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Service capacity procurement of logistics service supply chain with demand updating and loss-averse preference

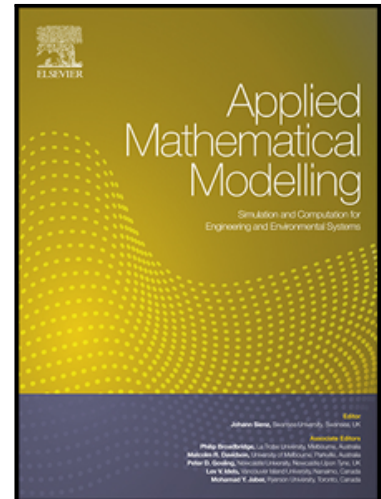Weihua Liu , Meili Wang , Donglei Zhu , Li Zhou

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Highlights

- Service capacity procurement of logistics service supply chain is analyzed.

- Demand updating and loss-averse preference are considered in four models building.

- The impact of loss-averse preference on supply chain member's decisions is studied.

- Conclusions are generated by four models comparison and numerical analysis.

Service capacity procurement of logistics service supply chain with

demand updating and loss-averse preference

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Conflict of Interests

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Abstract: This paper studies the impacts of loss-averse preference on the service capacity procurement decisions with demand updating in a logistics service supply chain, which consists of one logistics service integrator and one functional logistics service provider. It starts from a basic two-stage Stackelberg game model, then, extends to three scenarios where either the integrator or the provider or neither of them has loss-averse preference. The impact of loss-averse preference on the decisions of supply chain members is discussed by comparing the four models. Our results reveal, first, the loss-averse preferences do not always affect the decisions of supply chain members. If certain conditions are satisfied, the logistics service integrator can benefit from its loss-averse preference. Second, the increased service level can affect the logistics service integrator's procurement strategy and the functional logistics service provider's pricing strategy. This effect is only related to the loss-averse preference of the functional logistics service provider. Last, under certain conditions, the total service capacity decreases with the increased service level, regardless of whether or not the supply chain members have loss-averse preferences.

Key words: demand updating; loss-averse preference; procurement; service capacity; logistics service supply chain

1. Introduction

In recent years, e-commerce has been developing very quickly around the world and has created a massive demand for logistics. Majority of e-commerce companies outsource their logistics services, as it is very difficult for them to provide logistics services on their own. Thus, logistics service supply chain (LSSC) is formed. An LSSC usually consists of a logistics service integrator (LSI) and several functional logistics service providers (FLSPs), where LSI provides customized logistics services for e-commerce companies by integrating the service capacities of multiple FLSPs. FLSPs consist of traditional functional logistics enterprises, such as transportation and storage enterprises, among others. These FLSPs are

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integrated as the suppliers by the LSI when the LSI trying to provide the integrated services. For example, LSIs, such as China P.G. Logistics Group [1], Chinese Yuantong Express Logistics Company [2], and Robinson Global Logistics Co., Ltd. [3], purchase transportation capacity and storage capacity separately from different FLSPs to provide a systematic logistics service to customers. Accordingly, capacity procurement is an important part in LSSCs.

In practice, however, logistics service capacity procurement is not easy, especially when market demand updating and behavioral factors are taken into consideration [4]. For example, Chinese Yuantong Express Logistics Company, an LSI with more than 60 branches, provides integrated logistics services mainly to China Taobao Electronic Commerce. Taobao has their biggest sales promotion on November 11 annually. On November 11, 2015, the e-commerce turnover of Taobao was 91.217 billion RMB, 27.14 times that of the turnover in the corresponding period in 2011 [5]. All the branches of Yuantong collected 53,280,000 parcels (19.95 times of the parcels in the corresponding period in 2011) to be delivered to consumers located in 31 provinces in 3 to 5 days. To manage the sharp increase in logistics service demand, in October 2012, Yuantong pre-ordered capacity according to its demand forecast based on the e-commerce sales promotion, then purchased capacity for the second time in November when customer demand is realized [2]. If Yuantong finds that after updating the demand, the purchase quantity is too much, Yuantong will sell the remaining capacity at a lower price. However, the initial purchasing cost has been paid to his FLSP, which is regarded as a loss by Yuantong. On the other hand, it is expensive for his FLSP to expand their logistics capacity (such as purchasing transportation vehicles and constructing warehouses) if the logistics capacity is lower than the updating demand. Therefore, if Yuantong does not make use of the second purchasing opportunities to increase their purchasing capacity, his FLSP will be afraid that rush expansion of logistics capacity will cost too much and result in a loss of their profits. Consequently, the loss-averse preferences of both parties made it difficult for Yuantong to make effective decisions. Yuantong was under great pressure due to the sharply increased demand and FLSP's inadequate service capacity preparation. Warehouse overflow, delayed delivery and damaged goods occurred. These problems were not resolved before the sales promotion period in 2015 [6]. This example reveals LSI's

problems in building a scientific supply chain procurement strategy under sharply increased demand [7, 8].

From the perspective of theory, issues about supply chain decisions under demand updating and loss-averse have been studied individually. For example, in the research of supply chain decisions under demand updating scholars use the two ordering opportunities strategy to analyze the supply chain strategy [9, 10], and practical issues under complicated environments are explored [11-14]. Studies of strategies in supply chain with loss-averse mainly focus on supply chain coordination [15, 16] and inventory management [17] in manufacturing companies. The most relevant papers for this study are Ma et al. [18] and Qin [19], both of which take market demand updating and loss aversion preference into consideration. Ma et al. [18] built a model by punishing retailers who do not gain target profits and they provided optimal purchasing strategies for retailers. It focused on the fashion supply chain, but did not consider the properties of service and the combination of supply chain members' loss aversion preferences. Qin [19] studied a loss-averse supplier under a push contract and a pull contract. This paper differs from Qin [19] in that this article mainly focuses on the related decision-making problems, such as pricing and ordering quantity in the logistics service supply chain instead of coordinating the supply chain.

In addition, Service Only Supply Chain is a supply chain system in which the "products" are pure services, and physical products do not play a role, such as therapy, health care exams, financial consulting and fortune telling [20]. Logistics service supply chain is Service Only Supply Chain in the logistics field. The LSI purchases logistics service capacity, such as transport capacity and storage capacity, from FLSPs. After integration, the LSI sells the integrated logistics service capacity to customers. Therefore, different from the previous literature about the supply chain decisions in manufacturing companies, this paper considers two important characteristics of the service supply chain. One is inseparability and the other is perishability: service production and consummation always occur simultaneously, and the service capacity cannot be stored after the selling season [21]. Under demand updating, market demand is not realized in the first stage, thus procurement of the LSI in the first stage is a pre-order and the FLSP does not hand over the functional service capacity to the LSI. While in a manufacturing supply chain, a retailer can purchase and store a product for selling.

The service level is the other important property of service. The LSI and FLSP must pay an additional cost to guarantee the service level required by customers. The service-level guarantee cost will be explained in detail in Section 3. Liu et al. [22], also relevant to this paper, considers demand updating and service quality guarantees when developing logistics service purchasing strategies. However, our paper focuses on pricing and ordering quantity problems in an LSSC and considers two important properties of service, which are inseparability and perishability.

Accordingly, this paper attempts to explore the impact of the loss-averse preference on the LSI's order quantity and the FLSP's pricing strategy under demand updating, and tries to answer the three following questions:

(1) How do the loss-averse behaviors of the LSI and FLSP affect the pricing and purchasing decisions? What if only one of the supply chain members has a loss-averse preference?

(2) Do the loss-averse preferences of the LSI and FLSP definitely affect the optimal decisions of supply chain members? If not, what are the conditions?

(3) Are there interactions between the loss-averse preference of the LSI and that of the FLSP? If so, what are the interactions?

To answer the questions above, we consider a two-echelon LSSC consisting of a loss-averse FLSP and a loss-averse LSI that purchase logistics service capacity from the FLSP before and after demand updating (Supply chains often contain multiple LSIs, FLSPs and customers, LSIs and FLSPs cooperate to satisfy the customer demand, therefore the roles of LSIs and FLSPs are often discussed emphatically. Similarly, this study aims to explore the impact of the loss-averse behavior of supply chain members, and we also focus on LSI and FLSP). We build a basic model to maximize the utilities of the LSI and FLSP who both have loss-averse preferences. But in practice, there are special scenarios where only one side has loss-averse preference or neither side has loss-averse preference. These special scenarios include: (a) only the LSI has loss-averse preference, (b) only the FLSP has loss-averse preference, and (c) neither of them has loss-averse preference (the detailed cases can be seen in section 4.2). After comparing the LSI's optimal procurement strategy and the FLSP's optimal pricing strategy among the basic model and the three scenarios above, the impact of the loss-averse

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preference on making the optimal decision is analyzed. In doing so, our paper makes the following three contributions: First, this paper takes both demand updating and loss-averse preference into consideration, exploring the interaction mechanism and a combination of these factors. Second, the current literature only considers the situation of one supply chain member having loss aversion behavior and studies the effects of loss aversion behavior in the case of complicated factors, such as asymmetric information [23] or sudden disruptions [24]. Conversely, this paper takes the loss aversion behavior of both the LSI and FLSP into consideration and explores the effects of loss-averse preferences with four combinations on supply chain decision making by comparing the optimal decisions in the basic model and three special cases. Third, this paper generates some unexpected conclusions. For example, the LSI can benefit from its loss-averse preference if certain conditions are satisfied. Additionally, the loss-averse preferences of the LSI and FLSP do not always affect the decisions of supply chain members.

The rest of the paper is organized as follows. Section 2 reviews the recent relevant literature. Section 3 provides the background for our study and develops a few necessary hypotheses. Section 4 builds a basic model (model I) and three special scenarios. By comparing the basic model with the three scenarios, Section 5 discusses the effects and interactions of the loss-averse preference of the LSI and that of the FLSP. Section 6 is a numerical analysis. Section 7 provides conclusions, management insights, and future directions for research.

2. Literature review

The topics most relevant to our study are LSSC capacity procurement, market demand updating, and loss-averse preference. The most relevant existing literature related to these three aspects will be reviewed in Sections 2.1 to 2.3.

2.1 Supply chain coordination under demand updating

Current studies of supply chain coordination under demand updating focus on two aspects. One is the expression of demand updating. The other is two-stage ordering policies in supply chain under demand updating. The Bayesian updating method [12], conditional distribution method [25], and AR(1) process [10] are widely used to perform demand

updating.

The more complex two-stage ordering policy based on the demand information updating has been paid increasing attention by researchers. Gurnani and Tang [9] studied a retailer ordering a seasonal product prior to a single selling season, and improved the forecast by updating demand and presenting a nested news vendor model for determining the optimal order quantity. Afterwards, many scholars extended the issue to more complicated situations, such as allowing retailers to purchase from external markets, studying single and multi-period quantity flexibility contracts in a spot market and discussing the impact of the forecast quality and the level of flexibility on the optimal decisions [11]. Based on this, service levels are considered [26]. Because the decision-making processes of supply chain members are often subject to various conditions, capacity constraints [13] and capital constraints [14] are introduced into the two-stage ordering policy.

With the rapid change of market, such as e-coherence market in recent years, demand updating began to be incorporated into service capacity procurement decisions. For example, Liu et al. [22] studied the logistics service supply chain and explored the influence of demand uncertainty revelation and quality guarantee change cost on the supply chain members' optimal decision making by comparing the four combinations of uncertainty complete revelation/uncertainty incomplete revelation (UCR/UIR) and GCC/no guarantee change cost (NGCC). The differences between this paper and Liu et al. [22] are in three aspects. First, in Liu et al. [22], the LSI purchases and sells service capacity in both periods, however, we study a one-period-two-stage process in which the LSI purchases service capacity in both stages, but only sells at the end of the second period. Second, although this paper and Liu et al. [22] both consider demand updating, this paper focuses on the purchasing quantity and pricing problem given two purchasing opportunities, while Liu et al. [22] attempted to determine the effects of the demand uncertainty revelation degree. Third, Liu et al. [22] studied the service quality guarantee, while we study loss aversion behavior.

2.2 Loss-averse preference

Behavioral operations in supply chains have been developed very fast recently and many behaviors have been considered in the literature [27]. As one typical behavior, studies of

loss-averse preference have shown that people are more averse to losses than they are attracted to the same-sized gains [18]. To extend the literature on supply chain, loss-averse has been introduced into the current supply chain decision-making models that focus on supply chain coordination with uncertain demand [15] and inventory management [19]. On one hand, scholars usually use contracts to solve the supply chain coordination problem with uncertain demand. for example, Wang and Webster [28] considered a decentralized supply chain and found that a special class of distribution-free GLB contracts exist to improve supply chain performance. Li et al. [29] conducted a mean variance (MV) analysis of a fast fashion supply chain consisting of one supplier and n risk averse retailers. They determined that a simple return contract can be sufficient to achieve coordination. On the other hand, in the study of the inventory management, loss-averse preference has also drawn the attention of scholars studying more complex factors, such as asymmetric information [23], sudden disruptions [24] and consumer loss aversion [30]. However, the current literature on the loss-averse preference has mainly focused on retailers [31] or manufacturers [32] in manufacturing supply chains, rather than on supply chain members in service supply chain. In practice, supply chain members often have loss-averse preferences. It is common for both supplier and retailer have loss-averse, it is more realistic to consider that both members have loss-averse preferences than to consider that a single supply chain member has loss-averse preference. Obviously, it is more likely to show the complicate influence mechanism and obtain the cross-effects of both members' loss-averse preferences.

Recently, interdisciplinary studies of demand updating and loss-averse preference have been conducted. Some scholars, such as Ma et al. [18] and Qin [19] have conducted exploratory studies. Ma et al. [18] built models by punishing decision makers (retailers) for not reaching their target profits. They found that the optimal first-stage order quantity decreases as the penalty coefficient increases. The optimal first-stage order quantity always decreases as information is more accurate. However, their models focused on demand updating in the fashion supply chain and did not consider the combination of loss-averse preferences of the LSI and FLSP. Qin [19] studied how the supplier's loss-averse preference and information updating affect the push contract and pull contract, but it did not focus on LSSCs. Qin [19] discovered that with no additional information updating, there is no

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difference between the push contract and the pull contract for any wholesale price and the loss averse supplier. In addition, Chiu and Choi [33] studied the use of the mean-variance (MV) theory in multi-echelon supply chain problems and supply chain problems with information updating, to provide a better method to conduct the interdisciplinary studies of demand updating and loss-averse preference.

2.3 Summary of literature review and model orientation

From sections 2.1 and 2.2, it can be seen that demand updating and loss aversion have a crucial impact on supply chain decision making. Although the current research on supply chain demand updating and loss aversion is relatively abundant, the majority of current researches mainly focus on the manufacturing supply chain. Few scholars have focused on the influences of demand updating and loss aversion in the service supply chain. The most relevant research to this article is the study by Ma et al [18], Qin [19] and Liu et al. [22]. Ma et al [18] and Qin [19] consider both market demand updating and loss aversion by supply chain members. However, Ma et al [18] focus only on the fashion supply chain, but do not address the logistics service supply chain, service feature factors, and the behavioral mix of different members. Qin [19] only studies the contract coordination problem and does not consider the product pricing and order quantity decision-making problems and the service product features. Liu et al. [22] consider logistics service capacity purchasing decisions under the demand uncertainty revelation and quality guarantee change but do not consider the loss-averse behavior of supply chain members.

In this paper, the research will focus on these issues and study service supply chain procurement capabilities in depth. We will build the service capacity purchasing model with a combination of loss aversion behavior to maximize the utility of the LSI and FLSP under demand updating and at a given service level. We obtain the optimal purchase quantity of the LSI and the optimal pricing strategy of the FLSP in different situations and analyze the effects of market demand updating and loss aversion on the optimal decision.

3. Problem description and assumptions

In this paper, we consider a two-echelon LSSC in which an LSI purchases logistics

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service capacity from an FLSP. The LSI is faced with uncertain market demand and updates its demand based on the observed market signals. A uniform distribution can be used in demand updating problems [34], thus our paper supposes that market demand D_0 is uniformly distributed before demand updating, with a cumulative distribution function (CDF) of $F(x)$ and a probability distribution function (PDF) of $f(x)$. At the beginning of the second stage, the LSI observes market signals and updates market demand with a conditional distribution method (the same method used by Iyer and Bergen [25]). The market signal x_e can be thought of as the mean or variance of the demand [18, 34], so market demand D_1 after demand updating is also uniformly distributed (see Wang and Liu [34] for proof), with a CDF of $F(x|x_e)$ and a PDF of $f(x|x_e)$. The LSI must pay a demand updating cost c_I when updating the market demand. c_I is a constant and has nothing to do with the real purchasing quantity, especially when advanced information technology is used [35].

The LSI orders capacity in the first stage instead of procuring all the capacity in the second stage. In this way, buyers can adjust the procurement quantity based on the updated market information to best satisfy the market demand and obtain the most favorable prices for ordering in advance. The FLSP can obtain orders with a certain amount of purchasing quantity. In the first stage, the LSI orders service capacity Q_1 from the FLSP and pays the scheduled cost $w_1 Q_1$ (also the purchasing cost, w_1 is the unit wholesale price in the first stage). $w_1 Q_1$ is a payment to the FLSP to reserve the capacity for the LSI.

To prevent the FLSP from not providing service capacity Q_1 in the second stage, the scheduled cost translates into income for the FLSP once demand has been realized. A similar payment mechanism also exists in Taobao [36]. Additionally, the unit wholesale price in the first and second stage set by the FLSP has a range, similar to Gurnani and Tang [9], so the wholesale price is between (w_l, w_h).

Notice that the cost of using logistics service capacity has two parts, one is the FLSP's unit operation cost c, the other is the service-level guarantee cost. The unit operation cost is the cost under basic service level γ_0, such as the sum of vehicle depreciation and unit fuel costs of transportation. On the basis of γ_0 ($0 \leq \gamma_0 \leq 1$), when customers require a higher service level, the total service level will be increased to $\gamma_0 + \gamma$. The upper limit of the total service level is 1, so $\gamma \leq 1 - \gamma_0$. The additional cost needs to be paid for the increased service level γ, which is called the service-level guarantee cost. The LSI and FLSP must work together to make sure the service reaches a certain level, so they have to share the service-level guarantee cost. Suppose the service-level guarantee cost contribution ratio of the LSI is φ and FLSP $1 - \varphi$, respectively [37]. Thus, the unit service-level guarantee cost is $\rho\varphi\gamma$ for the LSI and $\rho(1-\varphi)\gamma$ for the FLSP. ρ is the coefficient of the service-level guarantee cost.

Our paper considers the effects of the loss-averse preferences of both the LSI and FLSP on supply chain decision making. These loss-averse preferences will be described in Section 4. Here, we make some basic assumptions:

Assumption 1: The FLSP gives the LSI two procurement opportunities. To ensure cooperation between the FLSP and LSI, we introduce a minimum order quantity (MOQ). It is assumed that the LSI's order quantity before demand updating is Q_1, $Q_1 \geq \tau$, where τ is the MOQ before demand updating.

In the manufacturing sector, many manufacturers state their MOQ requirement together with their product information [38]. In the logistics service supply chain, FLSPs will make use of economies of scale when they operate and require that LSIs purchase more than MOQ to reduce the FLSP's marginal cost. The MOQ in the logistics service supply chain refers to the minimum purchase volume of the logistics service capacity. In practice, an FLSP always requires an LSI to order more than the MOQ to decrease the marginal cost and help to achieve economies of scale. For example, in the transportation service, FLSPs provide service with a standard unit of a truckload, container or case [39], which means the MOQ is 1.

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Assumption 2: It is assumed that the FLSP is dominant in the LSSC.

This is very common in logistics service such as the rail transport service. For example, China railway company (CRC), one of the largest state-owned logistics enterprises in China, is an FLSP in the field of railway logistics services. CRC has dominated the service supply chain when it cooperates with other Chinese LSIs, such as S.F. Express and STO. Express [40]. In addition, in other transportation modes, when there are always fewer FLSPs that could offer services to the routes characterized by remote locations, complex operations and difficult delivery of goods, in the practical logistics service, LSI must obey the specific arrangement of FLSPs. Therefore, the FLSP is assumed as the leader and the LSI as the follower [40].

Assumption 3: Under demand updating, to make sure the FLSP has enough capacity, the LSI shares the demand information with the FLSP, but the FLSP cannot arbitrarily manipulate wholesale prices.

The information sharing between the FLSP and the LSI is often used in practice, for example, Chinese Yuantong Express Logistics Company receives demand information from its customer (China Taobao Electronic Commerce) and shares the information with its FLSPs to help the FLSPs prepare sufficient service capacity. What needs to be specified is that the FLSP will not increase wholesale prices arbitrarily. First, notice that the FLSP dominates the LSSC and needs to know demand information. In an LSSC, the LSI is the closest connection to customers and thus has the customer demand information. As a player in the upstream of the LSSC, the FLSP cannot trade with customers downstream directly in practice but has to count on the LSI to receive the demand. Second, the FLSP cannot manipulate the wholesale prices. The LSI's optimal purchasing policy is related to a tradeoff between the loss caused by the mismatch between supply and demand, and the cost of the functional logistics service capacity. An excessive wholesale price set by the FLSP will cause the LSI to decrease the purchase quantity and decrease the purchase cost. Although this may cause an increase in the mismatch loss, the total cost paid by the LSI will still decrease. Third, long-term strategic cooperation is quite important in the supply chain. Even if the FLSP can earn extra short-term profits over the current period by setting excessive wholesale prices, the long-term cooperation with the LSI will be affected negatively, and so will be the FLSP's long-term

profits. Thus, the FLSP cannot arbitrarily manipulate wholesale prices.

According to Assumption 2, Fig. 1 shows the decision-making process for service capacity procurement in an LSSC with demand updating and loss-averse preferences:

Step 1: At $t = 0$, the LSI forecasts market demand and both obtain an increased service level γ and service-level guarantee cost coefficient of ρ. Additionally, the service-level guarantee cost contribution ratio φ is decided after negotiation. The FLSP decides the wholesale price w_1 in the first stage to maximize its utility according to the demand forecast shared by the LSI and gives w_1 to the LSI.

Step 2: The LSI decides the order quantity Q_1 based on demand forecast and wholesale price w_1 in the first stage to maximize its utility. The LSI pays the pre-order cost $w_1 Q_1$, which is the payment to the FLSP to reserve capacity.

Step 3: At $t = 1$, the LSI observes the market signal x_e and received the updated demand distribution $f(x|x_e)$ based on x_e. The LSI shares the market demand after updating the FLSP, and the FLSP decides the wholesale price w_2 in the second stage to maximize its utility and gives w_2 to the LSI.

Step 4: The LSI decides the order quantity q in the second stage based on $f(x|x_e)$ and wholesale price w_2 to maximize its utility. The total ordering quantity of the LSI is Q_2, $Q_2 = Q_1 + q$. The LSI pays the purchasing cost $w_2 q$ for the second stage and the FLSP receives the total revenue $w_1 Q_1 + w_2 q$ for both stages.
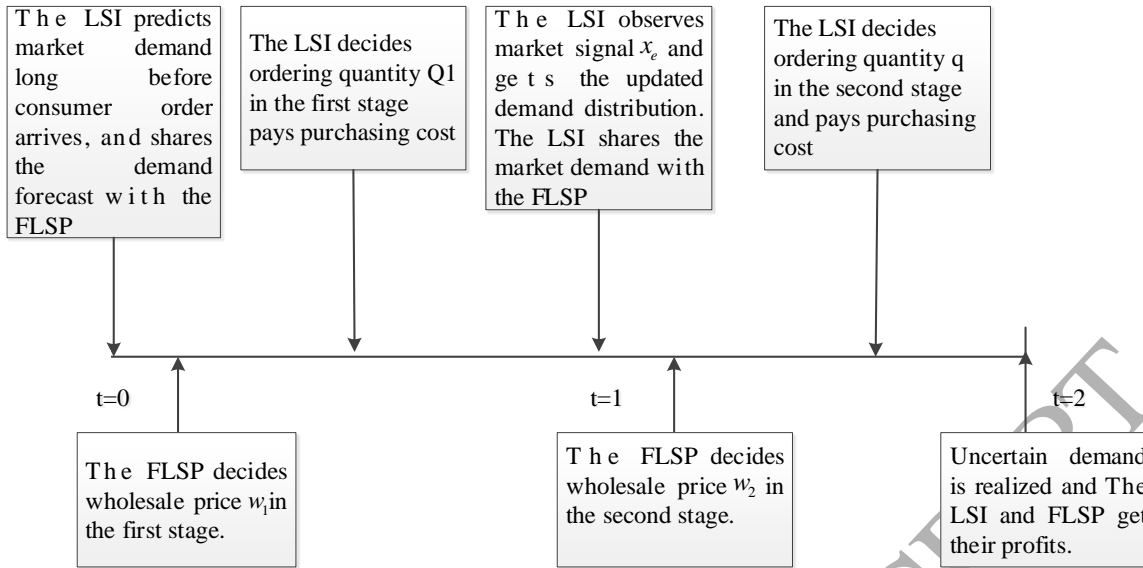
Fig. 1 Process of capacity procurement in an LSSC with demand updating and loss-averse

The decision variables are the LSI's pre-order quantity Q_1 and total order quantity Q_2; the FLSP's wholesale prices in the first and second stages are w_1 and w_2. The notations for the models are summarized in Table 1.

Table 1.   Notations for the models

Parameter	Description
b	The unit stock-out cost of the LSI.
c	The FLSP's unit operation cost (under the basic service level γ_0)
C_I	Demand updating cost paid by the LSI
$f(x)$	Probability distribution function of market demand before demand updating
$F(x)$	Cumulative distribution function of market demand before demand updating
$f(x\|x_e)$	Probability distribution function of market demand after demand updating
$F(x\|x_e)$	Cumulative distribution function of market demand after demand updating
q	The order quantity in the second stage. $q = Q_2 - Q_1 \geq 0$
Q_1	The order quantity of the LSI in the first stage of the basic model. Q_1^i is the order quantity of the LSI in the first stage of scenario i, where $i =$ I , II, III.

Q_{1H} and Q_{1H}^i are the optimal order quantities under $q = 0$; Q_{1L} and Q_{1L}^i are the optimal order quantities under $q > 0$.

Q_2 The total order quantity of the LSI in the basic model. Q_2^i is the total order quantity of the LSI in scenario i, where $i=$ I, II, III. Q_{2H} and Q_{2H}^i are the optimal total order quantities under $q = 0$; Q_{2L} and Q_{2L}^i are the optimal total order quantities under $q > 0$.

w_1 The FLSP's wholesale price before demand updating in the basic model. w_{1H} and w_{1L} are the optimal wholesale prices under $q = 0$ and $q > 0$, respectively. w_1^i is the optimal wholesale price in scenario i, where $i=$ I, II, III.

w_2 The FLSP's wholesale price after demand updating in the basic model. w_2 can be bigger or smaller than w_1. w_{2H} and w_{2L} are the optimal wholesale prices under $q = 0$ and $q > 0$, respectively. w_2^i is the optimal wholesale price in scenario i, where $i=$ I, II, III.

p The constant unit market price p, which is the LSI sells its integrated service to consumers

s The unit income derived from disposing of surplus capacity at the end of the period.

Π_I The LSI's total profit in the two stages. Π_{Ij} is the LSI's profit in stage j. $j \in \{1,2\}$.

$\Delta\Pi_I$ The change in the LSI's profit in the second stage.

Π_V The FLSP's total profit in the two stages. Π_{Vj} is the FLSP's profit in stage j. $j \in \{1,2\}$.

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$\Delta\Pi_V$	The change in the FLSP's profit in the second stage.
U_I	The LSI's total utility in the two stages.
U_V	The FLSP's total utility in the two stages.
θ	The FLSP's loss-averse coefficient.
k	The LSI's loss-averse coefficient.
φ	Service-level guarantee cost contribution ratio
ρ	Service-level guarantee cost coefficient
γ	Increased service level
m	The upper limit of market signal fluctuations

4. Model building

In this section, we consider the loss-averse preferences of the LSI and FLSP in the LSSC and build a basic two-stage Stackelberg game model (Model I) to maximize the supply chain members' utility. Based on the basic model, we also discuss the dynamic pricing strategy of the FLSP in three specific scenarios: only the LSI has a loss-averse preference (scenario I), only the FLSP has a loss-averse preference (scenario II), and neither of them have loss-averse preferences (scenario III). After demand updating, the FLSP will not buy back from the LSI, meaning that the procurement quantity in the second stage is $q = \max(Q_2 - Q_1, 0)$. Thus, our paper only discusses two situations: the LSI purchases service capacity in both stages ($q > 0$), or it only purchases capacity in the first stage ($q = 0$).

4.1 Basic model

4.1.1 Utility functions

(1) The LSI's profit function and utility function

We first consider the profit function. In the first stage, the LSI places a pre-order according to the original market demand. Although the LSI pays the purchasing cost in the first stage, the FLSP does not hand over the logistics service capacity to the LSI. The market

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demand has not yet been realized. Therefore, the LSI has neither received the income from disposing of the surplus capacity nor has it paid the stock-out cost for insufficient integrated service capacity. Furthermore, the LSI only places a pre-order and does not earn real profits in the first stage, so we call it the nominal profit. The function is as follows:

$$\Pi_{I1}(Q_1) = p \min(Q_1, x) - w_1 Q_1 - \rho\varphi\gamma Q_1 \tag{1}$$

In Eq. (1), the first item is the expected revenue, the second item is the purchasing cost in the first stage and the third item is the logistics service level guarantee cost of the LSI in the first stage. It should be noted that the total logistics service level guarantee cost $\rho\gamma Q$ is shared by the LSI and FLSP. In practice, the LSI and FLSP need to work together to meet the customers' service level requirements (such as the transportation time requirement). The FLSP is responsible for controlling the time of the transportation (such as road transport), and the LSI is responsible for the transfer of the different modes of transport, coordinating transport and transit, and providing the FLSP with a real-time customer requirement change.

At the beginning of the second stage, the LSI observes the market signal x_e and gets the updated demand distribution $f(x|x_e)$ based on x_e. Notice that, although x_e is not deterministic, LSI can still obtain deterministic $f(x|x_e)$ by calculation and determine its optimal purchasing quantity based on $f(x|x_e)$. This is explained in Section 3, as we use the conditional distribution method (the same method used by Iyer and Bergen [25]) and the market signal x_e can be thought of as the mean or variance of the demand [18, 34], so the market demand D_1 after demand updating is also uniformly distributed (see Wang and Liu [34] for proof), with a CDF of $F(x|x_e)$ and a PDF of $f(x|x_e)$. After demand updating, the LSI purchases the service capacity for the second time and the FLSP supplies the capacity before the demand realization at the end of the second stage. Thus, the second procurement is the real procurement, which is different from the first procurement. The LSI gains real revenue and its profit function in the second stage is:

$$\Pi_{I2}(Q_2) = p \min(Q_2, x) - w_2(Q_2 - Q_1)^+ - \rho\varphi\gamma(Q_2 - Q_1)^+ - b(x - Q_2)^+ + s(Q_2 - x)^+ - C_I \tag{2}$$

In Eq. (2), the first item is the expected revenue in the second stage, the second item is the purchasing cost in the second stage, where $(Q_2 - Q_1)^+$ is the expected purchasing quantity in the second stage. When the LSI does not purchase in the second stage, $(Q_2 - Q_1)^+ = 0$, otherwise, $(Q_2 - Q_1)^+ = Q_2 - Q_1$. The third item is the logistics service level guarantee cost of the LSI in the second stage, the fourth item is the stock-out cost, the fifth item is the income of disposing of the surplus capacity at the end of the period and the last item is the cost for demand updating.

We can calculate the total profit of the LSI at the end of the period using:

$$\Pi_I(Q_1, Q_2) = p \min(Q_2, x) - (w_1 + \rho\varphi\gamma)Q_1 - (w_2 + \rho\varphi\gamma)(Q_2 - Q_1)^+ - b(x - Q_2)^+ + s(Q_2 - x)^+ - C_I \quad (3)$$

Next, we calculate the utility function of the LSI when it has a loss-averse preference.

In Eq. (3), the first item is the expected revenue in the second stage, the second item is the purchasing cost and the logistics service level guarantee cost of the LSI in the first stage, the third item is the purchasing cost and the logistics service level guarantee cost of the LSI in the second stage, the fourth item is the stock-out cost, the fifth item is the income of disposing of the surplus capacity at the end of the period and the last item is the cost for demand updating.

According to dynamic reference introduced by Popescu and Wu [30], the customers' expected price in the current period is affected by the real price in the previous period, which is the dynamic reference point. Some scholars also use profits as reference points [19, 41]. For example, Qin [19] proposes that the utility function expression of loss aversion is $U(W) = \begin{cases} W - W_0, W \geq W_0 \\ \lambda(W - W_0), W < W_0 \end{cases}$, W_0 and W are the supplier's reference level (e.g., his initial wealth) at the beginning of the selling season and profit, respectively, λ is loss aversion coefficient. Similarly, in this paper, loss-averse preference of the LSI causes the LSI's utility in the current stage to be affected by that in the previous stage. A similar effect also happens to the FLSP. Thus, here we consider the LSI's profit in the previous stage to be the reference point of the current stage. In the first stage, the LSI does not have a reference point and thus shows no loss-averse preference. After demand updating, the LSI considers its nominal profit in the first stage to be the reference point to assess its real profit in the second stage and the

utility caused by the loss-averse preference is shown in the linear loss-averse utility function:

$$\Delta U_I = k\Delta\Pi_I = k\left(\Pi_{I2}(Q_2) - \Pi_{I1}(Q_1)\right) \tag{4}$$

In Eq. (4), k is the LSI's loss-averse coefficient. The loss-averse preference makes the LSI more sensitive to loss than to gain. Thus, when the LSI gains a higher profit in the second stage than that in the first stage, it has positive utility, and $0 < k < 1$. When the LSI gains a lower profit in the second stage than that in the first stage, it has negative utility and $k > 1$, the larger the loss-averse coefficient k, the higher the LSI's loss-averse level [19]. When the LSI's profit in the second stage is equal to that in the first stage, it has no utility and $k = 0$.

The utility of the LSI in the second stage consists of two parts: the LSI's profit in the second stage, and its utility tied to its change in profit. Thus, the utility in the second stage is:

$$U_{I2}(Q_2) = \Pi_{I2}(Q_2) + k\Delta\Pi_I \tag{5}$$

Similarly, the total utility gained by the LSI after demand is realized also consists of two parts, the total profit and the utility tied to the change in profit:

$$U_I(Q_1, Q_2) = \Pi_I(Q_1, Q_2) + k\Delta\Pi_I \tag{6}$$

It should be noted that the utility functions of the LSI and FLSP are separable because of the reference point effect. Thus, the model in this paper will be solved by using backward induction.

(2) The FLSP's profit function and utility function

First, we calculate the profit function of the FLSP. In the first stage, the FLSP does not deliver service capacity to the LSI and does not earn real profit. The FLSP only gains nominal profit:

$$\Pi_{V1}(w_1) = Q_1\left(w_1 - \rho(1-\varphi)\gamma - c\right) \tag{7}$$

In Eq.(7), $Q_1 w_1$ is the nominal revenue in the first stage, $Q_1\rho(1-\varphi)\gamma$ is the service-level guarantee cost of the FLSP, $Q_1 c$ is the operation cost of the FLSP. Notice that the operation cost is paid by the FLSP to use its service capacity, while the service-level guarantee cost is an extra cost paid for the increased service level. The FLSP has to reserve the service capacity and will use it in the second stage. For ease of calculation, we assume that the FLSP pays the cost in the first stage.

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The real profit gained by the FLSP in the second stage is:

$$\Pi_{V2}(w_2) = Q_1 w_1 + (Q_2 - Q_1)^+ (w_2 - \rho(1-\varphi)\gamma - c) \tag{8}$$

In Eq.(8), $Q_1 w_1 + (Q_2 - Q_1)^+ w_2$ is the revenue in the second stage, $(Q_2 - Q_1)^+ c$ is the cost for using capacity in the second stage, $(Q_2 - Q_1)^+ \rho(1-\varphi)\gamma$ is the service-level guarantee cost in the second stage.

The total profit of the FLSP is:

$$\Pi_V(w_1, w_2) = (w_1 - \rho(1-\varphi)\gamma - c)Q_1 + (Q_2 - Q_1)^+ (w_2 - \rho(1-\varphi)\gamma - c) \tag{9}$$

Next, we calculate the utility function of the FLSP. In the first stage, similar to the LSI, the FLSP's utility function is equal to its profit function.

In the second stage, the change in profit is:

$$\Delta\Pi_V = \Pi_{V2}(w_2) - \Pi_{V1}(w_1) = [\rho(1-\varphi)\gamma + c]Q_1 + (Q_2 - Q_1)^+ (w_2 - \rho(1-\varphi)\gamma - c) > 0 \tag{10}$$

The utility tied to the change in profit is:

$$\Delta U_V = \theta \Delta\Pi_V \tag{11}$$

where $0 < \theta < 1$. Here, θ will not be greater than 1, because the LSI's order quantity in the second stage is $q \geq 0$ and the FLSP's profit in the second stage cannot be smaller than that in the first stage.

The utility function of the FLSP in the second stage is:

$$U_{V2}(w_2) = \Pi_{V2}(w_2) + \theta\Delta\Pi_V \tag{12}$$

Similarly, the total utility gained by the FLSP after the demand is realized consists of two parts: the total profit and the utility tied to the change in profit.

$$U_V(w_1, w_2) = \Pi_V(w_1, w_2) + \theta\Delta\Pi_V \tag{13}$$

4.1.2 Optimal procurement strategies in the second stage

In this section, we use backward induction to solve the model. Accordingly, in Section 4.1.2, we attempt to determine the optimal solution of the LSI and FLSP in the second stage. According to Assumption 3, the FLSP is the leader and the LSI is the follower. We used the Stackelberg solution approach to solve the model. In practice, the order of decision making in the LSSC is: the FLSP first determines the wholesale price of service capacity, and then the

LSI determines the purchase volume according to the wholesale price and market demand.

For LSI, according to Assumption 3, we first determine the optimal total purchasing quantity Q_2. When $Q_1 = Q_2$, the LSI does not purchase service capacity in the second stage. Thus, we only consider the situation of $Q_1 < Q_2$.

The LSI's utility in the second stage is:

$$U_{I2}(Q_2) = \Pi_{I2} + k\Delta\Pi_I$$

For FLSP, when $Q_1 = Q_2$, the LSI does not purchase service capacity in the second stage, thus the actual profit of the FLSP in the second stage equals to its nominal profit in the first stage.

$$\Pi_{V_2} = Q_1 w_1$$

The FLSP's utility in the second stage is:

$$U_{V2} = \Pi_{V2} + \theta\Delta\Pi_V$$
$$= Q_1 w_1 + \theta Q_1 \left[c + \rho(1-\varphi)\gamma \right]$$

The FLSP's utility in the second stage is independent of w_2. According to assumption 2, w_2 can be an arbitrary value which satisfies:

$$w_{2H} \in (w_l, w_h)$$

When $Q_1 < Q_2$, the actual profit of the FLSP in the second stage is:

$$\Pi_{V2}(w_2) = Q_1 w_1 + (Q_2 - Q_1)(w_2 - \rho(1-\varphi)\gamma - c)$$

The FLSP's utility in the second stage is:

$$U_{V2}(w_2) = (1+\theta)(Q_1 w_1 + (Q_2 - Q_1)(w_2 - \rho(1-\varphi)\gamma)) + \theta Q_1(w_1 - \rho(1-\varphi)\gamma)$$

After derivation and calculation, we obtain the optimal solutions of LSI and FLSP in the second stage, as shown in Proposition 1.

Proposition 1: In the second stage, the optimal solution of the LSI is: when $Q_1 < Q_2$, then

$Q_{2L} = F^{-1}(\dfrac{p+b-w_2-\rho\varphi\gamma}{p+b-s} \mid x_e)$. And the optimal solution of the FLSP is: when $Q_1 = Q_2$,

then $w_{2H} \in (w_l, w_h)$; when $Q_1 < Q_2$, then $w_{2L} = (Q_{2L} - Q_{1L})f(x \mid x_e)(p+b-s) + \rho(1-\varphi)\gamma$.

The proof of Proposition 1 is shown in Appendix A.

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4.1.3 Optimal procurement strategies in the first stage

Section 4.1.3 will attempt to determine the optimal solutions of the LSI and FLSP in the first stage.

For LSI, when $Q_1 = Q_2$, the total utility of the LSI is:

$$U_I(Q_1) = (1+k)(p \min(Q_1, x) - b(x - Q_1)^+ + s(Q_1 - x)^+ - c_I)$$
$$+ (k-1)(w_1 + \rho\varphi\gamma)Q_1 - kp \min(Q_1, y)$$

And when $Q_1 < Q_2$, the total utility of the LSI is:

$$U_I(Q_1, Q_{2L}) = (1+k)(p \min(Q_2, x) - (w_2 + \rho\varphi\gamma)(Q_2 - Q_1) - b(x - Q_2)^+ + s(Q_2 - x)^+ - c_I)$$
$$+ (k-1)(w_1 + \rho\varphi\gamma)Q_1 - kp \min(Q_1, y)$$

For FLSP, when $Q_1 = Q_2$, the total utility of the FLSP is:

$$U_V = Q_1 w_1 + (\theta - 1)Q_1 \left[\rho(1-\varphi)\gamma + c\right]$$

When $Q_1 < Q_2$, the total utility of the FLSP is:

$$U_V(w_1, w_2) = Q_1 w_1 + (1+\theta)(Q_2 - Q_1)(w_2 - \rho(1-\varphi)\gamma) + \theta Q_1 \rho(1-\varphi)\gamma$$

After derivation and calculation, we obtain the optimal solutions of LSI and FLSP in the first stage, as shown in Proposition 2. The proof is shown in Appendix B.

Proposition 2: In the first stage, the optimal solution of the LSI is: when $Q_1 = Q_2$, then

$$Q_{1H} = F^{-1}(\frac{(1+k)(p+b) - (k-1)(w_1 + \rho\varphi\gamma) - kp(1 - F(Q_{1H}))}{(1+k)(p+b-s)} | x_e) \;; \quad \text{when} \quad Q_1 < Q_2 \;, \quad \text{then}$$

$Q_{1L} = \tau$, τ is MOQ. And the optimal solution of the FLSP is: when $Q_1 = Q_2$, if $k < 1$, then

$w_{1H} = w_h$, if $k > 1$, then $w_{1H} = Q_{1H} \frac{(1+k)(p+b-s)f(x|x_e) - kpf(x)}{k-1} + (1-\theta)\rho(1-\varphi)\gamma$.

When $Q_1 < Q_2$, then $w_{1L} = w_h$.

4.2 Special cases of the basic model

We have studied the optimal strategies when both the LSI and FLSP have loss aversion preferences. However, in practice, there are situations where only one side has a loss aversion preference or neither side has a loss aversion preference.

For example, in the cooperation between China Railway Company (CRC) and S.F. Express, CRC is the FLSP in the field of railway logistics services and S.F. Express is the LSI. In July 2014, they began their cooperation by launching special e-commerce trains operating on the existing Shanghai–Shenzhen, Beijing–Guangzhou and Beijing–Shanghai railway lines. The special trains were contracted to S.F. Express [40]. As a state-owned sole proprietorship managed by the central government, CRC provided the diversified services such as passenger and freight transport services, national railway network construction and import and export business, and does not pay much attention to managing its logistics business in these three lines, which only accounts for a small part of its annual sales. Thus, CRC does not have a loss aversion preference in the cooperation with S.F. Express. However, for S.F. Express, the Shanghai–Shenzhen, Beijing–Guangzhou and Beijing–Shanghai lines are important and valuable lines. Accordingly, S.F. Express tries to avoid losses on these lines. In this situation, the two players are a loss averse LSI and non-loss averse FLSP.

In the case of Tianjin SND Logistics Company, a professional LSI, and its FLSPs, the LSI does not have a loss aversion preference, while the FLSPs do have a loss aversion preference. The FLSPs can dominate the supply chain in the situation where there are fewer providers that offer service to the routes characterized by remote locations, complex operations and difficult delivery of goods, such as Tianjin-Henan. The services of remote locations only account for a small part of SND's total services, however, these services are of vital importance to the FLSPs, as these FLSPs are small local providers. Thus, the FLSPs are highly loss averse, while Tianjin SND Logistics Company is loss neutral.

There is also a case where both the LSI and the FLSP are loss neutral. China Post Group Corporation (CPGC) is a state-owned FLSP company with a history of more than 120 years of providing common postal services and commercialize competitive postal services. In November 2017, CPGC and CRC signed a strategic cooperation agreement in Beijing. They established a long-term new type of strategic partnership to take advantage of their abundant resources in terms of logistics, information, finance and capital. They achieved convergence and expansion of their business by integrating CRC's railway transport capacity with CPGC's terminal delivery capability. Both CRC and CPGC are large enterprises with standardized and scientific decision-making processes. Thus, they do not have a loss aversion preference in their

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cooperation.

According to the three situations above, this section will determine the LSI's optimal purchasing strategies and the FLSP's optimal pricing strategies when one or both sides do not have loss-averse preferences. This section expands the basic model to three specific scenarios: Scenario I, where the LSI has a loss-averse preference, but the FLSP does not ($\theta = 0$); Scenario II, where the FLSP has a loss-averse preference ($k = 0$), but the LSI does not; Scenario III where neither the LSI nor the FLSP have loss-averse preferences ($\theta = 0, k = 0$). As is operated in practice, after demand updating, the FLSP will not buy back from the LSI, meaning that the procurement quantity in the second stage is $q = \max(Q_2 - Q_1, 0)$. Thus, our paper only discusses two situations: the LSI purchases service capacity in both stages ($q > 0$), or it only purchases capacity in the first stage ($q = 0$). As the solving methods in special cases are the same as that in the basic model, we omitted the solving process and directly conclude the optimal decisions in Table 2 and 3. From Table 2 and Table 3, we find that in each case, the LSI and the FLSP can choose $q_2 = 0$ or $q_2 > 0$. The two choices and their optimal procurement and pricing are sufficient and necessary. That is, when the LSI and the FLSP make an optimal decision in the first stage, if the LSI purchases more capacity in the second stage or not has been decided.

Table 2 Comparison of the LSI's procurement strategies for the basic model and three special scenarios

		Q_1	Q_2
Basic Model	$q > 0$	$Q_{1L} = \tau$	$Q_{2L} = F^{-1}(\dfrac{p+b-w_2-\rho\varphi\gamma}{p+b-s}\mid x_e)$
	$q = 0$	$Q_{1H} = F^{-1}\left(\dfrac{(1+k)(p+b)-(k-1)(w_1+\rho\varphi\gamma)-kp(1-F(Q_{1H}))}{(1+k)(p+b-s)}\mid x_e\right)$	$Q_{2H} = Q_{1H}$
Scenario I	$q > 0$	$Q_{1L}^{I} = \tau$	$Q_{2L}^{I} = F^{-1}(\dfrac{p+b-w_2^{I}-\rho\varphi\gamma}{p+b-s}\mid x_e)$
	$q = 0$	$Q_{1H}^{I} = F^{-1}\left(\dfrac{(1+k)(p+b)-(k-1)(w_1^{I}+\rho\varphi\gamma)-kp(1-F(Q_{1H}^{I}))}{(1+k)(p+b-s)}\mid x_e\right)$	$Q_{2H}^{I} = Q_{1H}^{I}$
Scenario II	$q > 0$	$Q_{1L}^{II} = \tau$	$Q_{2L}^{II} = F^{-1}(\dfrac{p+b-w_2^{II}-\rho\varphi\gamma}{p+b-s}\mid x_e)$
	$q = 0$	$Q_{1H}^{II} = F^{-1}(\dfrac{p+b-w_1^{II}-\rho\varphi\gamma}{p+b-s}\mid x_e)$	$Q_{2H}^{II} = Q_{1H}^{II}$
Scenario III	$q > 0$	$Q_{1L}^{III} = \tau$	$Q_{2L}^{III} = F^{-1}(\dfrac{p+b-w_2^{III}-\rho\varphi\gamma}{p+b-s}\mid x_e)$
	$q = 0$	$Q_{1H}^{III} = F^{-1}(\dfrac{p+b-w_1^{III}-\rho\varphi\gamma}{p+b-s}\mid x_e)$	$Q_{2H}^{III} = Q_{1H}^{III}$

Table 3 Comparison of the FLSP's pricing strategies for the basic model and three special scenarios

		w_1	w_2
Basic Model	$q > 0$	$w_{1L} = w_h$	$w_{2L} = (Q_{2L} - Q_{1L}) f(x \mid x_e)(p+b-s) + \rho(1-\varphi)\gamma + c$
	$q = 0$ $g(k) < 1$	$w_{1H} = w_h$	$w_{2H} \in (w_l, w_h)$
	$q = 0$ $g(k) > 1$	$w_{1H} = Q_{1H} \dfrac{(1+k)(p+b-s)f(x\mid x_e) - kpf(x)}{k-1} + (1-\theta)\big(\rho(1-\varphi)\gamma + c\big)$	
Scenario I	$q > 0$	$w_{1L}^{\mathrm{I}} = w_h$	$w_{2L}^{\mathrm{I}} = (Q_{2L}^{\mathrm{I}} - Q_{1L}^{\mathrm{I}}) f(x \mid x_e)(p+b-s) + \rho(1-\varphi)\gamma + c$
	$q = 0$ $g(k) < 1$	$w_{1H}^{\mathrm{I}} = w_h$	$w_{2H}^{\mathrm{I}} \in (w_l, w_h)$
	$q = 0$ $g(k) > 1$	$w_{1H}^{\mathrm{I}} = Q_{1H}^{\mathrm{I}} \dfrac{(1+k)(p+b-s)f(x\mid x_e) - kpf(x)}{k-1} + \rho(1-\varphi)\gamma + c$	
Scenario II	$q > 0$	$w_{1L}^{\mathrm{II}} = w_h$	$w_{2L}^{\mathrm{II}} = (Q_{2L}^{\mathrm{II}} - \tau) f(x \mid x_e)(p+b-s) + \rho(1-\varphi)\gamma + c$
	$q = 0$	$w_{1H}^{II} = Q_{1H}^{II}(p+b-s)f(x \mid x_e) + (1-\theta)\big(\rho(1-\theta)\gamma + c\big)$	$w_{2H}^{\mathrm{II}} \in (w_l, w_h)$
Scenario III	$q > 0$	$w_{1L}^{\mathrm{III}} = w_h$	$w_{2L}^{\mathrm{III}} = (Q_{2L}^{\mathrm{III}} - \tau) f(x \mid x_e)(p+b-s) + \rho(1-\varphi)\gamma + c$
	$q = 0$	$w_{1H}^{\mathrm{III}} = Q_{1H}^{\mathrm{III}}(p+b-s)f\big(x \mid x_e\big) + \rho(1-\varphi)\gamma + c$	$w_{2H}^{\mathrm{III}} \in (w_l, w_h)$

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5. Discussion

5.1 The impacts of loss-averse on pricing and order quantity

5.1.1 The impacts of the LSI's loss-averse preference

Different conditions influence the impact of the LSI's loss-averse preference on the supply chain members' decision making. In this section, we discuss the conditions under which the LSI's loss-averse preference can affect supply chain decisions and the nature of that effect.

Theorem 1: *When $q > 0$, in comparing the basic model and scenarios I–III, we get:*

$$Q_{1L} = Q_{1L}^{\mathrm{I}} = Q_{1L}^{\mathrm{II}} = Q_{1L}^{\mathrm{III}}; \quad Q_{2L} = Q_{2L}^{\mathrm{I}} = Q_{2L}^{\mathrm{II}} = Q_{2L}^{\mathrm{III}}$$
$$w_{1L} = w_{1L}^{\mathrm{I}} = w_{1L}^{\mathrm{II}} = w_{1L}^{\mathrm{III}}; \quad w_{2L} = w_{2L}^{\mathrm{I}} = w_{2L}^{\mathrm{II}} = w_{2L}^{\mathrm{III}}$$

The proof is shown in Appendix C.

Theorem 1 shows that, when the LSI purchases service capacity in both stages, the LSI's loss-averse preference does not affect the LSI's optimal purchasing quantities and the FLSP's optimal wholesale prices. This may be because the LSI chooses to buy, in both stages, when the future demand is bullish, loss aversion preference brings positive benefits to the LSI and FLSP and thus does not impact optimal decisions.

Theorem 2: *Under the condition of $q = 0$, when:*

$$2\rho\gamma > -\tau k p f(x) + k p(1 - F(\tau))$$

is satisfied, then: $Q_{1H}^{\mathrm{I}} > Q_{1H}^{\mathrm{III}}$

The proof is shown in Appendix D.

Theorem 2 shows that when the LSI only purchases service ability in the first stage, under the appropriate conditions, the loss aversion of the LSI will cause the LSI's total purchasing quantity to increase. Therefore, for the loss-averse integrator

who buys only in the first stage, the total purchase quantity should be appropriately increased to obtain the best procurement effect.

Theorem 3: *Under the condition of* $q = 0$,

if $k < 1$,

$$w_{1H}^{I} > w_{1H}^{III}$$

if $k > 1$, *and the condition in Theorem 2 and*

$$kpf(x) + (2-k)(p+b-s)f(x|x_e) < 0$$

are all satisfied, then $w_{1H}^{I} < w_{1H}^{III}$.

The proof is shown in Appendix E.

Theorem 3 demonstrates the effects of the LSI's loss aversion preference when the FLSP is loss neutral. It shows that the LSI can benefit from its own loss aversion preference when $q = 0$. Theorems 2 and 3 demonstrate that, when the FLSP does not have a loss-averse preference, the loss-averse preference of an LSI that only purchases in the first stage can increase the LSI's order quantity and make the FLSP set a lower price. Under this condition, therefore, loss-averse preferences are beneficial to the LSI. The FLSP can also make use of the LSI's loss-averse preference to set a higher price when $q = 0$ and $k < 1$.

5.1.2 The impacts of the FLSP's loss-averse preference

From Theorem 1 we find that:

$$Q_{1L} = Q_{1L}^{I} \qquad Q_{2L} = Q_{2L}^{I} \qquad w_{1L} = w_{1L}^{I} \qquad w_{2L} = w_{2L}^{I}$$
$$Q_{1L}^{II} = Q_{1L}^{III} \qquad Q_{2L}^{II} = Q_{2L}^{III} \qquad w_{1L}^{II} = w_{1L}^{III} \qquad w_{2L}^{II} = w_{2L}^{III}$$

Thus, when $q > 0$, the loss-averse preference of the FLSP has no effect on the LSI's procurement strategy or on the FLSP's pricing strategy.

Furthermore, when $q = 0$ and $k < 1$, the FLSP's loss-averse preference cannot affect supply chain decisions, as: $w_{1H} = w_{1H}^{I} = w_h \quad and \quad Q_{1H} = Q_{1H}^{I}$.

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We can conclude that the effects of the FLSP's loss-averse preference are limited. However, the FLSP's loss-averse preference can affect the supply chain members' decision making under certain conditions.

Theorem 4: *When* $q = 0$ *and* $k > 1$,

$$Q_{1H} < \overset{\cdot}{Q}_{1H} \qquad w_{1H} > w_{1H}^{\mathrm{I}}$$

and

$$Q_{1H}^{\mathrm{II}} < Q_{1H}^{\mathrm{III}} \qquad w_{1H}^{\mathrm{II}} > w_{1H}^{\mathrm{III}}$$

Theorem 4 shows that when the LSI only purchases in the first stage, the FLSP's loss-averse preference will affect the decisions of the supply chain members, regardless of whether or not the LSI has a loss-averse preference. To be specific, the FLSP's loss-averse preference causes the wholesale price to increase and the order quantity to decrease in stage one. It should be noted that the LSI's loss aversion coefficient $k > 1$ indicates that the profit of the LSI' in the second stage is less than the profit in the first stage, and the LSI has negative utility. As a result, the FLSP's loss aversion at this time has a negative impact on the LSI's utility. In addition, the LSI's purchasing quantity decreases due to the loss aversion preference of the FLSP. Accordingly, the FLSP should note when its loss-averse preference affects the supply chain decision making, and adjust its pricing strategy accordingly. A similar study is also mentioned in Özer et al. [42]. Özer et al. [42] studied the effect of risk aversion on manufacturing firms in the production supply chain and found that the risk-averse coefficient will affect the manufacturer's choice of contract and increase the advance purchase quantity and, hence, reduce the profit volatility. A manufacturer with higher risk aversion offers a greater discount.

Overall, the loss-averse preference of the LSI can more easily affect supply chain decision making than that of the FLSP.

Theorem 4 can be proven with a method similar to that found in Appendix F.

5.2 The impacts of service level parameters on pricing and order

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quantity

Theorem 5: *When the FLSP does not have a loss-averse preference,*

(1) The LSI's total order quantity decreases with increased service level γ ;

(2) When $0 < \varphi < \dfrac{1}{2}$: If $q = 0$, the wholesale price in the first stage increases with the increased service level γ (when the LSI has loss-averse preference and $k > 1$); If $q > 0$, the wholesale price in the second stage increases with the increase in service level γ .

Theorem 5 can be easily understood. For the LSI, the increase in γ will increase its cost and decrease its total order quantity. When $0 < \varphi < \dfrac{1}{2}$, the LSI pays a small portion of the logistics service-level guarantee cost, while the FLSP pays most of the cost. Thus, the increase in γ will cause the FLSP's wholesale price to increase. Theorem 5 also indicates that when $\varphi > \dfrac{1}{2}$, the FLSP's wholesale price decreases with the logistics service-level. As the LSI's total order quantity also decreases with the service level, the FLSP's profit will decrease when $\varphi > \dfrac{1}{2}$. As a result, when $q = 0$, a service-level guarantee cost contribution ratio $0 < \varphi < \dfrac{1}{2}$ is more beneficial to the FLSP.

Theorem 5 can be proven in Appendix F.

Theorem 6: *When the FLSP has a loss-averse preference*

(1) The LSI's total order quantity decreases with the increased service level γ ;

(2) If $q = 0$ and $-\varphi + (1 - \theta)(1 - \varphi) > 0$, the wholesale price in the first stage increases with the increased service level γ (when the LSI has a loss-averse preference and $k > 1$).

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(3) If $q > 0$ and $0 < \varphi < \dfrac{1}{2}$, the wholesale price in the second stage increases with the increased service level γ.

Theorems 5 and 6 demonstrate that the increased service level can affect the LSI's procurement strategy. However, this effect has nothing to do with the loss averse preference of the LSI and FLSP. The increased service level can affect the FLSP's pricing strategy under certain conditions. This effect depends not on the LSI, but on whether the FLSP has a loss-averse preference. Thus, both sides should pay attention to the contribution ratio of the logistics service-level guarantee cost, which can affect the costs for both sides and the FLSP's pricing.

In summary, in this section, we analyze the impacts of LSI and FLSP's loss-averse on pricing and order quantity, and the impacts of service level parameters on pricing and order quantity. Although there are some related studies taking market demand updating and loss-averse preference into consideration, such as Ma et al. [18] and Qin [19], Ma et al. [18] did not consider the properties of service and the combination of supply chain members' loss aversion preferences. Qin [19] focused on coordinating the supply chain. This paper is different from them. We more focus on the impact of loss-averse preference and service level on the decision-making of supply chain members in the service supply chain. With the comparisons mentioned above, the comprehensive impacts are generated which are not shown in previous literature.

6. Numerical analysis

Tables 2 and 3 show the optimal purchasing quantities and optimal wholesale prices when supply chain members use two different types of strategies ($q > 0$ and $q = 0$). However, we have not proven whether the optimal purchasing quantities Q_1 and Q_2 satisfy the relationship above. In this section, we use Matlab 2018R to conduct a numerical analysis to verify the existence of the LSI's and FLSP's optimal

strategy, and explore some other conclusions.

Based on the method of numerical analysis used by Wang and Liu [34], we assume that the demand before updating is uniformly distributed and $F \sim U(\alpha_0, \beta_0)$. Suppose that market signal x_e is the mean and the CDF of market signal x_e is $G(\cdot)$, $G \sim U(0, m)$. m is the upper limit of market signal x_e fluctuations. In practice, there are many ways for the LSI to obtain market signals. For example, in October of each year, Yuantong Express, the Chinese LSI mentioned in the section of the introduction, puts the initial order to the FLSP according to the market demand prediction prepared for the Singles' Day. From October to November, Taobao customers continue to book, purchase and change their orders, and the market demand for logistics services also keeps changing. Taobao will share the updated demand information with Yuantong Express. Demand updating cannot change the distribution pattern of the market demand, which means that after updating, the demand is also uniformly distributed and $F \sim U(\alpha_1, \beta_1)$. According to Wang and Liu [34], $\alpha_1 = \alpha_0 - 4(0.5m - x_e)$ $\beta_1 = \beta_0 - 4(0.5m - x_e)$ and the LSI and the FLSP make decisions according to the newly updated demand. Similar to Wang and Liu [34], we set the basic parameters as: demand parameters $\alpha_0 = 1000$, $\beta_0 = 3000$, $\tau = 800$, demand updating cost paid by the LSI $C_l = 25$, market price of the integrated logistics service provided $p = 60$, unit salvage of unsold service capacity $s = 10$, unit stock-out costs for the LSI $b = 5$, unit operation cost for the FLSP $c = 10$, service-level guarantee cost coefficient $\rho = 10$, service-level guarantee cost contribution ratio $\varphi = 0.2$, basic service level $\gamma_0 = 0.2$, increased service level $\gamma = 0.75$, lower limit of wholesale price $w_l = 10$, upper limit of wholesale price $w_h = 45$, market signal parameter $m = 500$.

6.1 The LSI has two types of purchasing strategies

In this section, we prove that the LSI has two types of purchasing strategies. It can purchase service capacity only in the first stage or in both stages with different demand updates.

Fig. 2 shows the LSI's utility in the basic model. Based on our parameter setting, when $q > 0$, the LSI can make more profit in the second stage and $k = 0.7$; when $q = 0$, the LSI makes more profit in the first stage and $k = 3.1$. Fig. 2 shows that the optimal decision changes with market signal x_e. The LSI should not take the second purchasing opportunity, instead, should purchase all service capacity in the first stage when $x_e < 370$. If the market signal is quite large, such as $x_e > 370$, the LSI should purchase more capacity in the second stage.
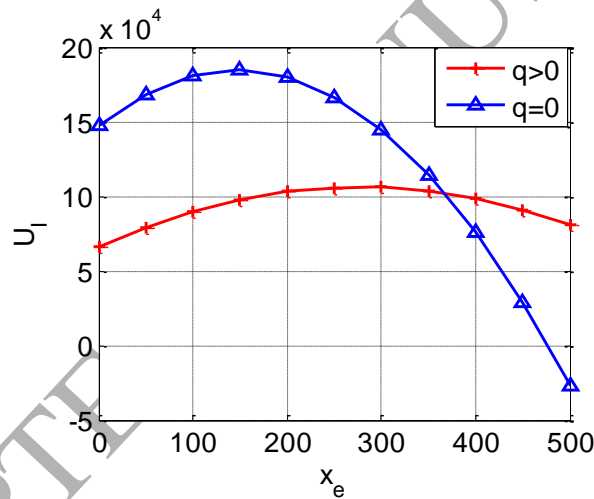
Fig. 2 Utility function of the LSI in the Basic Model, $\theta = 0.7$

Fig. 3-6 show the LSI's optimal choice when the FLSP does not have a loss-averse preference, when the LSI does not have a loss-averse preference and when neither of them have loss-averse preferences.
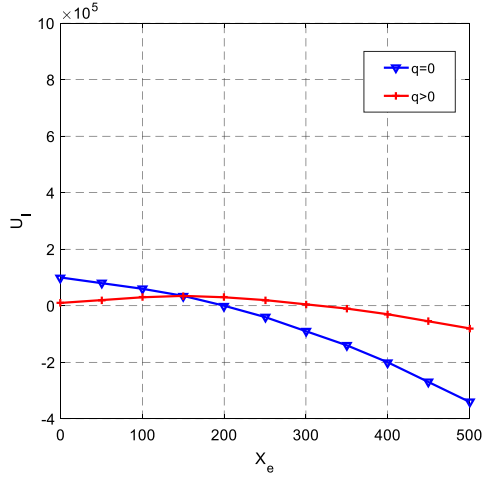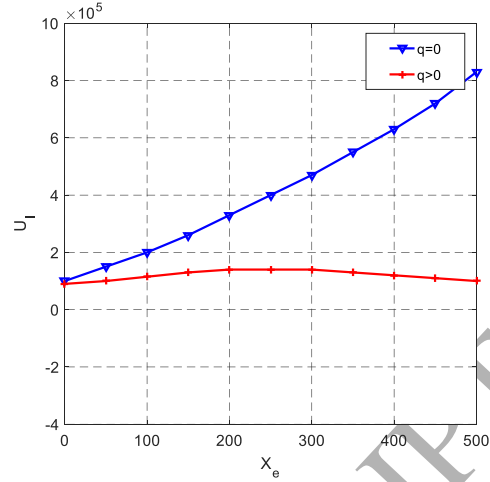
Fig. 3 Utility function of the LSI in
Scenario I, k =1.9

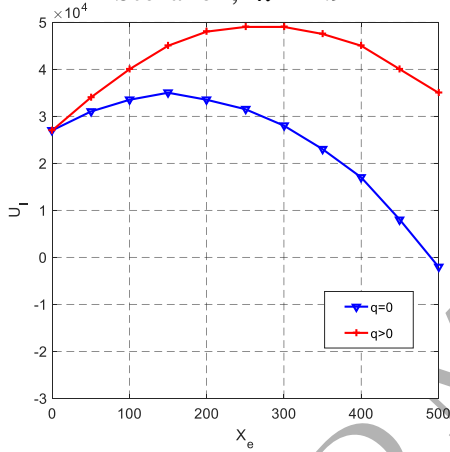Fig. 4 Utility function of the LSI in
Scenario I, k =0.95

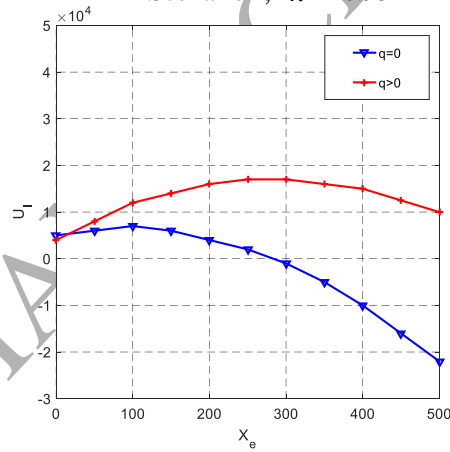Fig. 5 Utility function of the LSI in
Scenario II, θ =0.27

Fig. 6 Utility function of the LSI in
Scenario III

From Fig. 2 to Fig. 6, we find that the LSI's optimal strategy changes with the market signal x_e. By comparing Fig. 5 and Fig. 6, we find that when the LSI does not have a loss-averse preference, the loss-averse preference of the FLSP can bring higher utility to the LSI. Comparing Fig. 6 with Fig. 3, when FLSP does not have a loss-averse preference, the LSI's utility increases if the loss-averse coefficient $k > 1$, $x_e \leq 150$ and the LSI purchases capacity in the second stage, the LSI's utility decreases if the loss-averse coefficient $k > 1$, $x_e \geq 150$ and the LSI gives up the second purchasing opportunity. Comparing Fig. 6 with Fig. 4, the LSI's utility increases if $k < 1$ and the LSI only purchases capacity in the first stage. Thus, Theorems 2 and 3 are verified. By comparing Fig. 6 with Fig. 2, we find that the LSI can benefit from loss-averse preferences of the LSI and FLSP, as its utility increases

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greatly.

6.2 The FLSP has two types of pricing strategies

In this section, we numerically show that the FLSP has two types of pricing strategies. In practice, the FLSP always makes pricing strategies before the LSI places an order, thus the FLSP sets the wholesale prices to make the LSI purchase service capacity only in the first stage or in both stages.

Figs. 7-8 show the FLSP's utility in the Basic Model, and when both the LSI and FLSP have loss-averse preferences, the value of the LSI's loss-averse coefficient k has a great effect on the FLSP's optimal strategies. If $k > 1$, the FLSP should set a high wholesale price in the first stage to motivate the LSI to take the second purchasing opportunity. Otherwise, the FLSP should make the LSI purchase only in the first stage by setting a relatively low first stage wholesale price compared to that when $k > 1$.
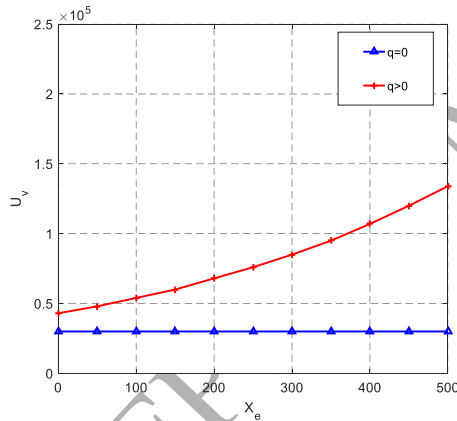

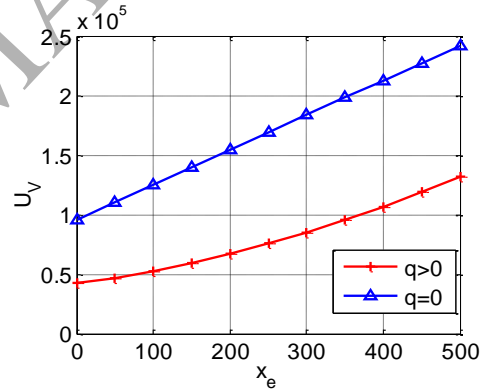Fig. 7 Utility function of the FLSP in the Basic Model, $k = 3.1$, $\theta = 0.7$

Fig. 8 Utility function of the FLSP in the Basic Model, $k = 0.7$, $\theta = 0.7$

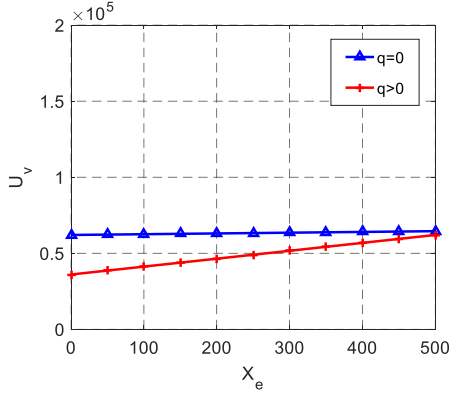Fig. 9-12 show the FLSP's optimal choice in Scenarios I to III.

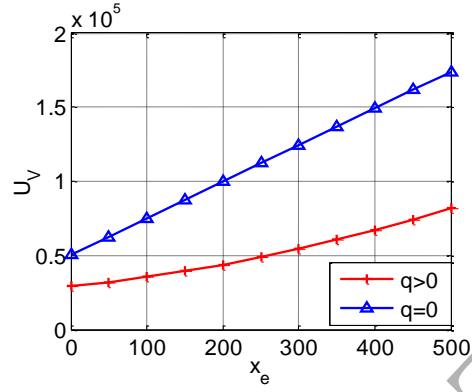Fig. 9 Utility function of the FLSP in Scenario I, k =1.9

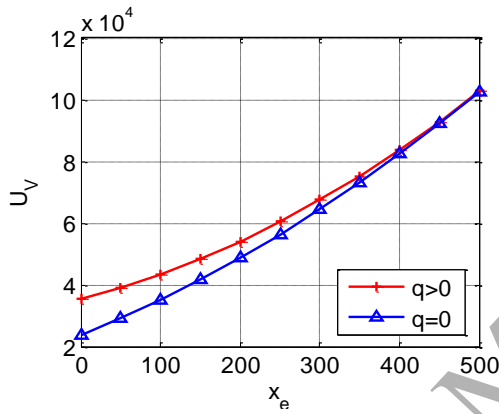Fig. 10 Utility function of the FLSP in Scenario I, k =0.95

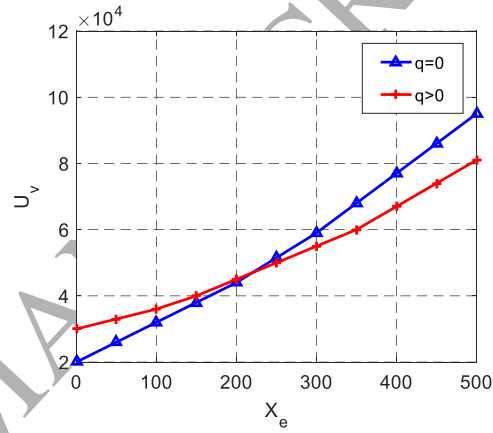Fig. 11 Utility function of the FLSP in Scenario II, θ =0.27

Fig. 12 Utility function of the FLSP in Scenario III

From Fig. 7 to Fig. 12, we find that the FLSP's optimal strategies change with the market signal x_e. Comparing Fig. 11 and Fig. 12, it indicates that without the LSI's loss-averse preference, the FLSP's loss-averse preference helps to increase its utility. Comparing Fig. 12 with Fig. 10, when the FLSP does not have a loss-averse preference, and the LSI's loss-averse coefficient $k < 1$, the LSI's loss-averse preference decreases the FLSP's utility. However, when $k > 1$, the effect is quite complicated. Comparing Fig. 12 with Fig. 7 and 8, we find that the FLSP can benefit from the loss-averse preference of the LSI and FLSP, as its utility increases greatly.

From Sections 6.1 and 6.2, we can see that under the same circumstances, the optimal strategies for the LSI and the FLSP can be different. For example, when the LSI's loss-averse coefficient $k > 1$, the FLSP does not have a loss-averse preference,

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and the market signal $x_e = 200$. The FLSP should set a lower wholesale price in the first stage to stimulate the LSI to only purchase in the first stage. However, the LSI should purchase capacity in both stages to obtain higher utility. In practice, the FLSP decides the wholesale prices and then the LSI decides the purchasing quantity. However, the LSI masters the market demand and thus has more power. Accordingly, both sides should take the other side's loss-averse preference into consideration when making its own decisions.

7. Conclusion and future research directions

7.1 Main conclusions

We have considered a two-echelon LSSC consisting of a loss averse FLSP and a loss averse LSI, under demand updating. We have studied the effect of the supply chain members' loss-averse preferences by comparing the basic model and the three scenarios where one or both sides do not have loss-averse preferences. We have arrived at the following main conclusions:

1. When purchasing in both stages, the LSI's loss-averse preference does not affect the LSI's optimal purchasing quantities and FLSP's optimal wholesale prices. When the LSI only purchases in the first stage, and with appropriate conditions satisfied, the loss-averse preference of the LSI causes its order quantities to increase and the wholesale price to decrease. Different from Liu et al. [43] which studied the impact of loss aversion on the news vendor game with product substitution and found that each retailer's equilibrium order quantity is decreasing with the loss aversion coefficient and increasing with the substitution rate,our paper finds that the LSI's loss-averse preference can be of benefit to the LSI and should be used.

2. The loss-averse preference can affect the decisions of supply chain members only if certain conditions are satisfied. A similar study is also mentioned in Özer et al. [42]. When the LSI purchases only in the first stage and $k > 1$, the loss-averse preference of the FLSP can cause the wholesale price to increase in the first stage and the LSI's total order quantity to decrease. When $q = 0$, the effect of the loss-averse preferences can be observed.

3. The LSI's total order quantity decreases with the increased service level, regardless of the supply chain members' loss-averse preferences. Wholesale prices set by the FLSP increase with the increased service level when certain conditions are satisfied.

7.2 Management insights

Our paper considers service level in its analysis and thus is valuable for LSSC members, especially when they are developing procurement strategies. In addition, our paper also points to the impacts of the loss-averse preferences of supply chain members. These important conclusions can help the managers of LSI and FLSP to make better decisions.

First, the LSI's loss-averse preference will increase its order quantities under appropriate conditions. Therefore, if the LSI predicts that market demand is going to increase in the second stage, the LSI should act in a loss-averse manner. This finding is useful for LSIs, such as the Chinese Yuantong Express Logistics Company. The rapid development of e-commerce in China has increased the demand for logistics, indicating that Yuantong should exhibit loss-averse behavior. This requires the LSI to make rational decisions, and avoid individual loss aversion behavior. It requires enterprises to establish a set of scientific and sound decision-making systems.

Second, when the LSI makes procurement decisions, it should not only consider demand updating, but should also pay attention to the loss-averse preferences of supply chain members. In practice, logistics enterprises have different scales and different levels of management. Some enterprises have standardized decision-making mechanisms while others rely on managers to make decisions. Therefore, supply chain members should pay attention to distinguish between different types of logistics enterprises and develop appropriate policies. The effects of loss-averse preference of the LSI are greater than those of the FLSP, thus the LSI should pay more attention to its loss-averse preference when making decisions.

Third, the LSI, as a member in the LSSC, should also consider the effect of service level and the allocation of its guarantee cost on decision making. For example,

if the LSI pays a small part of the service-level guarantee cost, the wholesale prices set by the FLSP will increase with the increased service level.

The research results from this paper are also valuable for FLSPs. In regard to loss-averse preferences, the FLSP should pay attention to the following three points.

First, the FLSP can make beneficial use of the LSI's loss-averse preference, because the LSI's loss-averse preference can increase the wholesale prices.

Second, the FLSP's loss-averse preference causes the wholesale prices to increase in the first stage. However, at this point, the profits of the LSI in the second stage are less than those in the first stage, and the LSI has negative utility. The FLSP's loss aversion behavior has a negative impact on the LSI's utility. As an FLSP, managers should be aware of the circumstances under which their loss aversion can affect the decisions of supply chain members and appropriately adjust pricing strategies.

Third, the FLSP's profit is related to the logistics service level and the guarantee cost contribution ratio, which causes the wholesale prices to either increase or decrease. Therefore, before making pricing decisions, the FLSP should negotiate the contribution ratio with the LSI to maximize its profit.

7.3 Limitations and future research directions

Our paper has revealed the impacts of demand updating and loss-averse preferences on the LSI's and FLSP's decision making. However, this study also has some shortcomings. For example, we have assumed that the market price p in the second stage is the same as that in the first stage, while in reality, the market price always changes. Accordingly, future work can introduce variable pricing. Second, buyback is not allowed in our paper. Thus, future work can expand our paper by allowing the LSI to return surplus capacity to the FLSP if market demand shrinks. Third, we have considered profit as the single factor that influences the LSI's and FLSP's loss-averse preferences. In reality, other factors can also affect the loss-averse preferences of supply chain members. Future work can explore LSSC capacity procurement problems considering more complex loss-averse behaviors.

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Appendix

Appendix A. Proof of Proposition 1

(1)The optimal solution of the LSI in the second stage

The LSI's utility in the second stage is:

$$U_{I2}(Q_2) = \Pi_{I2} + k\Delta\Pi_I$$

Take the first derivative of Q_2 with respect to $U_{I2}(Q_2)$ and we have:

$$\frac{\partial U_{I2}(Q_2)}{\partial Q_2} = (1+k)\left[(p+b)\int_{Q_2}^{\infty} f(x|x_e)dx - (w_2 + \rho\varphi\gamma) + s\int_{0}^{Q_2} f(x|x_e)dx\right]$$

As $k>0$, take the second derivative of Q_2 with respect to $U_{I2}(Q_2)$ and we have:

$$\frac{\partial^2 U_{I2}(Q_2)}{\partial^2 Q_2} = -(1+k)(p+b-s)f(Q_2|x_e) \leq 0$$

$U_{I2}(Q_2)$ is a concave function on the ordering quantity in the second phase. It ensures the existence of optimal solution of Q_2, let $\dfrac{\partial U_{I2}(Q_2)}{\partial Q_2} = 0$ and

$$Q_{2L} = F^{-1}(\frac{p+b-w_2-\rho\varphi\gamma}{p+b-s}|x_e)$$

(2)The optimal solution of the FLSP in the second stage

The FLSP's utility in the second stage is:

$$U_{V2}(w_2) = (1+\theta)(Q_1w_1 + (Q_2-Q_1)(w_2-\rho(1-\varphi)\gamma)) + \theta Q_1(w_1-\rho(1-\varphi)\gamma)$$

From the analysis in (1), the LSI's optimal purchasing quantity in the second stage Q_{2L} is dependent on w_2, thus take the first derivative of w_2 with respect to Q_{2L} and we have:

$$\frac{\partial Q_{2L}}{\partial w_2} = \frac{-1}{(p+b-s)f(\dfrac{p+b-w_2-\rho\varphi\gamma}{p+b-s}|x_e)}$$

Take $\dfrac{\partial Q_{2L}}{\partial w_2}$ into $U_{V2}(w_2)$, and take the second derivative of w_2 with respect

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to $U_{V2}(w_1, w_2)$, and we have:

$$\frac{\partial^2 U_{V2}(w_2)}{\partial^2 w_2} = 2(1+\lambda(\theta))\frac{\partial Q_{2L}}{\partial w_2} = \frac{-2(1+\lambda(\theta))}{(p+b-s)f\left(\frac{p+b-w_2-\rho\psi\gamma}{p+b-s}\Big| x_e\right)} < 0$$

$U_{V2}(w_2)$ is a concave function on w_2 in the second phase. It ensures the

existence of the optimal solution of w_2, let $\dfrac{\partial U_{V2}(w_2)}{\partial w_2} = 0$ and

$$w_{2L} = (Q_{2L} - Q_{1L})f(x\,|\,x_e)(p+b-s) + \rho(1-\varphi)\gamma$$

Appendix B. Proof of Proposition 2

(1)The optimal solution of the LSI in the first stage

When $Q_1 = Q_2$, the total utility of the LSI is:

$$U_I(Q_1) = (1+k)(p\min(Q_1, x) - b(x-Q_1)^+ + s(Q_1-x)^+ - c_I)$$
$$+ (k-1)(w_1 + \rho\varphi\gamma)Q_1 - kp\min(Q_1, y)$$

Take the first derivative of Q_1 with respect to $U_I(Q_1)$ and we have:

$$\frac{\partial U_I(Q_1)}{\partial Q_1} = (1+k)\big(p+b-(p+b-s)F(Q_1|x_e)\big) + (k-1)(w_1 + \rho\varphi\gamma) - pk\big(1-F(Q_1)\big)$$

Take the second derivative of Q_1 with respect to $U_I(Q_1)$ and we have:

$$\frac{\partial^2 U_I(Q_1)}{\partial^2 Q_1} = -(1+k)(p+b-s)f(Q_1|x_e) + pkf(Q_1)$$

When $(1+k)(p+b-s)f(x\,|\,x_e) - kpf(x) > 0$ is satisfied, $U_I(Q_1)$ is a concave

function on Q_1. It ensures the existence of an optimal solution of Q_1, let

$\dfrac{\partial U_I(Q_1)}{\partial Q_1} = 0$ and

$$Q_{1H} = F^{-1}\big(\frac{(1+k)(p+b) - (k-1)(w_1 + \rho\varphi\gamma) - kp(1-F(Q_{1H}))}{(1+k)(p+b-s)}\,|\,x_e\big)$$

When $Q_1 < Q_2$, the total utility of the LSI is:

$$U_I(Q_1, Q_{2L}) = (1+k)(p\min(Q_2, x) - (w_2 + \rho\varphi\gamma)(Q_2 - Q_1) - b(x - Q_2)^+ + s(Q_2 - x)^+ - c_I)$$
$$+ (k-1)(w_1 + \rho\varphi\gamma)Q_1 - kp\min(Q_1, y)$$

Take $Q_{2L} = F^{-1}(\dfrac{p + b - w_2 - \rho\varphi\gamma}{p + b - s} | x_e)$ into $U_I(Q_1, Q_{2L})$ and take the first

derivative of Q_1 with respect to $U_I(Q_1, Q_{2L})$, and we have:

$$\frac{\partial U_I(Q_1, Q_{2L})}{\partial Q_1} = (1+k)w_2 + (k-1)w_1 + 2k\rho\theta\gamma - pk(1 - F(Q_1))$$

Take the second derivative of Q_1 with respect to $U_I(Q_1, Q_{2L})$, and we have:

$$\frac{\partial^2 U_I(Q_1, Q_{2L})}{\partial^2 Q_1} = pkf(Q_1) > 0$$

Accordingly, when $\dfrac{s - w_2 - \rho\varphi\gamma}{p + b - s} < -\dfrac{(1+k)w_2 + (k-1)w_1 + 2k\rho\varphi\gamma}{pk}$, LSI's total

utility decreases on $Q_1 \in [\tau, Q_{2L}]$, so $Q_{1L} = \tau$, τ is MOQ.

(2) The optimal solution of the FLSP in the first stage

When $Q_1 = Q_2$, the total utility of the FLSP is:

$$U_V = Q_1 w_1 + (\theta - 1)Q_1[\rho(1 - \varphi)\gamma + c]$$

From the analysis in (1), the LSI's optimal purchasing quantity in the first stage

Q_{1H} is dependent on w_1,

$$Q_{1H} = F^{-1}(\frac{(1+k)(p+b) - (k-1)(w_1 + \rho\varphi\gamma) - kp(1 - F(Q_{1H}))}{(1+k)(p+b-s)} | x_e)$$

Thus,

$$(1+k)(p+b-s)F(Q_{1H}|x_e) = (1+k)(p+b) - (k-1)(w_1 + \rho\varphi\gamma) - kp(1 - F(Q_{1H}))$$

Take the first derivative of w_1 with respect to Q_{1H}, and we have:

$$(1+k)(p+b-s)f(Q_{1H}|x_e)\frac{\partial Q_{1H}}{\partial w_1} = -(k-1) + kpf(Q_{1H})\frac{\partial Q_{1H}}{\partial w_1}$$

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Thus, $\dfrac{\partial Q_{1H}}{\partial w_1} = \dfrac{1-k}{(1+k)(p+b-s)f(Q_{1H}|x_e)-kpf(Q_{1H})}$

From Appendix A, $(1+k)(p+b-s)f(x|x_e)-kpf(x)>0$. Thus, when $k<1$,

$\dfrac{\partial Q_{1H}}{\partial w_1}>0$; when $k>1$, $\dfrac{\partial Q_{1H}}{\partial w_1}<0$.

Then, take the first derivative of w_1 with respect to U_V, and we have:

$$\frac{\partial U_V}{\partial w_1} = \left(\frac{\partial Q_{1H}}{\partial w_1} w_1 + v \right) + (\theta-1)\frac{\partial Q_{1H}}{\partial w_1}\big(\rho(1-\varphi)\gamma+c\big)$$

If $k<1$, $\dfrac{\partial U_V}{\partial w_1} = Q_{1H} + \dfrac{\partial Q_{1H}}{\partial w_1}\big(w_1+(\theta-1)\big(\rho(1-\varphi)\gamma+c\big)\big)>0$, increases with w_1,

then $w_{1H}=w_h$.

If $k>1$, $\dfrac{\partial^2 U_V}{\partial^2 w_1} = 2\dfrac{\partial Q_{1H}}{\partial w_1}<0$. U_V is a concave function of w_1. It ensures the

existence of an optimal solution of w_1, let $\dfrac{\partial U_V}{\partial w_1}=0$ and

$$w_{1H} = Q_{1H}\frac{(1+k)(p+b-s)f(x|x_e)-kpf(x)}{k-1}+(1-\theta)\rho(1-\varphi)\gamma$$

When $Q_1<Q_2$, the total utility of the FLSP is:

$$U_V(w_1,w_2) = Q_1w_1+(1+\theta)(Q_2-Q_1)(w_2-\rho(1-\varphi)\gamma)+\theta Q_1\rho(1-\varphi)\gamma$$

Take $w_{2L}=(Q_{2L}-Q_{1L})f(x|x_e)(p+b-s)+\rho(1-\varphi)\gamma$ into $U_V(w_1,w_2)$, and

take the first derivative of w_1 with respect to $U_V(w_1,w_2)$, and we have

$\dfrac{\partial U_V(w_1,w_2)}{\partial w_1}=Q_{1L}>0$. $U_V(w_1,w_2)$ increases with w_1, thus $w_{1L}=w_h$.

Appendix C. Proof of Theorem 1

From Table 2 and 3, we can get:

$$Q_{1L}=Q_{1L}^{\mathrm{I}}=Q_{1L}^{\mathrm{II}}=Q_{1L}^{\mathrm{III}}=\tau; \qquad w_{1L}=w_{1L}^{\mathrm{I}}=w_{1L}^{\mathrm{II}}=w_{1L}^{\mathrm{III}}=w_h;$$

To find out the relationship among the optimal strategies of the LSI and the FLSP in the second stage, we first solve simultaneous Eq.(C.1) and Eq. (C.2)

$$Q_2 = F^{-1}(\frac{p+b-w_2-\rho\varphi\gamma}{p+b-s} \mid x_e)$$ Eq. (C.1)

$$w_2 = (Q_2 - \tau)f(x \mid x_e)(p+b-s) + \rho(1-\varphi)\gamma$$ Eq. (C.2)

Let $G(w_2) = F(\dfrac{w_2 - \rho(1-\varphi)\gamma}{f(x \mid x_e)(p+b-s)} + \tau \mid x_e) - \dfrac{p+b-w_2-\rho\varphi\gamma}{p+b-s}$ Eq. (C.3)

$G(w_2)$ is a function of w_2. Take the second derivative of w_2 we can get:

$$\frac{\partial G(w_2)}{\partial w_2} = \frac{2}{p+b-s} > 0$$ Eq. (C.4)

Eq. (C.4) shows that $G(w_2)$ is the strictly monotone increasing function of w_2 and $w_2 \in (w_l, w_h)$. To ensure that there is at least one solution of w_2 which satisfy the equation (C.3), the following conditions should be satisfied: when $w_2 = w_l$, $G(w_l) < 0$ and when $w_2 = w_h$, $G(w_h) > 0$. Thus the w_2 which makes $G(w_2) = 0$ is the one and only optimal wholesale in the second stage. It means that: $Q_{2L} = Q_{2L}^{\mathrm{I}} = Q_{2L}^{\mathrm{II}} = Q_{2L}^{\mathrm{III}}; \quad w_{2L} = w_{2L}^{\mathrm{I}} = w_{2L}^{\mathrm{II}} = w_{2L}^{\mathrm{III}}$

Appendix D. Proof of Theorem 2

When $Q_{1H}^{\mathrm{I}} > Q_{1H}^{\mathrm{III}}$, $F(x \mid x_e)$ is strictly monotone increasing function:

$$F(Q_{1H}^{\mathrm{I}} \mid x_e) > F(Q_{1H}^{\mathrm{III}} \mid x_e)$$

Besides, $Q_{1H}^{I}(k>1) > Q_{1H}^{III}(k<1)$

So we only consider when $k>1$. We can get:

$$(Q_{1H}^{I} - Q_{1H}^{III})(1+k)(p+b-s)f(x \mid x_e) - Q_{1H}^{I}kpf(x) + kp(1-F(Q_{1H}^{I})) < 2\rho\gamma$$

As $Q_{1H}^{I} - Q_{1H}^{III} > 0$, $2\rho\gamma > -Q_{1H}^{I}kpf(x) + kp(1-F(Q_{1H}^{I}))$

Let $H(m) = -mkpf(x) + kp(1-F(m))$ and take the second derivative of m on

$H(m)$, we can find out that $H(m)$ decreases with m and $H(m)_{\max} = H(\tau)$.

Thus, when $2\rho\gamma > -\tau kpf(x) + kp(1 - F(\tau))$, $Q_{1H}^{I} > Q_{1H}^{III}$.

Appendix E. Proof of Theorem 3

When $k < 1$, $w_{1H}^{I} = w_h$ and $w_{1H}^{I} > w_{1H}^{III}$

When $k > 1$: If $w_{1H}^{I} < w_{1H}^{III}$ and theorem 2 is satisfied,

$$\frac{kpf(x)}{1-k} - \frac{(2-k)(p+b-s)f(x|x_e)}{k-1}Q_{1H}^{I} > \left(Q_{1H}^{I} - Q_{1H}^{III}\right)(p+b-s)f\left(x|x_e\right) > 0$$

As $k > 1$, $kpf(x) + (2-k)(p+b-s)f(x|x_e) < 0$

Appendix F. Proof of Theorem 5

From Scenario III, when neither of the LSI and the FSLP has no loss-averse and $q > 0$

$$Q_{2L}^{III} = F^{-1}(\frac{p+b-w_2^{III} - \rho\varphi\gamma}{p+b-s} | x_e)$$

and $w_{2L}^{III} = (Q_{2L}^{III} - \tau)f(x|x_e)(p+b-s) + \rho(1-\varphi)\gamma$

take the second derivative of γ on Q_{2L}^{III} and w_{2L}^{III} respectively, we can get:

$$\frac{\partial w_{2L}^{III}}{\partial\gamma} = \frac{\rho}{2f(x|x_e)(p+b-s)} < 0, \quad \frac{\partial w_{2L}^{III}}{\partial\gamma} = \rho\left(\frac{1}{2} - \varphi\right)$$

If $0 < \varphi < \frac{1}{2}$, $\frac{\partial w_{2L}^{III}}{\partial\gamma} > 0$, If $\frac{1}{2} < \varphi < 1$, $\frac{\partial w_{2L}^{III}}{\partial\gamma} < 0$

Similarly, when $q = 0$, $\frac{\partial Q_{1H}^{III}}{\partial\gamma} < 0$

and if $0 < \varphi < \frac{1}{2}$, then $\frac{\partial w_{1H}^{III}}{\partial\gamma} > 0$. If $\frac{1}{2} < \varphi < 1$, then $\frac{\partial w_{1H}^{III}}{\partial\gamma} < 0$.

We can get the same conclusion from Scenario I.