamma e'_{32}) - \frac{k_1}{2} e'_{31}^2 - \frac{k_2}{2} \theta e'_{32}^2. \]  

(15)

The expected utility function of the TPL is

\[ U'_{32} = (p'_{32} - c_2)(A + \beta e'_{31} + \gamma e'_{32}) - \frac{k_2(1 - \theta)}{2} e'_{32}^2 - l(p'_{32} - c_2)^2 \sigma^2. \]  

(16)

Using Timing Sequence 2 and a similar solving process and method as in Section 4.2, we can obtain Proposition 6.
Proposition 6. When the cost-sharing logistics contract is provided by the TPL, the promotion effort and the logistics service effort are \( e_{31}^* = \beta ((mk_2 \beta^2 + 2mk_1 k_2 \alpha^2 - k_1 \gamma^2)B - mk_1 k_2 A)/[k_1 (2mk_2 \beta^2 + mk_1 k_2 \alpha^2 - k_1 \gamma^2)] \) and \( e_{32}^* = (k_1 \gamma A + \beta^2 B)/(2mk_2 \beta^2 + 2mk_1 k_2 \alpha^2 - k_1 \gamma^2) \), respectively, and the market demand of green agriculture products is \( D^*_3 = [(k_1 A + \beta^2 B)(2mk_1 k_2 \alpha^2 + mk_2 \beta^2)]/[k_1 (2mk_2 \beta^2 + 2mk_1 k_2 \alpha^2 - k_1 \gamma^2)] \).

Considering that the logistics service effort cannot be negative, we let \( 2mk_2 \beta^2 + 2mk_1 k_2 \alpha^2 - k_1 \gamma^2 > 0 \). Considering that the promotion effort cannot be negative, we let \( (mk_2 \beta^2 + 2mk_1 k_2 \alpha^2 - k_1 \gamma^2)B - mk_1 k_2 A > 0 \).

For \( \partial e_{31}^*/\partial \gamma^2 = \beta ((k_1 - 1)(2mk_1 k_2 \alpha^2 - k_1 \gamma^2) + mk_2 \beta^2 (k_1 - 2)]B - mk_1 k_2 A)/[k_1 (2mk_2 \beta^2 + 2mk_1 k_2 \alpha^2 - k_1 \gamma^2)^2] \), we observe that \( \partial e_{31}^*/\partial \gamma^2 > 0 \) when \( B > k_1 A/\gamma^2 \); that is, \( \gamma \) has a positive effect on \( e_{31}^* \). The larger the marginal effect of the logistics service effort on the demand, the more willing the e-tailer is to apply effort.

For \( \partial e_{32}^*/\partial \beta^2 = \gamma ((2mk_1 k_2 \alpha^2 - k_1 \gamma^2)B - 2mk_1 k_2 A)/(2mk_2 \beta^2 + 2mk_1 k_2 \alpha^2 - k_1 \gamma^2)^2 < 0 \), we observe that \( \beta \) has a negative effect on \( e_{32}^* \); that is, the larger the marginal effect of the promotion effort on the demand, the more unwilling the e-tailer is to apply effort. By comparing \( e_{31}^* \) and \( e_{32}^* \), we obtain \( p_{32}^* > p_{32}^* \) when \( \theta < 2mk_1 k_2 \alpha^2 B(k_2 \beta^2 - k_1 \gamma^2) - k_1 \gamma^2 k_2 \beta^2 (c_1 - p_1))/[2(k_1 k_2 \alpha^2 \beta^2)^2 B] \).

4.3.3. Sensitivity analysis. To intuitively show the optimal results, we list all green promotion efforts of the e-tailer, green logistics service efforts of the TPL, and market demands of green agriculture products under different contract scenarios and different timing sequences in Table 3. In the table, \( A = D_0 - \alpha p_1, B = p_1 - c_1 - c_2, C = k_2 \beta^2, G = k_1 \gamma^2, K = k_1 k_2 A, m = 1 - \theta \), and \( N = 2k_1 k_2 \alpha^2 \).

In order to ensure the non-negative nature of the promotion efforts and logistics efforts in Table 3, the following conditions need to be met: \( k_2 \beta^2 < k_1 \gamma^2 \) and \( (k_2 \beta^2 - k_1 \gamma^2 + 2k_1 k_2 \alpha^2)B > k_1 k_2 A \). These conditions are obtained from the above solving process of the models. Once these conditions are met, we can theoretically
obtain the optimal results in Table 3. When the contract is provided by the e-tailer, the optimal promotion effort can be obtained based on the concave nature of the e-tailer’s expected utility function, and the optimal logistics effort can be obtained based on the concave nature of the TPL’s expected utility function. When the contract is provided by the TPL, the optimal logistics effort can be obtained based on the positive definiteness of the Hessian matrix of the TPL’s expected utility function, and the optimal promotion effort can be obtained based on the concave nature of the e-tailer’s expected utility function. It is noted that there is no need to use optimization software in this paper.

Table 3 shows the influence of main parameters on the optimal values of the promotion effort, logistics effort and market demand. For the promotion effort of the e-tailer, the marginal effect coefficient of promotion effort on demand $\beta$ always has a positive effect on it under all four contract scenarios and the marginal effect coefficient of logistics effort on demand $\gamma$ always has a negative effect on it under three scenarios except the scenario in which the cost-sharing contract is provided by the TPL. For the logistics effort of the TPL, the $\beta$ always has a negative effect on it under three scenarios except the scenario in which the fixed-price contract is provided by the TPL and the $\gamma$ always has a positive effect on it under three scenarios except the scenario in which the cost-sharing contract is provided by the e-tailer. For the market demand, the $\beta$ always has a positive effect on it under three scenarios except the scenario in which the cost-sharing contract is provided by the TPL and the $\gamma$ always has a positive effect on it under all four contract scenarios.

Note that this paper studied the design issue of three types of contracts under two types of decision-making timing sequences. Once the decision-making timing sequence and contract type are determined, the optimal contract results are determined. That is, the promotion effort of the e-tailer and the logistics effort of the TPL are the optimal decisions for themselves. In other words, the optimal choice of both parties constitutes the game equilibrium strategy. It is noted that both the e-tailer and TPL should pay more attention to contract provider and contract type, which determine their optimal options.

Considering that the optimal results under a fixed-price contract are the same as those under a revenue-sharing contract, this section primarily analyzes the difference in the coordination effect between fixed-price and cost-sharing contracts. In the following, we determine effective contracts for the supply chain based on two types of timing sequences that depend on the different contract providers.

(1) Contract provided by the e-tailer

As can be seen from $e_{11}^{*}$ and $e_{31}^{*}$, we can get $e_{11}^{*} - e_{31}^{*} = -k_1 k_2 A \gamma^2 \theta (3 - 2\theta) + \gamma^2 B \theta (2 - \theta - k_1 \gamma^2)$. We obtain $e_{11}^{*} > e_{31}^{*}$ when $\theta < (2k_2 \beta^2 - k_1 \gamma^2)/k_2 \beta^2$; that

| Contract Provided by | Promotion effort | Logistics effort | Market demand |
|----------------------|------------------|-----------------|--------------|
| Fixed-price (Revenue-sharing) E-tailer | $-\beta \left[ k_2 A + \gamma^2 B \right]$ | $\gamma \left[ K + (C - G) B \right]$ | $-\gamma \left[ k_2 A + \gamma^2 B \right]$ |
| TPL | $\beta \left[ (N + C - G) B - K \right]$ | $\gamma \left[ \beta^2 B + k_1 A \right]$ | $\gamma \left( 2C + N - G \right)$ |
| Cost-sharing E-tailer | $\beta \left[ m^2 C + (\theta - 2) G \right]$ | $\gamma \left( k_1 A + \beta^2 B \right)$ | $m \left( N + C \right) \left( k_1 A + \beta^2 B \right)$ |
| TPL | $\beta \left[ m^2 C + (\theta - 2) G \right]$ | $\gamma \left( k_1 A + \beta^2 B \right)$ | $m \left( N + C \right) \left( k_1 A + \beta^2 B \right)$ |

In this paper, we assume that the promotion effort and logistics effort are the optimal decisions for both parties. It is noted that there is no need to use optimization software in this paper.

Table 3 shows the influence of main parameters on the optimal values of the promotion effort, logistics effort and market demand. For the promotion effort of the e-tailer, the marginal effect coefficient of promotion effort on demand $\beta$ always has a positive effect on it under all four contract scenarios and the marginal effect coefficient of logistics effort on demand $\gamma$ always has a negative effect on it under three scenarios except the scenario in which the cost-sharing contract is provided by the TPL. For the logistics effort of the TPL, the $\beta$ always has a negative effect on it under three scenarios except the scenario in which the fixed-price contract is provided by the TPL and the $\gamma$ always has a positive effect on it under three scenarios except the scenario in which the cost-sharing contract is provided by the e-tailer. For the market demand, the $\beta$ always has a positive effect on it under three scenarios except the scenario in which the cost-sharing contract is provided by the TPL and the $\gamma$ always has a positive effect on it under all four contract scenarios.

Note that this paper studied the design issue of three types of contracts under two types of decision-making timing sequences. Once the decision-making timing sequence and contract type are determined, the optimal contract results are determined. That is, the promotion effort of the e-tailer and the logistics effort of the TPL are the optimal decisions for themselves. In other words, the optimal choice of both parties constitutes the game equilibrium strategy. It is noted that both the e-tailer and TPL should pay more attention to contract provider and contract type, which determine their optimal options.

Considering that the optimal results under a fixed-price contract are the same as those under a revenue-sharing contract, this section primarily analyzes the difference in the coordination effect between fixed-price and cost-sharing contracts. In the following, we determine effective contracts for the supply chain based on two types of timing sequences that depend on the different contract providers.

(1) Contract provided by the e-tailer

As can be seen from $e_{11}^{*}$ and $e_{31}^{*}$, we can get $e_{11}^{*} - e_{31}^{*} = -k_1 k_2 A \gamma^2 \theta (3 - 2\theta) + \gamma^2 B \theta (2 - \theta - k_1 \gamma^2)$. We obtain $e_{11}^{*} > e_{31}^{*}$ when $\theta < (2k_2 \beta^2 - k_1 \gamma^2)/k_2 \beta^2$; that
is, when $\theta$ is smaller than a threshold, the promotion effort under the fixed-price contract is greater than that under the cost-sharing contract. Here, the cost-sharing contract is more effective than the fixed-price contract.

As can be seen from $e_{12}'$ and $e_{32}'$, we can get $e_{12}' - e_{32}' = -\theta(k_1k_2A + k_2\beta^2B)(mk_2\beta^2 + k_1\gamma^2) + k_1\gamma^2B\theta[(2 - \theta)k_2\beta^2 - k_1\gamma^2]$. When $\theta \geq (2k_2\beta^2 - k_1\gamma^2)/k_2\beta^2$, we can obtain $e_{12}' < e_{32}'$; that is, when $\theta$ is greater than a threshold, the logistics service effort under the fixed-price contract is lower than that under the cost-sharing contract. Here, the cost-sharing contract is more effective than the fixed-price contract.

By recalling the function structure of market demand, we can conclude that $D_1^* < D_3^*$; that is, the market demand under the fixed-price contract is lower than that under the cost-sharing contract when $\theta \geq (2k_2\beta^2 - k_1\gamma^2)/k_2\beta^2$. Here, the cost-sharing contract is more effective than the fixed-price contract.

In summary, when the logistics service contract is provided by the e-tailer and the cost-sharing proportion of the e-tailer is greater than a threshold, the cost-sharing contract is the most effective for the supply chain.

(2) Contract provided by the TPL

As can be seen from $e_{11}'$ and $e_{31}'$, we can obtain $e_{11}' - e_{31}' = k_1\gamma^2\theta(k_1k_2A + k_2\gamma^2B) > 0$; that is, the promotion effort under the fixed-price contract is greater than that under the cost-sharing contract. Here, the fixed-price contract is more effective than the cost-sharing contract.

As can be seen from $e_{12}'$ and $e_{32}'$, we can obtain $e_{12}' - e_{32}' = \gamma(\beta^2 + k_1A)(2k_2\beta^2 + 2k_1k_2\sigma^2 - k_1\gamma^2) - \gamma(\beta^2 + k_1A)(2mk_2\beta^2 + 2mk_1k_2\sigma^2 - k_1\gamma^2) < 0$; that is, the logistics service effort under the fixed-price contract is lower than that under the cost-sharing contract. Here, the cost-sharing contract is more effective than the fixed-price contract.

By comparing $D_1^*$ and $D_3^*$, we can get $D_1^* - D_3^* = -k_2\beta^2(\gamma^2 + k_2A)/[2k_2(k_2\beta^2 - 2k_1\gamma^2)] > 0$, that is, the market demand of green agriculture products under the fixed-price contract is smaller than that under the cost-sharing contract. Here, the cost-sharing contract is superior to the fixed-price contract.

In summary, when the logistics contract is provided by the TPL, although the promotion effort is reduced, the cost-sharing contract is the most effective for the supply chain.

Thus, we can draw the following conclusions: 1) When the logistics contract is provided by TPL, the cost-sharing contract is always the most effective. 2) When the logistics contract is provided by the e-tailer, the cost-sharing contract is the most effective under certain conditions; that is, the logistics cost-sharing proportion of the e-tailer must exceed a certain threshold. However, as to which is the better one between the cost-sharing contract provided by the e-tailer and the cost-sharing contract provided by the TPL is still an interesting question. Below, we provide the answer in detail.

On one hand, recalling statements in Section 4.3.2, if $\theta < [2k_1k_2\sigma^2B(k_2\beta^2 - k_1\gamma^2) - k_1\gamma^2k_2\beta^2(c_1 - p_1)]/(2k_1k_2^2\beta^2\sigma^2B)$, we have $D_3^* < D_1^*$. Here, the cost-sharing contract provided by the TPL is more effective than that provided by the e-tailer. On the other hand, the cost-sharing contract provided by the e-tailer is the most effective in all the contracts provided by the e-tailer when $\theta \geq (2k_2\beta^2 - k_1\gamma^2)/k_2\beta^2$. Therefore, we can perform further analysis.

Let $\theta_1 = [2k_1k_2\sigma^2B(k_2\beta^2 - k_1\gamma^2) - k_1\gamma^2k_2\beta^2(c_1 - p_1)]/(2k_1k_2^2\sigma^2k_2\beta^2B)$, $\theta_2 = (2k_2\beta^2 - k_1\gamma^2)/k_2\beta^2$. By sorting, we obtain $\theta_1 > \theta_2$ when $\gamma^2 - 2k_2\sigma^2(p_1 - c_1) = \gamma^2 \gamma^2 < 2k_2\sigma^2(p_1 - c_1)$.
Here, the cost-sharing contract provided by the TPL is always the most effective, regardless of the contract type and contract provider.

The above condition can be easily achieved when \( \gamma^2 > 2k_2\sigma^2 \). This indicates that the cost-sharing contract provided by the TPL is always the most effective when the marginal effect of the logistics service effort on the market demand is sufficiently large. However, when \( \theta_1 < \theta_2 \), determining which is theoretically the best one is difficult. Therefore, we will numerically discuss this concern in detail.

Regarding the issue of who will gain the maximum benefit, we give the following explanations. On one hand, review the green agriculture product supply chain consisting of an e-tailer and a TPL, the status of the e-tailer and TPL may be not equal, which means that their profits may not be comparable. For example, in the e-tailer sale channel of fresh flowers, the cost of fresh flowers in the place of origin is very low but the price in the sales market is very high. The e-tailer pays the TPL the minimum reward that makes it willing to provide logistics service, and leaves a lot of sales profits for itself. At this time, the profit between the e-tailer and TPL is incomparable. On the other hand, different contract scenarios make the e-tailer or TPL get different profits. In other words, both the e-tailer and TPL need to find the optimal contract scenario that maximizes their profits. In the following, we will discuss which type of contract under different timing sequence scenarios is optimal for the e-tailer and TPL numerically.

5. **Numerical experiments.** MATLAB software was used for the numerical experiments to intuitively study the coordination effect of fixed-price, revenue-sharing, and cost-sharing contracts on the supply chain. Assume a fresh flowers supply chain consisting of an e-tailer and a TPL, we estimate the relevant parameters accordingly. When determining the parameter value, three basic conditions of the theoretical model part must be satisfied, i.e., \( p_1 > c_1 + c_2 \), \( k_2\beta^2 < k_1\gamma^2 \) and \( (k_2\beta^2 - k_1\gamma^2 + 2k_1k_2\sigma^2)B > k_1k_2A \). The specific parameters are shown in Table 4.

| Table 4. Parameter setting |
|---------------------------|
| Parameters | \( c_1 \) | \( c_2 \) | \( D_0 \) | \( k_1 \) | \( l \) | \( p_1 \) | \( \alpha \) | \( \beta \) | \( \gamma \) | \( \theta \) | \( \sigma \) | \( \varphi \) |
| Value | 2 | 4 | 70 | 10 | 2 | 20 | 2 | 9 | 12 | 0.5 | 3 | 0.4 |

Considering that the e-tailer seeks to encourage the TPL to apply effort, this section primarily studies the effect of the effort cost coefficient of the TPL \( k_2 \) on the optimal results of the three types of contracts. Let \( k_2 \in [8, 12] \). Figure 3 to Figure 9 show the effects of \( k_2 \) on the promotion effort, the logistics service effort, the market demand of green agriculture products, the e-tailer’s expected utility, the TPL’s expected utility, the supply chain’s expected utility, and logistics service price, respectively. In Figures 3 to 9, Scenarios 1, 2, and 3 represent the fixed-price, revenue-sharing, and cost-sharing contract provided by the e-tailer, and Scenarios 4, 5, and 6 represent the fixed-price, revenue-sharing, and cost-sharing contracts provided by the TPL.

Figure 3 shows that, as \( k_2 \) increases, the promotion effort gradually increases; that is, the higher the marginal cost of the logistics service effort, the more willing the e-tailer is to exert effort. The promotion effort under the cost-sharing contract provided by the TPL is the smallest. When the e-tailer must share the logistics cost
and the logistics contract is provided by the TPL, the e-tailer is the least willing to exert effort in the promotion.

For promotion effort, the cost-sharing contract provided by the e-tailer is more effective than the fixed-price (revenue-sharing) contract provided by the TPL. The promotion effort under the fixed-price contract provided by the e-tailer is larger than that provided by the TPL. The e-tailer is more willing to exert more effort under the fixed-price contract it provides.

An intersection is shown in Figure 3. When $k_2$ is lower than the horizontal ordinate of the intersection, the cost-sharing contract provided by the e-tailer is more effective than the fixed-price contract provided by the e-tailer. Thereafter, the fixed-price contract provided by the e-tailer is more effective than the cost-sharing contract provided by the e-tailer.

Figure 4 shows that, as $k_2$ increases, the logistics service effort gradually decreases; that is, the higher the marginal cost of the logistics service effort, the more unwilling the TPL is to exert effort. Generally, the logistics service effort under the two types of cost-sharing contracts is greater than that under the revenue-sharing contracts, indicating that the cost-sharing contracts under the two types of timing sequences are more effective than the other two contracts. Regardless of the provider of the cost-sharing contract, the TPL will increase its logistics service effort when the e-tailer shares logistics costs.

The logistics service effort under the cost-sharing contract it provides is the largest. When the e-tailer must share the logistics cost and the logistics contract is provided by the TPL, the TPL is the most willing to exert effort in the logistics service. For the logistics service effort, the fixed-price contract provided by the TPL is more effective than that provided by the e-tailer. The logistics service effort under the fixed-price contract provided by the e-tailer is the smallest. When the e-tailer does not share the logistics cost and the logistics contract is provided by the e-tailer, the TPL is the least willing to exert effort in the logistics service.

Figure 5 shows that, as $k_2$ increases, the market demand of green agriculture products gradually decreases; that is, the higher the marginal cost of the logistics
service effort, the smaller the market demand of green agriculture products is. The market demand under the two types of cost-sharing contracts is greater than that under the revenue-sharing contracts, indicating that the cost-sharing contract under the two types of timing sequences is better than the other two contracts.

For market demand of green agriculture products, the cost-sharing contract provided by the TPL is the most effective, followed by the cost-sharing contract provided by the e-tailer, the fixed-price contract provided by the TPL, and the fixed-price contract provided by the e-tailer. When the TPL provides the logistics contract and the e-tailer shares the logistics cost, the largest market demand of green agriculture products can be achieved. The effect of $k_2$ on market demand of green agriculture products is similar to that on logistics service effort, which means that
the market demand of green agriculture products is primarily determined by the logistics service.

Figure 6. Effect of logistics marginal effort cost coefficient $k_2$ on e-tailer’s expected utility.

Figure 6 shows that, as $k_2$ increases, the e-tailer’s expected utility under all contract scenarios except for the cost-sharing contract provided by the TPL gradually decreases. In contrast, the e-tailer’s expected utility under the cost-sharing contract provided by the TPL increases with $k_2$. The larger the logistics service effort cost coefficient of the TPL, the larger the e-tailer’s expected utility under the cost-sharing contract provided by the TPL. Considering that the promotion effort increases rapidly with $k_2$, this is easy to understand.

For the e-tailer’s expected utility, the cost-sharing contract provided by the e-tailer is the most effective. When the e-tailer provides the logistics contract and shares the logistics cost with the TPL, it can obtain the largest expected utility. The difference between the e-tailer’s expected utility under the fixed-price contract provided by the e-tailer and that under the fixed-price contract provided by the TPL is not significant.

An intersection is shown in Figure 6. When $k_2$ is lower than the horizontal ordinate of the intersection, the e-tailer obtains a lower expected utility from the cost-sharing contract provided by the TPL than from the fixed-price contract and the revenue-sharing contract. Thereafter, the cost-sharing contract provided by the TPL improves. When the logistics service effort cost coefficient of the TPL is larger than a threshold, the cost-sharing contract is welcomed by the e-tailer regardless of the contract providers.

Figure 7 shows that, as $k_2$ increases, the TPL’s expected utility gradually decreases; that is, the higher the marginal cost of the logistics service effort, the smaller the TPL’s expected utility is. Regardless of the contract providers, the cost-sharing contract always benefits the TPL. The logistics cost-sharing of the e-tailer is always welcomed by the TPL. In particular, the TPL can obtain the largest expected utility from the cost-sharing contract it provides. Thus, the TPL providing the logistics contract when the e-tailer shares the logistics cost is optimal.
The TPL’s expected utility under the fixed-price contract provided by the e-tailer is the smallest. When the e-tailer does not share the logistics cost, the fixed-price contract provided by the e-tailer is the most unfavorable for the TPL. Thus, the TPL must provide the logistics contract regardless of the type of contract. Therefore, the TPL benefits when it strives for the contract decision-making power with the e-tailer.

Figure 8 shows that as $k_2$ increases, the supply chain’s expected utility under all contract scenarios except for the cost-sharing contract provided by the TPL gradually decreases. In contrast, the supply chain’s expected utility under the cost-sharing contract provided by the TPL first increases with $k_2$ and subsequently decreases.
The supply chain’s expected utility under the cost-sharing contract provided by the TPL is the largest. The cost-sharing contract provided by the TPL is the most effective for supply chain coordination. The cost-sharing contract provided by the e-tailer is the second-most effective one in supply chain coordination. When the fixed-price contract is provided by the TPL, the performance of the supply chain can improve. The supply chain’s expected utility under the fixed-price contract provided by the e-tailer is the smallest. The coordination effect of the fixed-price contract provided by the e-tailer on the supply chain is the least effective.

Figure 9 shows that, as $k_2$ increases, the logistics service price under all contract scenarios gradually decreases. However, the logistics service price under scenarios 3, 4, and 5 is not significantly affected by the effort cost coefficient of the TPL. The logistics service price under the cost-sharing contract provided by the TPL is the largest, followed by that under the fixed-price contract provided by the TPL. The logistics service price under the cost-sharing contract provided by the e-tailer or that under the fixed-price contract provided by the e-tailer, which is larger, is conditional, but both are larger than that under the revenue-sharing contract provided by the TPL. The revenue-sharing contract provided by the e-tailer minimizes the logistics service price.

A counterintuitive phenomenon can be observed in Figure 9. The logistics service price can be lower than zero in some contracts, such as in scenarios 2 and 5. Here, the TPL pays the e-tailer the logistics service fee instead. This is an interesting observation. Considering that this scenario only occurs under revenue-sharing contracts, the possible explanations are as follows. Recalling the statements in Sections 5.1 and 5.2, the fixed-price contract can be considered a type of revenue-sharing contract, and the revenue sharing is accomplished through the logistics service price.

On one hand, the logistics service effort is the largest under the cost-sharing contract provided by the TPL, and the smallest under the revenue-sharing contract provided by the e-tailer (Figure 4). Therefore, the e-tailer provides the maximum incentive to motivate the TPL to apply effort under the cost-sharing contract provided by the TPL. Therefore, the logistics service price under scenario 6 is the
largest. The promotion effort is the largest under the revenue-sharing contract provided by the e-tailer, and the smallest under the cost-sharing contract provided by the TPL (Figure 3). Here, the TPL provides the maximum incentive to motivate the e-tailer to exert effort under the revenue-sharing contract provided by the e-tailer. Therefore, the logistics service price under scenario 2 is the smallest.

On the other hand, the TPL is not concerned about the logistics service price but about the sum of the sharing product price and the logistics service price under the revenue-sharing contracts. It does not matter that the logistics service price is negative. The TPL shares its revenue with the e-tailer when the logistics service price is negative.

In summary, compared with fixed-price contract, the revenue-sharing contract cannot do better in coordinating the supply chain, but it can change the logistics service price. When both the e-tailer and TPL can apply efforts to increase the market demand of green agriculture products, the logistics service price can achieve flexible coordination between the promotion effort of the e-tailer and the logistics service effort.

6. Conclusion. The use of live broadcasting on network platforms to sell green agriculture products is increasing, creating concerns about contract design and supply chain coordination. This study considers an e-tailer supply chain of green agriculture products consisting of an e-tailer and a TPL, and studies the coordination problems of the e-tailer supply chain based on fixed-price, revenue-sharing, and cost-sharing contracts. Considering that both the promotion effort and the logistics service effort can affect demand, the optimal green efforts of both parties and the logistics service price are provided under two timing sequences that are based on the contract providers, i.e., the e-tailer or the TPL.

This study investigates the effects of three different types of logistics contracts under two different timing sequences on the e-tailer supply chain of green agriculture products and establishes a green effort incentive mechanism for the e-tailer and TPL to promote the sale of green agriculture products through online platforms and achieve green and low-carbon supply chains.

First, the fixed-price contract is considered and the promotion effort, the logistics service effort, and the market demand of green agriculture products under two different timing sequences are obtained. Second, the revenue-sharing contract is used to coordinate the supply chain, and the optimal results are analyzed. Third, the cost-sharing contract is used to coordinate the supply chain, and the coordination effect is analyzed. Fourth, the optimal results under different timing sequences and contract scenarios are discussed theoretically and numerically, and several conclusions are obtained. The results indicate that different types of contracts and contract providers determine the coordination effect of the supply chain of green agriculture products. The detailed results are as follows:

First, the cost-sharing contract is always effective for the market demand of green agriculture products regardless of the contract providers. The cost-sharing contract is always the most effective when the logistics contract is provided by the TPL. When the logistics contract is provided by the e-tailer, the cost-sharing contract is the most effective under certain conditions. That is, the logistics cost-sharing proportion of the e-tailer must exceed a threshold. When the marginal effect of the logistics service effort on the market demand is sufficiently large, the cost-sharing contract provided by the TPL is always the most effective in all types of contracts.
Second, both the contract types and providers affect the promotion effort. When the logistics contract is provided by the TPL, the promotion effort under the cost-sharing contract is always the smallest. When the logistics contract is provided by the e-tailer, the promotion effort under the cost-sharing contract is smaller than that under the fixed-price contract when the cost-sharing proportion of the e-tailer is smaller than a threshold.

Third, the cost-sharing contract is always effective for the logistics service effort, regardless of the contract providers. The cost-sharing contract provided by the TPL is always the most effective under all contract scenarios. When the e-tailer provides the logistics contract, the fixed-price contract as well as the revenue-sharing contract is always the least effective when the cost-sharing proportion of the e-tailer is greater than a threshold.

Fourth, the cost-sharing contract provided by the e-tailer can provide the e-tailer with the largest expected utility. The e-tailer’s expected utility under the cost-sharing contract provided by the TPL increases with the effort cost coefficient of the TPL. The cost-sharing contract is welcomed by the e-tailer when the effort cost coefficient of the TPL is larger than a threshold.

Finally, the TPL can obtain the largest expected utility from the cost-sharing contract it provides. The cost-sharing contract provided by the e-tailer also benefits the TPL compared with the fixed-price and revenue contracts. The fixed-price contract provided by the e-tailer is least welcomed by the TPL. In summary, the cost-sharing contract effectively coordinates the supply chain of green agriculture products in two different timing sequences.

This study considers the market price as exogenous. One interesting research topic could be to examine the price which can also be endogenous and determined by the e-tailer. Therefore, a possible extension to this study is combining the decision-making of efforts and the decision-making of market prices. This study considers a two-tie e-tailer supply, a three-tier e-tailer supply chain consisting of a farmer, an e-tailer and a TPL can be considered in the future. Studying the interaction of the three parties in the supply chain of green agriculture products will be another interesting extension. In addition, the theoretical results of this paper can be further verified in practice. Therefore, case analysis also can be considered in the future.

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