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Research Article

Three-Echelon Supply Chain Contractual Coordination with Loss-Averse Multiple Retailer Preference

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In this paper, we propose a supply chain contract model aimed to coordinate a three-echelon supply chain, which is based on the revenue-sharing allocation with loss-aversion preference. We consider a three-echelon supply chain consisting of a risk-neutral manufacturer, a risk-neutral distributor, and loss-averse multiple retailers. To address this model, we consider a shortage product produced and sold within a single period in the stochastic market. The model allows the system efficiency to be achieved as well as it will improve the profits of all supply chain members by tuning the contract parameters. We used the expected utility function to describe the loss-aversion member's influence coefficient. The decisions of chain members under different conditions are studied by simulation analyses. The paper also analysed the relationship between different revenue-sharing coefficient combinations with multiple retailers in the supply chain system. Furthermore, the study has addressed the supply chain coordination decision bias in the centralized and decentralized systems.

1. Introduction

Majorities of supply chain (SC) management literatures have mainly focused on SC coordination with two-stage leader-follower member's game theory. The SC members decision-making behaviours' efficiency analysed, identified, and compared with the centralized system control. The centralized control assures the system efficiency. Both centralized and decentralized conditions are difficult to be verified due to different objectives, which often make the hypothesis of a centralized control not realistic. Moreover, in practice, a decentralized SC consists of multiple decision makers pursuing different independent objectives. The decentralized SC approaches with contractual coordination have been studied in order to improve overall competitiveness in fast-growing marketplace. Research by Cachon and Lariviere [1] has proven that contractual sharing mechanism is advantageous in achieving coordination in two-stage SC. Giannoccaro and Pontrandolfo [2] have developed and proposed a three-stage coordination approach by providing the incentives to make SC members' decisions coherent among each other. SC models with the three stages involve the existence of several decision makers pursuing different objectives, possibly conflicting among each other [3]. The incentives let the risk and the revenue shared among all SC members. Additionally, traditional SC contractual models are based on risk neutrality, where members make independent decisions in order to maximize own profits. In practice, there is a lack of research study on the risk, revenue, cost, and gain-loss contractual sharing approaches with the three-stage SC. A gain-loss sharing contract specifies that the upstream member's decision influences the downstream member's gains or losses. Hence decision-making behaviours are also identified as the main phenomenon of loss-aversion in the prospect theory, which states that managers are more sensitive to losses than to gains [4]. Loss-aversion is both intuitively appealing and well supported in finance, economics, marketing, and organizational behaviour [5, 6]. For example, there are economic field tests supporting loss-aversion in financial markets [7], life savings and consumptions [8], labour supply [9], marketing [10], real estate [11], and organizational behaviour [12, 13]. However, in most SC models, decision makers are assumed to be loss-neutral, which maximizes the profit in an uncertain environment [14]. Several experimental studies and managerial decision-making practices under uncertainty have asserted that enterprise managers' decision-making behaviours deviate from expected profit maximization due to loss-aversion [15–18]. In the scope of two-stage SC coordination with uncertain demand where the manufacturer is risk-neutral and the retailer is loss-averse, the role of gain-loss sharing provision mitigating the loss-aversion effect, which decreases the retailer order quantity and total SC profit [19]. Recently, few authors have applied gain-loss prospect theory through SC contractual coordination such as wholesale price contract [20], buy-back contract [21], option contract [22], and revenue-sharing (RS) contracts on which other types of contract models are based. He and Zhao [20] studied the inventory, production, and contracting decisions of a multi-echelon SC with both demand and supply uncertainty. They proposed a return policy used by the manufacturer and the retailer combined with the wholesale price contract used by the raw-material supplier and the manufacturer, which can effectively coordinate the SC. They also investigated the impact of the supplier's risk attitude on the decision-making, as well as the impact of spot market price for raw material on the performance of entire SC.

Li and Wang [21] have investigated the channel coordination issue of a two-stage SC with a risk-neutral manufacturer and a loss-averse retailer facing stochastic demand that is sensitive to the sales effort. Under the loss-averse newsvendor setting, a distribution-free gain-loss sharing and buy-back (GLB) contract have been shown to be able to coordinate the SC. However, they found that a GLB contract remains ineffective in managing SC when retailer sales efforts influence the demand. Liu et al. [22] investigated a single-period two-stage SC composed of a risk-neutral supplier and a loss-averse retailer with an option contract. They found that there always exists a Pareto option contract for the studied SC configuration. Qinhua et al. [23] have also studied the RS contractual approach to improve the performance and to achieve the efficiency of SC performance. Moreover, comparative results confirm that there respectively exists only one wholesale price that the supplier charges the retailer and only one quota of the retailer's revenue that the retailer gives to the supplier; the wholesale price and the quota are both the increasing functions of the supplier's loss-averse preferences. Hou et al. [24] studied the RS contract in a three-echelon SC a risk-neutral or a risk-averse retailer. Although RS contracts can coordinate the SC with a risk-neutral retailer, they are not always able to coordinate the SC with a risk-averse retailer. It is interesting that the SC with a risk-averse retailer can be coordinated by executing a designed risk-sharing contract, which is based on any kind of RS contract. Finally, any kind of RS contract is not absolutely better than another. Based on the risk-sharing contract, the retailer's preference is equivalent between the two contracts; but for the distributor and the manufacturer, their preferences between the two contracts are positively related to their own profit share in the SC. More recently, Sang [25] presented the RS contract in a two-stage SC between one manufacturer and one retailer based on the prospect theory. The models of centralized decision-making system and RS contract are built by the method of prospect theory, and their optimal policies are also analysed. The paper shows that the retailer and the manufacturer can be coordinated by the RS contract, in which they obtain the same total expected utilities as the centralized decision-making system. Most of these studies considered the problem of SC coordination with two stages. Moreover, a large part of them focuses on channel coordination and paying less attention to gain-loss preference. Apart from the existing literature, this paper is the first work that analytically models and characterizes the SC coordination problem considering multiple retailers under a decentralized system, which faces a stochastic market demand. Furthermore, particular attention is devoted to support the fine tuning of the contract parameters so as to achieve the win-win condition.

The major contributions of this work can be summarized as follows:

(i) This paper investigated the decision-making and contractual coordination conditions for a three-echelon SC in both centralized and decentralized systems with given a loss-averse retailer.

(ii) The study developed a RS contract model for a three-echelon SC with loss-averse multiple retailers and derive the retailer's and distributor's decision-making policies.

(iii) This research analysed the difference between the decision-making policies of a loss-averse retailer. Finally, we discuss the effect of loss-aversion on the retailer's utility and order quantity and the wholesale prices of the distributor and the manufacturer.

The remainder of this paper is structured as follows: Section 2 presents the problem description, hypothesis, and assumptions. In Section 3, we investigate the centralized supply chain decision with loss-aversion. The case of decentralized supply chain decision with loss-aversion is given in Section 4. Supply chain RS contract with loss-averse preference is presented in Section 5, whereas results and discussion illustrated in Section 6. We conclude our findings and highlight possible future work in Section 7.

2. Problem Description and Hypothesis

In this paper, we consider a three-echelon sustainable SC consisting of a risk-neutral manufacturer, a risk-neutral distributor, and multiple loss-averse retailers, in which a single-period product is produced and sold under stochastic market demand. The retailer provides RS contract and shares profit quota with the distributor and manufacturer. The retailer uses a newsboy type of commodity and orders according to the demand forecast before the selling season. The distributor orders the shortage product from the manufacturer according to the retailer's order, and the manufacturer produces according to the order quantity of distributor. SC information between retailer, distributor, and manufacturer is symmetric. SC members' decision-making needs to focus on the basis of symmetric information. Furthermore, considering a risk-neutral manufacturer, a risk-neutral distributor, and a competing n retailers in the three-echelon SC, n retailers sell the product of the same newsboy type, n retailers order the product from the distributor of their own forecasts of the market demand, and distributor orders from the manufacturer. The manufacturer produces according to the total order quantity. The meanings of the other symbols used in this article are in Table 1.

2.1. Research Assumptions

(1) Every retailer market demand and the retailer's order quantity are directly proportional to each other. If the market demand is high, the retailer's n order quantity will also increase to meet increased customer demand and market needs $X_i = (Q_i/Q)X$.

(2) The SC information is symmetric for all members. The SC members' selection is determined by the symmetric information.

(3) Only the retailer is loss aversion, the distributor and the manufacturer are risk-neutral.

2.2. Description Method of Loss-Aversion. The utility function has been widely applied in economics, operations management, and other disciplines. Based on the analyses of the loss-aversion feature by Kahneman and Tversky [4], the loss-aversion feature with a retailer utility function was described using a linear segment function model. Loss-aversion parameters are given in Table 2. The linear segment loss-aversion utility function model could be expressed as follows:

$$U_i(\pi_i) = \begin{cases} \pi_i - \pi_i^0, & \pi_i \geq 0, \\ \lambda(\pi_i - \pi_i^0), & \pi_i < 0. \end{cases} \tag{1}$$

Table 1: The listing of notations.

Symbol	Meaning
p	Retail price
c	Manufacturer production cost
ω_1	Manufacturer wholesale price
ω_2	Distributors wholesale prices
s_r	Retailers surplus value
π_m	Manufacturer profit
π_d	Distributer profit
π_r	Retailer profit
SC	Supply chain
X	Retailer market demand
π	SC total profit
Q_r	Retailer total order quantity, $Q_r = \sum_{i=1}^{n} Q_i$
Q_{-i}	The i^{th} retailer order quantity, $Q_{-i} = Q - Q_{-i}$
Q	Centralized SC decision-making order quantity
Q_i	The i^{th} retailer ordering quantity in decentralized SC
$F(x)$	Market demand distribution function
$f(x)$	Market demand density function $x > 0$, $f(x) > 0$
X_i	The i^{th} random demand of retailer market
$F(x_i)$	X_i, the position of the distribution function $i = (1, 2, 3, \ldots, n)$
$f(x_i)$	X_i, the position of density function $i = (1, 2, 3, \ldots, n)$
ϕ_1	Between manufacturer and distributor sharing ratio
ϕ_2	Between distributor and retailer's sharing ratio

Table 2: Loss-averse parameters.

Symbol	Meaning
U_i	The i^{th} retailer's loss-aversion utility
π_i	The i retailer's expected profit
π_i^0	The i^{th} retailer's initial condition set, i.e., in order to without loss, set $\pi_i^0 = 0$
λ_i	The retailer's loss-aversion coefficient, if $\lambda_i = 1$, indicates that the retailer is risk-neutral, if $\lambda_i > 1$, indicates that the retailer is having loss-aversion features, and a higher value of λ_i corresponds to a higher level of loss-aversion. There is a kink at the reference level 0; if $\lambda_1 = \lambda_2 = \ldots = \lambda_n = \lambda$ indicates there is no loss

3. Centralized Supply Chain Decision with Loss-Aversion

In centralized SC, the manufacturer, in terms of a large amount of production, is at the core of the entire SC status. Therefore, the manufacturer is the leader of the entire SC. The SC decision-making problem is a typical newsboy problem. The expected profit of the centralized SC can be determined by the following expression:

$$E[\pi(Q,x)] = (p-c)Q - (p-s_r)\int_0^Q (Q-x)f(x)dx. \tag{2}$$

We find the first derivative of equation (1) with respect to Q and setting the first derivative equal to zero. It can be seen that the $E[\pi(Q,x)]$ is a concave function of order quantity Q:

$$\frac{\partial E[\pi(Q,x)]}{\partial Q} = (p-c) - (p-s_r)F(Q) = 0. \tag{3}$$

Then, optimal order quantity of centralized SC can be satisfied by Q^*:

$$Q^* = F^{-1}\left(\frac{p-c}{p-s_r}\right). \tag{4}$$

The centralized SC profit function can be described as follows:

$$\pi(Q^*) = E[\pi(Q^*,x)] = (p-c)F^{-1}\left(\frac{p-c}{p-s_r}\right) - (p-s_r)F(x)dx. \tag{5}$$

4. Decentralized Supply Chain Decision with Loss-Aversion

In this section, the retailer makes a decision according to the distributor wholesale price ω_2 and the RS ratio ϕ_2. To determine their optimal order quantity, the retailer's decision aims to maximize expected utility. The retailer has a loss-averse preference. The loss-aversion utility function is used to describe the retailer's loss-aversion tendency, and λ_i represents the retailer's loss-averse level.

In this case, the i^{th} retailer's profit function is engaged by the following:

$$\pi_{ri}(Q_i, x_i) = \begin{cases} \phi_2(p - s_r) - (\omega_2 - \phi_2 s_r)Q_i, & x_i \le Q_i, \\ \phi_2 p Q_i - \omega_2 Q_i, & x_i > Q_i. \end{cases} \tag{6}$$

According to equation (6), the retailer's profit and loss balance of i retailer is given by

$$Q_i = \left(\frac{\omega_2 - \phi_2 s_r}{\phi_2(p - s_r)}\right). \tag{7}$$

According to equation (6), retailer expected profit is given by

$$E[\pi_{ri}(Q_i, x_i)] = \int_0^{Q_i} [\phi_2(p - s_r)x_i - (\omega_2 - \phi_2 s_r)Q_i] g(x_i)dx_i + \int_{Q_i}^{+\infty} (\phi_2 p - \omega_2)Q_i g(x_i)dx_i. \tag{8}$$

According to equations (7) and (8), the retailer expected utility is given by

$$\begin{aligned} E[U(\pi_{ri}(Q_i, x_i))] = \lambda \int_0^{((\phi_2 - \phi_2 s_r)/(\phi_2(p - s_r)))Q_i} & \cdot [\phi_2(p - s_r)x_i - (\omega_2 - \phi_2 s_r)Q_i] g(x_i)dx_i \\ & + \int_{((\phi_2 - \phi_2 s_r)/(\phi_2(p - s_r)))Q_i}^{Q_i} [\phi_2(p - s_r)x_i \\ & - (\omega_2 - \phi_2 s_r)Q_i] g(x_i)dx_i \\ & + \int_{Q_i}^{+\infty} \phi_2(p - \omega_2)Q_i g(x_i)dx_i. \end{aligned} \tag{9}$$

Research on other assumptions are given by

$$G(x_i) = F\left(\frac{Q}{Q_i}x_i\right), \tag{10}$$

$$g(x_i) = \frac{Q}{Q_i} f\left(\frac{Q}{Q_i}x_i\right). \tag{11}$$

By substituting equations (10) and (11) into equations (8) and (9), the retailer expected profit is given by

$$E[\pi_{ri}(Q_i, x_i)] = \frac{Q_i}{Q}\left[(\phi_2 p - \omega_2)Q - \phi_2(p - s_r)\int_0^Q F(x)dx\right]. \tag{12}$$

The retailer expected utility is given by

$$\begin{aligned} E[U(\pi_{ri}(Q_i, x_i))] = \frac{Q_i}{Q}(\phi_2 p - \omega_2)Q - \phi_2(p - s_r) & \\ \cdot \int_0^Q F(x)dx \int_0^{((\phi_2 - \phi_2 s_r)/(\phi_2(p - s_r)))Q} & \\ \cdot [\phi_2(p - s_r)x - (\omega_2 - \omega_2 s_r)Q] f(x)dx. & \end{aligned} \tag{13}$$

The i^{th} retailer has the only optimal order quantity Q_i^*. The retailers expect that utility $E[U(\pi_{ri}(Q_i, x_i))]$ maximizes when $Q_i = Q_i^*$. Q_i is calculated by the following formula:

$$\begin{aligned} & (\phi_2 p - \omega_2) - \phi_2(p - s_r)F(Q_i^* - Q_i) \\ & \quad - (\omega_2 - \omega_2 s_r)F\left[\frac{\omega_2 - \omega_2 s_r}{\omega_2(p - s_r)}(Q_i^* - Q_{-i})\right] \\ & \quad \cdot \frac{\phi_2(p - s_r)}{(Q_i^* - Q_i)^2} Q_i \left[\int_0^{Q_i^* - Q_i} x f(x)dx + (\lambda - 1)\right. \\ & \quad \left. \cdot \int_0^{((\omega_2 - \omega_2 s_r)/(\omega_2(p - s_r)))(Q_i^* - Q_{-i})} x f(x)dx\right] = 0. \end{aligned} \tag{14}$$

If the retailer gets the right ordering amount, the function pros and cons depend on retailer expected utility $E[U(\pi_{ri}(Q_i, x_i))]$. We will find the first derivatives of Q_i:

$$\begin{aligned} \frac{\partial E[(\pi_{ri}(Q_i, x_i))]}{\partial Q_i} = & (\omega_2 p - \phi_2) - (p - s_r)F(Q_i + Q_{-i}) \\ & - (\lambda - 1)(\omega_2 - \phi_2 s_r) \\ & \cdot F\left[\frac{\omega_2 - \phi_2 s_r}{\phi_2(p - s_r)}(Q_i + Q_{-i})\right] \\ & + \frac{\phi_2(p - s_r)}{(Q_i + Q_{-i})^2} Q_{-i} \left[\int_0^{Q_i + Q_{-i}} f(x)dx\right. \\ & + (\lambda - 1)\int_0^{((\phi_2 - \phi_2 s_r)/(\phi_2(p - s_r)))(Q_i + Q_{-i})} \\ & \left. \cdot f(x)dx\right]. \end{aligned} \tag{15}$$

From equation (15), we can find the second-order derivatives of Q_i:

$$\frac{\partial^2 E[(\pi_{ri}(Q_i, x_i))]}{\partial Q_i^2} < 0. \tag{16}$$

Second-order derivatives are less than zero. Therefore, it is clear that the retailer expected utility with respect to Q_i is a concave function. So, the retailer optimal order quantity should be satisfied, as follows:

$$(\omega_2 p-\phi_2)-(p-s_r)F(Q_i^*+Q_{-i})-(\lambda-1)\cdot(\omega_2-\phi_2 s_r)F\left[\frac{\omega_2-\phi_2 s_r}{\phi_2(p-s_r)}(Q_i^*+Q_{-i})\right]\cdot\frac{\phi_2(p-s_r)}{(Q_i^*+Q_{-i})^2}Q_{-i}\left[\int_0^{Q_i^*+Q_{-i}}f(x)dx+(\lambda-1)\cdot\int_0^{((\phi_2-\phi_2 s_r)/(\phi_2(p-s_r)))(Q_i^*+Q_{-i})}xf(x)dx\right]=0. \tag{17}$$

The retailer optimal order quantity increases with the number of retailers increases. The Q_i is an increasing/decreasing function with respect to retailer's loss-aversion factor, and there is a unique Nash equilibrium between n retailers ordering quantity $(Q_1^*, Q_2^*, \ldots, Q_i^*)$. Among them, $Q_i^* = Q^*/n$. Then, n retailer optimal order quantity Q_i should be satisfied, as follows:

$$\omega_2 p-\phi_2-\phi_2(p-s_r)F(Q^*)-(\lambda-1)\cdot(\omega_2-\phi_2 s_r)F\frac{\omega_2-\phi_2 s_r}{\phi_2(p-s_r)}(Q^*)+\frac{(n-1)\phi_2(p-s_r)}{nQ^*}\left[\int_0^{Q^*}f(x)dx+(\lambda-1)\cdot\int_0^{((\omega_2-\phi_2 s_r)/(\phi_2(p-s_r)))Q^*}xf(x)dx\right]=0. \tag{18}$$

For any retailer, the most ordering quantities are satisfied, which is assumed by the preceding hypothesis equation (14). At the same time, n retailers decide their ordering strategy should be satisfied $Q_1^* = Q_2^* = \cdots = Q_i^* = Q_n^*$, that is, $Q^* = Q_i^*$ and $Q_{-i}^* = (n-1)Q_i^*$. By substituting equation (14) into equation (18), it needs to meet Nash equilibrium. Retailer total order quantity can be satisfied in equation (18). We set $k(Q)$ in the left side of equation (18). $k(Q)$ is given by

$$k(Q)=\omega_2 p-\phi_2-\phi_2(p-s_r)F(Q^*)-(\lambda-1)\cdot(\omega_2-\phi_2 s_r)F\frac{\omega_2-\phi_2 s_r}{\phi_2(p-s_r)}(Q^*)+\frac{(n-1)\phi_2(p-s_r)}{nQ^*}\left[\int_0^{Q^*}f(x)dx+(\lambda-1)\cdot\int_0^{((\omega_2-\phi_2 s_r)/(\phi_2(p-s_r)))Q^*}xf(x)dx\right]. \tag{19}$$

Equation (19) is concave in Q; therefore, $k(Q)$ first order derivatives should satisfy the following:

$$\frac{\partial k(Q)}{\partial Q}=-\frac{\omega_2(p-s_r)}{n}f(Q)-(\lambda-1)\cdot\frac{(\omega_2-\phi_2 s_r)^2}{n\phi_2(p-s_r)}f\left(\frac{\omega_2-\phi_2 s_r}{\phi_2(p-s_r)}Q\right)-\frac{(n-1)\omega_2(p-s_r)}{nQ^2}\int_0^{Q}xf(x)dx+(\lambda-1)\cdot\int_0^{((\omega_2-\phi_2 s_r)/(\phi_2(p-s_r)))Q}xf(x)dx<0. \tag{20}$$

The first derivative is less than 0, so the function $k(Q)$ is a decreasing function with respect to Q. Thus, there is a following limitation:

$$\lim_{Q\longrightarrow 0}k(Q,n,\lambda)=\phi_2 p-\omega_2\geq 0,$$
$$\lim_{Q\longrightarrow +\infty}k(Q,n,\lambda)=-\lambda(\phi_2-\omega_2 s_r)\leq 0. \tag{21}$$

Therefore, retailers have the unique optimal total order quantity Q^* in equation (18). From the above analysis, it is clear that the competition among the retailers increases with total ordering quantity increases, while the loss-aversion level decreases.

5. Supply Chain Revenue-Sharing Contract with Loss-Aversion

In the decentralized SC decision-making process, the manufacturer, the distributor, and the retailer make their own decision in case of loss-aversion. Therefore, members only consider their own expected profit to maximize or expected utility that will affect the overall performance of SC, and it may not be possible to achieve the best overall performance. The introduction of the RS contract can effectively coordinate the SC. It effectively achieves the decentralized SC coordination decision-making; in other words, it can achieve the overall decision-making operational performance, optimize the entire SC, and enables efficient coordination between manufacturer, distributor, and retailers. The manufacturer and the distributor are required to design the appropriate revenue-sharing contract coefficient to reach the retailer's overall order quantity when the SC expected profit is maximum. The manufacturer and the distributor accept ϕ_1, ω_1, ϕ_2, and ω_2 to achieve the entire SC coordination. There is only one SC coordination combination having (ϕ_1^*/ω_1^*), (ϕ_2^*/ω_2^*). The following combinations make the SC coordinate:

$$\frac{\partial(\phi_1/\omega_1)}{\partial(n)} > 0,$$
$$\frac{\partial(\phi_1^*/\omega_1^*)}{\partial(\lambda)} > 0,$$
$$\frac{\partial(\phi_2^*/\omega_2^*)}{\partial(n)} > 0, \tag{22}$$
$$\frac{\partial(\phi_2^*/\omega_2^*)}{\partial(\lambda)} > 0.$$

The following formula is established to make the above combinations achieve SC coordination:

$$\begin{aligned} &\omega_2 p - \phi_2 - \phi(p - s_r)F(Q^*) - (\lambda - 1) \\ &\cdot (\omega_2 - \phi_2 s_r) F \frac{\omega_2 - \phi_2 s_r}{\phi_2(p - s_r)}(Q^*) \\ &+ \frac{(n-1)\phi_2(p - s_r)}{nQ^*}\left[\int_0^{Q^*} f(x)dx + (\lambda - 1)\right. \\ &\left.\cdot \int_0^{((\omega_2 - \phi_2 s_r)/(\phi_2(p - s_r)))Q^*} x f(x)dx\right] = 0. \end{aligned} \tag{23}$$

By mathematical simplification of equation (23), we get the following equation:

$$\begin{aligned} &\frac{\omega_2}{\phi_2} + (\lambda - 1)\left(\frac{\omega_2}{\phi_2} - s_r\right) F \frac{\omega_2 - \phi_2 s_r}{\phi_2(p - s_r)}(Q^*) \\ &+ \frac{(n-1)(p - s_r)}{nQ^*}\left[\int_0^{Q^*} f(x)dx + (\lambda - 1)\right. \\ &\left.\cdot \int_0^{((\omega_2 - \phi_2 s_r)/(\phi_2(p - s_r)))Q^*} x f(x)dx\right] = 0. \end{aligned} \tag{24}$$

The left side of equation (24) is ω_2/ϕ_2, and we set $l(\omega_2/\phi_2)$ as follows:

$$\begin{aligned} l\left(\frac{\omega_2}{\phi_2}\right) &= \frac{\omega_2}{\phi_2} + (\lambda - 1)\left(\frac{\omega_2}{\phi_2} - s_r\right) F \frac{\omega_2 - \phi_2 s_r}{\phi_2(p - s_r)}(Q^*) \\ &+ \frac{(n-1)(p - s_r)}{nQ^*}\left[\int_0^{Q^*} f(x)dx + (\lambda - 1)\right. \\ &\left.\cdot \int_0^{((\omega_2 - \phi_2 s_r)/(\phi_2(p - s_r)))Q^*} x f(x)dx\right]. \end{aligned} \tag{25}$$

The function $l(\omega_2/\phi_2)$ is an increasing function with respect to ω_2/ϕ_2, so there is only a ω_2/ϕ_2 combination that makes the coordination between retailers. Similarly, there is also manufacturer coordination between the manufacturer and distributor combination.

We get the first derivative of equation (25) with respect to n:

$$\begin{aligned} \frac{\partial l(\omega_2/\phi_2)}{\partial n} &= (s_r - p)\left[\int_0^{Q^*} f(x)dx + (\lambda - 1)\right. \\ &\left.\cdot \int_0^{((\phi_2 - \phi_2 s_r)/(\phi_2(p - s_r)))Q^*} x f(x)dx\right] < 0. \end{aligned} \tag{26}$$

We also get the first derivative of equation (25) with respect to λ:

$$\begin{aligned} \frac{\partial l(\omega_2/\phi_2)}{\partial \lambda} &= \left(\frac{\omega_2}{\phi_2} - s_r\right) F\left(\frac{\phi_2 - \phi_2 s_r}{\phi_2(p - s_r)} Q^*\right) \\ &+ \frac{(1-n)(s_r - p)}{nQ^*}\int_0^{((\phi_2 - \phi_2 s_r)/(\phi_2(p - s_r)))Q^*} x f(x)dx < 0. \end{aligned} \tag{27}$$

So, the function $l(\omega_2/\phi_2)$ is a decreasing function with respect to n, while it is an increasing function with respect to λ; the above conditions derivatives also need to be meet, as follows:

$$\frac{\partial(\phi_1^*/\omega_1^*)}{\partial(n)} > 0,$$
$$\frac{\partial(\phi_1^*/\omega_1^*)}{\partial(\lambda)} > 0,$$
$$\frac{\partial(\phi_2^*/\omega_2^*)}{\partial(n)} > 0, \tag{28}$$
$$\frac{\partial(\phi_2^*/\omega_2^*)}{\partial(\lambda)} > 0.$$

In a three-echelon SC system with loss-averse multiple retailers, the RS contract can be applied, the SC is coordinated, and the optimal order quantity by the retailers is the same, i.e., $Q_i^* = Q^*/n$; the retailer expected utility is also equal to $Q_i^* = Q^*/n$. Equations (8) and (9) combine with the wholesale price and the RS coefficient, respectively, $\phi_2^*$and ω_2^*. Then, the retailer's expected profit is as follows:

$$E[\pi_{ri}(\phi_2^*, \omega_2^*)] = \frac{1}{n}\left[(\phi_2^* p - \omega_2^*)Q^* - \omega_2^*(p - s_r)\int_0^{Q^*} F(x)dx\right]. \tag{29}$$

The same combination can be obtained for each retailer expected utility:

$$\begin{aligned} E[U(\pi_{ri}(\phi_2^*, \omega_2^*))] &= \frac{1}{n}\left\{\pi_{ri}(\phi_2^*, \omega_2^*) + (\lambda - 1)\right. \\ &\cdot \int_0^{((\phi_2 - \phi_2 s_r)/(\phi_2(p - s_r)))Q^*} \\ &\cdot \left[\phi_2^*(p - s_r)x - (\omega_2^* - \phi_2^* s_r)\right. \\ &\left.\left.\cdot Q^*\right] f(x)dx\right\}. \end{aligned} \tag{30}$$

The total expected profit for n retailers loss-averse is given by

$$E[\pi_r(\phi_2^*, \omega_2^*)] = (\phi_2^* p - \omega_2^*)Q^* - \omega_2^*(p - s_r)\int_0^{Q^*} F(x)dx. \tag{31}$$

The total expected utility for n retailers loss-averse is given by

$$E[U(\pi_r(\phi_2^*, \omega_2^*))] = \pi_{ri}(\phi_2^*, \omega_2^*) + (\lambda - 1) \cdot \int_0^{((\phi_2^* - \phi_2^* s_r)/(\phi_2(p - s_r)))Q^*} [\phi_2^*(p - s_r)x - (\omega_2^* - \phi_2^* s_r)Q^*] f(x)dx. \tag{32}$$

Distributor expected profit is given by

$$E[\pi_d(\phi_1^*, \omega_1^*, \phi_2^*, \omega_2^*)] = \phi_1^*(1 - \phi_2^*)\left[(\phi_2^* p - \omega_2^*)Q^* - \omega_2^* \cdot (p - s_r)\int_0^{Q^*} F(x)dx\right]. \tag{33}$$

Manufacturer expected profit is given by

$$E[\pi_m(\phi_1^*, \omega_1^*)] = (\phi_1^* - c)Q^* + \phi_1^*(1 - \phi_1^*)(1 - \phi_2^*)\left[(\phi_2^* p - \omega_2^*)Q^* - \omega_2^*(p - s_r)\int_0^{Q^*} F(x)dx\right]. \tag{34}$$

In this section, in order to ensure coordination efficiency of overall SC, the retailers determine the profit allocation of the RS factor ϕ_1, ϕ_2. Therefore, the RS contract coordinates the entire SC. Retailer expected utility leads the manufacturer, and the distributor is willing to conclude the RS contract in order to coordinate entire SC. Thus, the following conditions need to be met:

$$\begin{cases} E[\pi_m(\phi_1^*, \omega_1^*)] \geq E[\pi_m(\phi_1)], \\ E[\pi_d(\phi_1^*, \omega_1^*, \phi_2^*, \omega_2^*)] \geq E[\pi_d(\phi_1, \omega_1)], \\ U[\pi_r(\phi_2^*, \omega_2^*)] \geq E[\pi_r(\phi_2, \omega_2)]. \end{cases} \tag{35}$$

According to equation (35), we get the reasonable value range of the RS coefficients ϕ_1, ϕ_2. However, in practice, due to the different bargaining power of the manufactuer, distributor, and retailers, the value size is also different because of the RS factor ϕ_1, ϕ_2. So, in the actual decision-making, RS coefficients ϕ_1, ϕ_2 lead the SC members, and make their own coordination and negotiation capabilities.

6. Results and Discussion

In this section, the paper has proposed numerical analysis to illustrate how the RS coefficients and the loss-averse factor affect coordination condition and profit allocation of the SC. The simulation analysis is illustrated to better explain the coordination process of the RS contract in the three-echelon SC considering loss-averse preference. In order to simplify the calculation study, a type of newsboy with a single product and with low price and cost of production was considered. The retail price is assumed $p = 40$, the entire SC total production cost is $c = 20$, and retailers unit product surplus is $s_r = 10$, assuming that the market demand obeys the uniform distribution $x \sim [A, B]$, with $A = 0$ and density of $B = 1000$. The probability density function is

$$f(x) = \begin{cases} \dfrac{1}{B - A}, & A \leq x \leq B, \\ 0, & \text{others}. \end{cases} \tag{36}$$

The market demand function is calculated by the following equation:

$$x = bp^{-k} + \varepsilon, \quad (b > 0,\ k \geq 1). \tag{37}$$

Other parameters and numerical values are given in Table 3.

The results showed the manufacturer and the distributor provided optimal pricing and retailers provided optimal order policy in a three-echelon decentralized SC system. According to the optimal pricing and the optimal ordering policy, optimal order quantity can be calculated under the decentralized SC system. By substituting the numerical values from Table 3 into equations (36) and (37), we calculated the SC optimal order quantity, and the result of optimal price combination value is (25, 800). The expected profit of manufacturer, distributor, and retailers is illustrated, where, the number of retailers is certain and the RS contract coefficient combination is certain with the retailer's loss-averse level. SC members' expectation is calculated under the different loss-averse coefficients with utility $n = 5$, $\phi_1 = 0.6$, and $\phi_2 = 0.7$. Expected profits under the decentralized decision-making with loss-averse level are shown in Figure 1. Moreover, Figure 1 illustrated that SC of all members expected profits as well as retailer utility will decrease while loss-averse level increased.

Assumed that the retailer's loss-averse is certain, which means that the retailer's loss-averse coefficient is constant, and between retailers and distributor sharing factor ϕ_1, distributor and manufacturer sharing factor ϕ_2 are constant and only the number of retailers n ranges from 1 to 25 and $\lambda = 2$, $\phi_1 = 0.5$, and $\phi_2 = 0.6$. We calculated each SC members profit with different numbers of retailers as shown in Figure 2.

Figure 2 presented that with the increase of retailer's number, while the loss-aversion level is certain and RS coefficient is determined, the SC members expected profit increases. When the number of retailers increased, the competition among the retailers and expected utility also increased. The following study presented the relationship between the retailer loss-averse coefficient λ and RS parameters ϕ_1, ϕ_2. The number of retailers ranges from 1 to 24 in the three-echelon SC with different values of ϕ_1, ϕ_2. The numerical value range is shown in Table 4.

Table 3: Parameter values.

Parameter	c	s_r	n	λ	p	k
Value	20	10	[1, 25]	[1, 4]	40	2

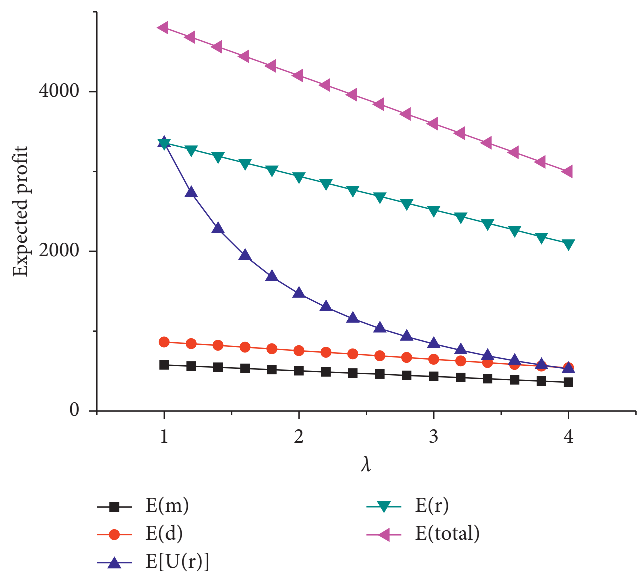

Figure 1: Expected profit with λ, where E(m), manufacturer; E(d), distributer; E[U(r)], retailer expected utility; E(r), retailer; E(total), total SC.

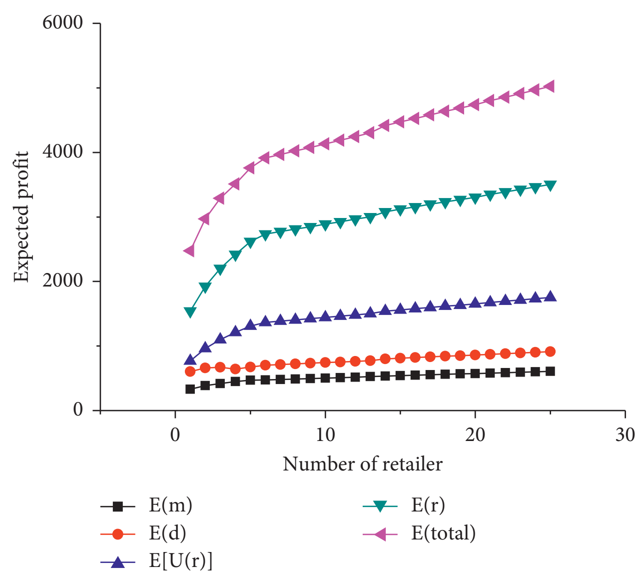

Figure 2: Expected profit with n retailer, where E(m), manufacturer; E(d), distributer; E[U(r)], retailer expected utility; E(r), retailer; E(total), total SC.

Table 4: The revenue-sharing parameters with λ.

λ	1	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
ϕ_1	0.9	0.80	0.75	0.73	0.71	0.7	0.67	0.65	0.63	0.61	0.59	0.57	0.55	0.53	0.51	0.50
ϕ_2	0.75	0.65	0.60	0.57	0.54	0.5	0.45	0.42	0.39	0.36	0.33	0.30	0.27	0.26	0.25	0.24

The retailer loss-aversion coefficient ϕ_1 and RS between manufacturer and distributor ϕ_2 combinations are shown in Table 4. The total revenue between the distributor and retailers increases with increase of RS coefficients. Table 5 showed the change of number of retailers with the RS contract parameters ϕ_1, ϕ_2.

The multiple retailers' loss-aversion coefficient λ gradually increased with the RS coefficient ϕ_2 decrease. When,

Table 5: Revenue-sharing parameters with retailer.

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ϕ_1	0.1	0.13	0.16	0.19	0.22	0.3	0.29	0.32	0.35	0.38	0.42	0.45	0.48	0.51	0.54	0.58	0.61	0.64	0.67	0.70	0.74	0.77	0.80	0.83
ϕ_2	0.45	0.46	0.48	0.50	0.52	0.5	0.56	0.58	0.60	0.62	0.64	0.65	0.67	0.69	0.71	0.73	0.75	0.77	0.79	0.81	0.83	0.84	0.86	0.88

Table 6: The SC members' expected profit with revenue-sharing ratio.

ϕ_1	ϕ_2	$E(\pi_m)$	$E(\pi_d)$	$E(\pi_r)$	$E(\pi_m)$%	$E(\pi_d)$%	$E(\pi_r)$%	$E(\pi)$
0.6	0.2	3020	4531	1888	32	48	20	**9440**
0.7	0.2	2265	5286	1888	24	56	20	**9440**
0.8	0.2	1510	6041	1888	16	64	20	**9440**
0.9	0.2	755	6796	1888	8	72	20	**9440**
0.9	0.3	660	5947	2832	7	63	30	**9440**
0.9	0.4	566	5097	3776	6	54	40	**9440**
0.9	0.5	472	4248	4720	5	45	50	**9440**
0.9	0.6	377	3398	5664	4	36	60	**9440**
0.9	0.7	283	2548	6608	3	27	70	**9440**
0.9	0.8	188	1699	7552	2	18	80	**9440**
0.9	0.9	94	849	8496	1	9	90	**9440**
1	1	0	0	9440	0	0	100	**9440**

the retailer's expected profit is small, they will focus on their own profit and sales to distributors. And according to the RS contract by ϕ_1 and ϕ_2 the range of SC coordination is $0.5 < \phi_1 < 1$ and $0.2 < \phi_1 \leq 1$. In case of SC without loss-aversion preference scenario, chain members' expected profit depends only on ϕ_1 and ϕ_2 as shown in Table 6 [26]. When the RS coefficient is combined (1, 1), the manufacturer and the distributor profits are equal to zero. The manufacturer and the distributor will not be willing to conclude a RS contract with the retailers. In this case, the SC is uncoordinated. In the following analysis, the RS contract coefficient enables the SC to achieve coordination when different RS contracts are obtained between the manufacturer and the distributor with multiple retailers. Assuming that the retailer's expected profit value remains constant, the trend is still changing. The expected profit of the distributor varies with the trend. Accordingly, the distributor expected profit is constant as shown in Table 6. It is clear that the different RS coefficients will have a different impact on the profit of the manufacturer, the distributor, and multiple retailers [26].

7. Conclusion and Future Research

Many researchers have compared the centralized and the decentralized cases in terms of coordination mechanism for SC members. This paper has addressed the problem of SC coordination under the hypothesis of a decentralized system because in the centralized SC system all members belong to a unique company. In particular, a contract model based on a RS mechanism has been proposed to coordinate a three-stage SC. In this paper, we have considered a three-echelon SC consisting of a multiple loss-averse retailer, risk-neutral manufacturer, and risk-neutral distributer under stochastic market demand. The research mainly focuses on analysing the influence of the loss-aversion coefficient λ of retailers and the number of retailers n on the expected return and the expected profit $E(\pi)$ among supply chain members.

Through the analysis of this paper, we can draw the following conclusions:

(i) The revenue-sharing ratio ϕ_1 and ϕ_2 equals to 1, and the manufacturer and the distributer earns zero from the retailer and they are not willing to conclude the RS contract with the retailer

(ii) When the retailer loss-averse coefficient λ increases, the manufacturer and the distributer RS ratio ϕ_1 and ϕ_2 increases and the retailer order quantity (expected profit) is the opposite

(iii) SC member's expected profit decreases with retailer loss-averse ratio λ increases

(iv) When the number of retailers increases, the manufacturer and the distributer RS ratio ϕ_1 and ϕ_2 also increases, as well as their expected profit increases

(v) When the λ increases, the retailer expected utility decreases and it is opposite with the number of retailers increases

(vi) All SC members maximizes their expected profit only when λ, n, ϕ_1, and ϕ_2 coefficients are in certain relationship as presented in Table 4 and Table 5

(vii) In case of SC without loss-aversion preference scenario, SC members' expected profit depends only on RS coefficients ϕ_1 and ϕ_2 as shown in Table 6.

This research did not consider the three-echelon SC chain coordination with loss-aversion status for multiple manufacturer, multiple distributer, and multiple retailer combinations in our setting environment, and it can be a further research direction.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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