

## Research Article

# Coordination of Supply Chain under Blockchain System-Based Product Lifecycle Information Sharing Effort

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The study proposes a supply chain contractual coordination model based on the product lifecycle information sharing effort and consumers' price sensitivity to a product with the Blockchain system. This paper examined the following five scenarios: (1) centralized supply chain with Blockchain system-based product lifecycle information sharing investment; (2) Stackelberg leader retailer processed and invested Blockchain system scenario; (3) retailer processed the Blockchain system cost-sharing scenario; (4) retailer processed Blockchain system investment through bargaining the revenue-sharing model; (5) Blockchain system investment under the cost and revenue-sharing contract. The study used the game theory reverse induction method to compare the Nash equilibrium solutions under different decision-making scenarios and discussed the chain member's constraint condition of Blockchain system investment. We simulated and analysed the products' lifecycle information sharing effort cost factor, the influence of price sensitivity coefficient, and expected profits of the supplier and retailer. The study results show that the product lifecycle information sharing effort under the Blockchain system increases the profit of the whole chain and decreases with the increase of customer's price sensitivity coefficient.

## 1. Introduction

Supply Chain Management (SCM) is concerned with efficient management of the financial, material, and information flows among supply chain (SC) members [1]. The researchers are developing SC coordination, integration, and collaboration subject modes with forward or reverse stream strategies between different economic institutions to improve the overall performance of SC. In a decentralized SC, upstream supplier and downstream chain member, as independent decision maker, make each decision focusing on its own profit. At the same time, as a member in the value chain, their decisions and behaviors are mutually influenced. The behavioral preferences are affecting the decision-making of each chain member. The behavioral preferences will lead to unperformed decision-making which will cause the traditional win-lose strategy and deviates from total SC profit maximization [2]. It is imperative that the decentralized SC members make decisions together in an effort

to minimize overall total cost and maximize total profit by customer satisfaction [3]. To improve overall performance, the SC members may behave as a part of the unified system and coordinate with each other under joint strategical decisions. Thus "coordination" comes into focus [4]. The most commonly accepted definition of the coordination in the SCM literature is "the act of managing dependencies between chain members and the joint effort of members working together towards mutually defined goals" [5]. The coordination of a strategic SC can be achieved by the independent segment of coordination such as "information systems' coordination," "logistics processes' coordination," and "contractual coordination" (financial trade-off's) [6]. Information sharing system coordination is necessary to support critical business decisions that may impact to price, quality, cost, availability, lead time, and profit share. Information flow is on both directions from the upstream chain members to the downstream chain consumers or conversely from downstream to the upstream. Information is available

from a single source, often from the carrier, and information sharing mostly depends on contractual responsibility with other chain members [7]. Additionally, different products flow consists of different information priority such as quality conditions, product availability, service level, market price, and even actual market potential (for more details, see [8]). As an example, the eggs are classified by the United States Department of Agriculture based on their external appearance and quality condition information, mostly priority of information sharing under the retailer's advantage. In the European Union, eggs are not based on their external appearance but on their used farming methods (conventional or organic, barn range, free-range) [9].

This study focuses on SC contractual coordination with Blockchain system-based proper lifecycle information sharing effort. Our model is based on the influence of product lifecycle information sharing effort and consumers' price sensitivity. The Nash equilibrium solution of the SCs is obtained by reverse induction method. The decisions of Blockchain system investment between the different contracts are analysed and compared with the centralized SC optimal decision. Finally, the constraints of the member's choice of blockchain investment are given, and the influence of the Blockchain system cost coefficient and the price sensitivity coefficient on the decision-making behaviors and expected profits of the suppliers and retailers are simulated. This paper further enriches the theoretical achievements on the SC contractual coordination and Blockchain system investigation. The paper is organized as follows. Section 2 provides the model establishment, assumptions, and nomenclature. Section 3 presents the various models' analysis under the BS investment and we also propose the fifth case as a BS cost sharing with revenue-sharing model. Section 4 and 5 provides the numerical study, comparison, and simulation analysis of the five cases. In Section 6, conclusion and direction of future research are given.

## 2. Literature Review

Only very recently were there some other new approaches introduced to the SCM practice. The available studies introduced and developed the Blockchain-based systems in a SC where the Blockchain system (BS) is a new solution for data management among SC members. Blockchain technology has been initially applied to the SC information system coordination segments such as international payment [10], healthcare [11], electric energy supply [12], and education [13] and even in logistics process traceability systems coordination [14]. The new decentralized traceability system based on Internet of Things (IoT) and the Blockchain technology will support SC products visibility in the physical distribution phase via proper real-time information sharing under the safety status of products. Additionally, Blockchain technologies reduce the risk of information sharing and data systems and bring more security to the information flow among all SC members. The applications of IoT and Blockchain technologies are mainly focused on the consumer, industrial, and public sectors. Most of the recent interest has mainly focused on the

consumer appliances. The industrial applications are promising to improve operational management outcomes in different fields of industries [15]. Utilization and development of Blockchain technology with IoT in back and forward information flows of a SC would effectively guarantee the trusted coordination, by gathering, transferring, and sharing the authentic data in planning, processing, distributing, and selling links [16]. As information sharing technology develops, the other coordination mechanisms such as contractual coordination of SC will be adopted accordingly. The activities transformed by the Blockchain system will lead to the costly efforts; total profit of SC will rise in the stochastic markets due to both higher sales volume and higher retail prices. At the same time, the benefits from these systematic examinations under contractual coordination remain unclear, as does sharing of its cost and profit among the SC members. None of the literature on SCM has discussed these interesting and trusted Blockchain technology benefits under contractual coordination theories until now.

## 3. Model Description, Assumptions, and Parameters

This section derives the model establishment and nomenclature. In this study, the terms of Blockchain system, blockchain technology, blockchain (BS), and information system have been used interchangeably to mean the proper lifecycle information sharing effort.

*3.1. Model Description and Establishment.* The study focuses on sharing contractual coordination with Blockchain system-based product proper lifecycle information sharing effort. The paper investigates a two-stage SC consisting of a supplier who sells the products to a retailer and the retailer who sells the supplier's products to consumers. Consumers are sensitive to the product price and product "Lifecycle Information Trustworthy" (LIT) and need to consider both the product price and the LIT level when buying products. To satisfy the consumers' demand with product LIT level, the retailer puts efforts by the adoption of new BT. In order to obtain the model demand function, we adopt the framework established by Ghosh and Shah's [17] and Song and Gao [18]. To further expand the study, we make a distinct category of study, investigating them according to their LIT level under BS investment. We need to define the meaning of "Product Lifecycle," "Lifecycle Information," "Trustworthy," and "Blockchain system" in this model.

- (i) "Product Lifecycle" demonstrates "the series of stages and functional activities through which a product passes from the point of origin to the point of consumption" and it is mainly based on time and the proper value-added chain members.
- (ii) "Lifecycle Information" describes the jointly collected data of product's specific information which interchanges between the series of stages and functional activities from the point of origin to the point of consumption.

- (iii) “Trustworthy” is used to indicate “the value of customer’s perspective in order to optimize customer utility.” From customers’ perspective, they are much worried about having product lifecycle information as proper as possible with products that may have an impact on health.
- (iv) In our study, the definition of “Blockchain system” defines as a new decentralized information sharing technology, which can store the product Lifecycle Information in the chain of blocks. Specific information of a product can be stored in a shared system for the all SC participants including customers.

**3.2. Assumptions and Nomenclature.** We assume that the SC members can influence the market demand by exerting the Blockchain system-based product proper lifecycle information sharing effort. To address this issue, we consider a SC model consisting of an upstream supplier and a downstream retailer. The model in this paper is based on the following assumptions.

**Hypothesis 1.** The supplier provides a product to the retailer at wholesale price and the retailer sells product to consumer at retail price. We assume that consumers are different in the valuation of the product’s proper lifecycle information trustworthy. We denote the “Lifecycle Information Trustworthy” level (alternatively called “LIT”), and for analytic simplicity we assume in the range of  $[0, 1]$ , with  $\beta = 0$  and a density of  $\beta = 1$  representing the consumer satisfaction, where the range of  $[0, 1]$  represents a “partial availability” and “full online availability” of product’s lifecycle information, respectively.

**Hypothesis 2.** The cost of the BS invested takes the form of  $I\beta^2$ , where  $I$  is the BS investment parameter and  $I > 0$ .

**Hypothesis 3.** Total demand during the season is stochastic and sensitive to the product price and product LIT. Consumer’s sensitivity forces to consider both the product price and the product LIT level. Consumers preference is to get informed about product proper lifecycle, and when the LIT level of a product is higher, and the product price is lower, the product sales are greater. The actual market place demand  $q$  is a linear function of the product price and product LIT level; at this point the demand function is expressed as

$$q_{p,\beta} = a - bp + \theta\beta. \quad (1)$$

**Hypothesis 4.** Consumer products can replace each other in the market with and without Blockchain system-based lifecycle information.

**Hypothesis 5.** The retailer is the leader and the supplier is the follower.

We make the following parameters and meanings (Table 1):

TABLE 1: Nomenclature.

Parameters	Meaning
$a$	Total market potential
$c$	Product cost
$b_n^i$	Sensitivity to product price
$p_n^i$	Product retail price
$w_n^i$	Product wholesale price
$\beta_n^i$	Product LIT level under BS
$\theta_n^i$	Sensitivity to the LIT level
$\varphi_n^i$	Cost sharing fraction
$\phi_n^i$	RS fraction via bargaining
$\pi_n^i$	Revenue-sharing fraction
$i = *$	Total profit
$i = s$	Optimal value
$i = r$	Supplier’s profit
$i = sc$	Retailer’s profit
$n = 1$	Total SC’s profit
$n = 2$	Centralized SC with BS
$n = 3$	SL retailer own BS invest
$n = 4$	SL retailer’s BS cost sharing
$n = 5$	BS via bargaining RS
	BS invest with cost and RS

## 4. The Models

In this section, the following scenarios are presented under the Stackelberg leader (SL) and Stackelberg follower (SF) power structures. For the comparison, we first examined a benchmark centralized SC model, which is known as the vertical integration model. The second is a decentralized SC scenario, where the retailer is a SL with passive SF supplier structural observation. The third scenario is the decentralized decision mode with Blockchain system cost sharing when the retailer is a SL and the supplier is a SF, similar to [17]. Through the fourth scenario, we examined RS via bargaining model, similar to [18]. The fifth scenario presents the Blockchain system-based strategical approach via cost sharing as well as with revenue sharing among the SC members under the SL retailer structure.

**4.1. Case 1: Centralized SC Mode with Blockchain System (A Benchmark).** In the centralized SC scenario, where the sales margin  $m$  takes form of  $m = p - c$ , the game model interdependence is no longer treated with contractual co-ordination but rather treated as one entity to get an optimal profit. The single decision-maker exerts the Blockchain system-based product proper lifecycle information sharing effort and sets the optimal price to maximize the whole centralized SC profit. The profit function in the centralized SC with BS investment is expressed as

$$\pi_1^{sc} = [(p - w) + (w - c)]q - I\beta^2 = (p - c)(a - bp + \theta\beta) - I\beta^2. \quad (2)$$

Taking the first and second partial derivatives of equation (2) with respect to  $m$  and  $\beta$ , and by setting the first derivatives of  $m_1$  and  $\beta_1$  equal to zero, we find that optimal  $\beta_1^*$ ,  $p_1^*$ , and  $m_1^*$  are

$$\beta_1^* = \frac{\theta(a - cb)}{4Ib - \theta^2}, \quad (3)$$

$$p_1^* = \frac{2Ia + 2Ibc - c\theta^2}{4Ib - \theta^2}, \quad (4)$$

$$m_1^* = \frac{2I(a - cb)}{4Ib - \theta^2}. \quad (5)$$

Substituting the optimal  $\beta_1^*$  and  $p_1^*$  from equations (3) and (4) into equation (2), we find that the optimal total profit in the centralized SC with BS investment is

$$\pi_1^{\text{sc}} = \frac{I(a - cb)^2}{4Ib - \theta^2}. \quad (6)$$

**4.2. Case 2: BS Based Information Sharing Effort under the Retailer Stackelberg Leadership.** In the decentralized SC scenario, the supplier and retailer are making their decisions interdependently. In this decentralized decision-making structure, the retailer as a SL and the supplier as a passive SF mode is examined. Because of asymmetry information, the market demand trustworthy (satisfaction) level is available for the downstream retailer and it is simply based on customers' experience of retention. The retailer as a SL exerts the Blockchain system-based product proper lifecycle information sharing effort and sets the selling price to maximize own profit. Accordingly, the supplier as a SF sets wholesale price. At this point, the profit functions of the SF supplier and SL retailer in the decentralized SC scenario with BS investment are given by

$$\pi_2^s = (w - c)q = (w - c)(a - b(m + w) + \theta\beta), \quad (7)$$

$$\pi_2^r = (p - w)q - I\beta^2 = (p - w)(a - b(m + w) + \theta\beta) - I\beta^2. \quad (8)$$

The total profit function of the whole decentralized SC with BS investment in any case is

$$\pi_n^{\text{sc}} = \pi_n^r + \pi_n^s = (p_n - c)(a - bp_n + \theta\beta_n) - I\beta_n^2 \quad (9)$$

First, we solve the profit function for the SF supplier. In this case, the SL retailer's sales margin is  $m = p - w$ ; using the inverse induction method, we obtain first and second derivatives of equation (7) and set the first derivative equal to zero:

$$w_2 = \frac{(a + bc - bm + \theta\beta)}{2b}. \quad (10)$$

Next, we solve the profit function for the supplier from equation (8) by obtaining the first and second partial derivatives with respect to  $m_2$  and  $\beta_2$ ; then, we set the first derivatives equal to zero and get optimal values of  $m_2^*$  and  $\beta_2^*$ :

$$\beta_2^* = \frac{\theta(a - bc)}{8Ib - \theta^2}, \quad (11)$$

$$m_2^* = \frac{4I(a - bc)}{8Ib - \theta^2}.$$

We are putting the optimal values of  $m_2^*$  and  $\beta_2^*$  into equations (1) and (10); therefore, our optimal retailer price is

$$w_2^* = \frac{2Ia + 6Ibc - c\theta^2}{8Ib - \theta^2}, \quad (12)$$

$$p_2^* = \frac{6Ia + 2Ibc - c\theta^2}{8Ib - \theta^2}.$$

Finally, we are substituting all the optimal values into equations (7)–(9) and getting the maximum profits for the supplier  $\pi_2^s$ , retailer  $\pi_2^r$ , and the whole SC  $\pi_2^{\text{sc}}$ . Specific values are listed in Table 2.

**4.3. Case 3: BS Based Effort Cost Sharing under the Retailer Stackelberg Leader Mode.** In the decentralized SC scenarios, the supplier's and retailer's total profit are less than the centralized SC and the BS based product lifecycle information sharing effort is lower. Therefore, to achieve the optimal product proper lifecycle information sharing in a decentralized SC, the SL must invest a higher BS investment. However, the game follower may not be motivated to invest for the BS based information sharing. To address this case issue, the cost sharing contractual coordination is presented to the decentralized SC with BS, similar to [17]. The retailer as a SL invests a higher BS investment with two main parameters: retailer's paid wholesale price  $w_3$  and the retailer's cost sharing coefficient  $\vartheta_3$ . In this case, the profit functions of the SF supplier and SL retailer with BS cost-sharing contract are as follows:

$$\pi_3^s = (w_3 - c)q - (1 - \vartheta_3)I\beta^2 = (w_3 - c)(a - bp + \theta\beta) - (1 - \vartheta_3)I\beta^2, \quad (13)$$

$$\pi_3^r = (p - w_3)q - \vartheta_3 I\beta^2 = (p - w_3)(a - b(p + m) + \theta\beta) - \vartheta_3 I\beta^2. \quad (14)$$

First, we solve the profit function for the retailer where the retailer's sales margin is  $m = p - w$ ; using the inverse induction method, we obtain first and second derivatives from equation (14) and set the first derivatives equal to zero:

$$w_3 = \frac{a + bc - bm + \theta\beta}{2b}, \quad (15)$$

$$q_3 = \frac{a - bc - bm + \theta\beta}{2}.$$

Next, we solve the profit function for the supplier from equation (13) by obtaining the first and second partial derivatives with respect to  $w_3$  and  $\beta_3$ ; then, we set the first derivatives equal to zero and get optimal values of  $w_3^*$  and  $\beta_3^*$ :

$$m_3^* = \frac{2I(a - cb)}{4Ib - \theta^2}. \quad (16)$$

In this case, the supplier has significant motivation to participate in LIT sharing effort investment because portion of cost will be shared by the retailer. Let the optimal LIT level be the same as in the centralized SC:

TABLE 2: Optimal values under the different SC decision-making.

$*/i$	Case 1	Case 2	Case 3	Case 4	Case 5
$\beta_i^*$	$(\theta(a-cb))/(4Ib-\theta^2)$	$(\theta(a-cb))/(8Ib-\theta^2)$	$(\theta(a-cb))/(4Ib-\theta^2)$	$(2\theta(a-cb))/(12Ib-3\theta^2)$	$(\theta(a-cb))/(4Ib-\theta^2)$
$q_i^*$	$(2Ib(\alpha-bc))/(4Ib-\theta^2)$	$(2Ib(\alpha-bc))/(8Ib-\theta^2)$	$(Ib(a-cb))/(4Ib-\theta^2)$	$(4Ib(a-cb))/(3(4Ib-\theta^2))$	$(2Ib(a-cb))/(4Ib-\theta^2)$
$\pi_i^*$	—	$(4I^2b(a-cb)^2)/((8Ib-\theta^2)^2)$	$(I(2Ib-\theta^2)(a-cb)^2)/(2(4Ib-\theta^2)^2)$	$(2I(a-cb)^2)/(3(4Ib-\theta^2))$	$(I(a^2-3abc+2b^2c^2))/(2(4Ib-\theta^2))$
$\pi_i^s$	—	$(I(a-cb)^2)/(8Ib-\theta^2)$	$(I(a-cb)^2)/2(4Ib-\theta^2)$	$(2I(a-cb)^2)/(36Ib-9\theta^2)$	$(Ia(a-cb))/(2(4Ib-\theta^2))$
$\pi_i^{sc}$	$(I(a-cb)^2)/(4Ib-\theta^2)$	$(I(12Ib-\theta^2)(a-cb)^2)/((8Ib-\theta^2)^2)$	$(I(3Ib-\theta^2)(a-cb)^2)/(4Ib-\theta^2)^2)$	$(8I(a-cb)^2)/(9(4Ib-\theta^2))$	$(I(a-cb)^2)/(4Ib-\theta^2)$



$$\beta_3^* = \beta_1^* = \frac{\theta(a - cb)}{4Ib - \theta^2}. \quad (17)$$

Finally, we are substituting all the optimal values; we get  $w_3^*$ ,  $q_3^*$ ,  $p_3^*$ ,  $m_3^*$ ,  $\pi_3^s$ ,  $\pi_3^r$ , and  $\pi_3^{sc}$ . Specific values are listed in Table 2.

**4.4. Case 4: Retailer's BS Investment under the Revenue-Sharing Contract via Bargaining.** In the decentralized SC scenarios, the supplier's and retailer's total profit are less than the centralized SC and the BS based lifecycle information sharing effort is lower. Therefore, to achieve the optimal product lifecycle information sharing in a decentralized SC, the SL must invest a higher BS investment. However, the game follower may not be motivated to invest for the BS-based information sharing. To address this case issue, the cost-sharing contractual coordination is presented to the decentralized SC with BS, similar to [18].

When the retailer as a SL invests a higher BS investment, the bargaining RS contract includes two parameters: retailer's paid wholesale price  $w_4$  and the retailer's cost-sharing coefficient  $\varphi_4$ . In this case, the profit functions of the SF supplier and SL retailer with BS cost sharing are as follows:

$$\pi_4^s = (w - c)(a - bp + \theta\beta) + (1 - \varphi_4)(p - w)(a - bp + \theta\beta), \quad (18)$$

$$\pi_4^r = \varphi_4(p - w)q - I\beta^2 = \varphi_4(p - w)(a - b(p + m) + \theta\beta) - I\beta^2. \quad (19)$$

First, we solve the profit function for the retailer where the retailer's sales margin is  $m = p - w$ ; using the inverse induction method, we obtain first and second derivatives from equation (19) and set the first derivatives equal to zero:

$$p_4 = \frac{a + bw + \theta\beta}{2b}. \quad (20)$$

Next, we solve the profit function for the supplier from equation (18) by obtaining the first and second partial derivatives with respect to  $w_4$  and  $\beta_4$ ; then, we set the first derivatives equal to zero and get optimal values of  $w_4^*$  and  $\beta_4^*$ :

$$w_4 = \frac{4\varphi_2 Ia + 4Ibc - c\theta^2}{4Ib + 4\varphi_2 Ib - \theta^2}, \quad (21)$$

$$\beta_4 = \frac{\theta(a - cb)}{4Ib + 4\varphi_2 Ib - \theta^2}.$$

We are putting the optimal values into equation (20); therefore, our optimal retailer price is

$$p_4^* = \frac{2Ia + 4\varphi_2 Ia + 2Ibc - c\theta^2}{4Ib + 4\varphi_2 Ib - \theta^2}. \quad (22)$$

To get the value of  $\varphi_4^*$  through cost-sharing contract, we used the approach proposed by [17, 19]:

$$\pi_4^{sc} = \pi_4^r \pi_4^s = \frac{4\varphi_2 b I^3 (a - bc)^4}{(4bI + 4\varphi_2 bI - \theta^2)^3}, \quad (23)$$

$$\varphi_4^* = \frac{4Ib - \theta^2}{8Ib}.$$

Finally, we substitute the value of  $\varphi_4^*$  in the above expressions; we get  $w_4^*$ ,  $q_4^*$ ,  $p_4^*$ ,  $m_4^*$ ,  $\pi_4^s$ ,  $\pi_4^r$ , and  $\pi_4^{sc}$ . Specific values are listed in Table 2.

**4.5. Case 5: BS Cost and Revenue-Sharing Model under Retailer Stackelberg Leadership.** In this case, a decentralized SC scenario under the retailer SL structure presents the Blockchain system investment via cost sharing as well as with revenue-sharing model.

We assume that the leader maximizes the profit of the whole SC as an effort added coordinator, and we use revenue-sharing contract to coordinate the retailer's and supplier's decision-making. In other words, the supplier is committed to providing the retailer a lower wholesale price  $w$ , while the retailer is committed to returning a certain percentage  $(1 - \phi_5)$  of sales revenue to the supplier for making up for the supplier's profit loss due to the lower wholesale price. The position  $w_5 < c$  guarantees channel coordination whereas  $\phi_5$  determines the distribution of total profits between the supplier and retailer.  $\phi_5$  is the SC profit quota gained by the retailer [20]. The profit functions of the supplier and the retailer in this decentralized SC with BS investment cost and revenue-sharing model scenario are given by

$$\pi_5^s = (w - c)(a - bp + \theta\beta) - (1 - \vartheta_3)I\beta^2 + (1 - \varphi_5)(p - w) \cdot (a - bp + \theta\beta), \quad (24)$$

$$\pi_5^r = \varphi_5(p - w)q - \vartheta_3 I\beta^2 = \varphi_5(p - w)(a - bp + \theta\beta) - \vartheta_3 I\beta^2. \quad (25)$$

The total profit function of the whole SC with BS cost is

$$\pi_5^{sc} = \pi_5^r + \pi_5^s. \quad (26)$$

First, we solve the profit function for the retailer where the retailer's sales margin is  $m = p - w$ ; using the inverse induction method, we obtain first and second derivatives from equation (8) and set the first derivatives equal to zero:

$$m_5 = \frac{a - wb + \theta\beta}{2b}. \quad (27)$$

Next, we solve the profit function for the supplier from equation (24) by obtaining the first and second partial derivatives with respect to  $w_5$  and  $\beta_5$ ; then, we set the first derivatives equal to zero and get optimal values of  $w_5^*$  and  $\beta_5^*$ :

$$w_5^* = \frac{2Ia + 2Ibc - c\theta^2}{4Ib - \theta^2}, \quad (28)$$

$$\beta_5^* = \frac{\theta(a - cb)}{4Ib - \theta^2}.$$

We are putting the optimal values into equation (27); therefore, our optimal retailer price is

$$p_5^* = \frac{c\theta^2 + 6Ia + 2Ibc}{8Ib - \theta^2}. \quad (29)$$

Finally, we are substituting all the optimal values into equations (9), (24), and (25) and getting the maximum profits for the supplier, retailer, and the whole SC under case 5. Specific values are listed in Table 2.

## 5. Comparison and Simulation Analysis

In order to obtain valuable conclusions and efficiency of the models, we use MATLAB software in this section. We explore the effects of different parameters on the decision-making behaviors and profits of SC members with the numerical values. We assume that the consumers sensitivity to price  $b$  is uniformly distributed within the consumer sensitivity from 0 to 1, with a density of 1, similar to [21]. In order to present the simulation within the feasibility region, we assign the values to parameters with changes to the similar researches of Ghosh and Shah's [17] and Song and Gao [18]. In the numerical example, the market potential  $a$  is known and forecasted for the single period. We set the parameters from Table 3 into previously analysed scenarios:

*5.1. Comparison.* We compare the cost coefficient of lifecycle information sharing effort, the consumer's price sensitivity coefficient, and expected profits of the suppliers and the retailers. The values of the parameters and the results under the five cases are summarized in Table 2.

Based on the above five models' optimal decision variables and total profits comparison, we can derive the following propositions.

**Proposition 1.** *The LIT level of a product is on the highest level under the centralized SC's effort added case and on the lowest level under the bargaining RS model and the decentralized SC SL effort added case model. The LIT level of the product under the cost and revenue-sharing contract is higher than that under the decentralized SC case, SL retailer cost-sharing case, and the bargaining revenue-sharing case. Under the cost and revenue-sharing contract if consumers' sensitivity to the price is greater, the coordinate of SC will be difficult. However, if consumers' sensitivity to the LIT is greater, the SC with BS investment will be easy to coordinate  $\beta_5^* = \beta_1^* = \beta_3^* < \beta_2^* < \beta_4^*$ .*

*Proof of Proposition 1.*

$$\frac{\theta(a - cb)}{4Ib - \theta^2} = \frac{\theta(a - cb)}{4Ib - \theta^2} = \frac{\theta(a - cb)}{4Ib - \theta^2} < \frac{\theta(a - cb)}{8Ib - \theta^2} < \frac{2\theta(a - cb)}{12Ib - 3\theta^2}. \quad (30)$$

**Proposition 2.** *When the cost-sharing coefficient  $\vartheta_3$  is equal to the revenue-sharing coefficient  $\phi_5$ , the SC with BS investment can be coordinated and win-win situation among the chain members can be achieved via the BS cost and*

TABLE 3: Parameters and values.

Parameter	$c$	$a$	$I$	$b$	$\theta$
Value	8	100	5	0.5	0.5

*revenue-sharing contract. If the BS investment cost and revenue-sharing contract is satisfying  $\vartheta_3 = \phi_5$ , then the SC with BS investment can be coordinated. The total profit of the SC with BS investment is largest under centralized control conditions and smallest under decentralized SL retailer SC decision-making conditions. Profitability under the cost and revenue-sharing contract is higher and conducive to consumers satisfaction with LIT preference.*

*Proof of Proposition 2.* The total profit under the BS investment cost and revenue-sharing contract is

$$\pi_5^{sc} = \pi_5^{sc} + \pi_5^{sc} = \frac{Ia(a - cb)}{2(4Ib - \theta^2)} + \frac{I(a^2 - 3abc + 2b^2c^2)}{2(4Ib - \theta^2)} = \frac{I(a - cb)^2}{4Ib - \theta^2}. \quad (31)$$

Then, we compare the SC profit under cost and revenue-sharing contract with other cases in the decentralized SC and benchmark SC; we got  $\pi_2^{sc} < \pi_3^{sc} < \pi_4^{sc} < \pi_5^{sc} < \pi_1^{sc}$ ; thus, we can see SC with the BS investment cost and revenue-sharing contract is more efficient with higher profit compared to the other cases.  $\square$

*5.2. Simulation Analysis.* We simulate the consumer's price sensitivity coefficient  $b$ , the lifecycle information sharing effort level under BS  $\beta$ , and the influence of sensitivity coefficients on the decision-making behaviors and expected profits of the suppliers and the retailers. To see the sensitivity of our results, we plot the optimal values of the parameters and the results shown in Figures 1–4. Figure 1 indicates the impacts of price sensitivity and BS-based LIT level on the expected profits of the retailers under four cases. Figure 3 shows the impact of the price sensitivity coefficient and BS-based LIT level on the expected profits of the suppliers. Figure 4 shows the impact of price sensitivity and BS-based LIT level on the expected profits of SCs under the various scenarios. As can be seen from Figure 4, the suppliers and retailers profit is comparatively higher than the other models.

To see both sensitivity performances in our model, we illustrate the model under the effects of consumers' sensitivity  $b$  and  $\beta$  on SC profit and the results are shown in Figure 2. It can be seen that, in case of SC's BS investment, the profit of whole chain increases with the increase of the LIT level and the SC profit decreases with the increase of customer's price sensitivity.

## 6. Conclusions and Future Research

This paper examined two-stage SC consisting of a supplier and a retailer where the retailer is the leader. The following five scenarios were examined: a benchmark model where there is a single decision-maker; a decentralized model via retailer invested lifecycle information sharing effort; a

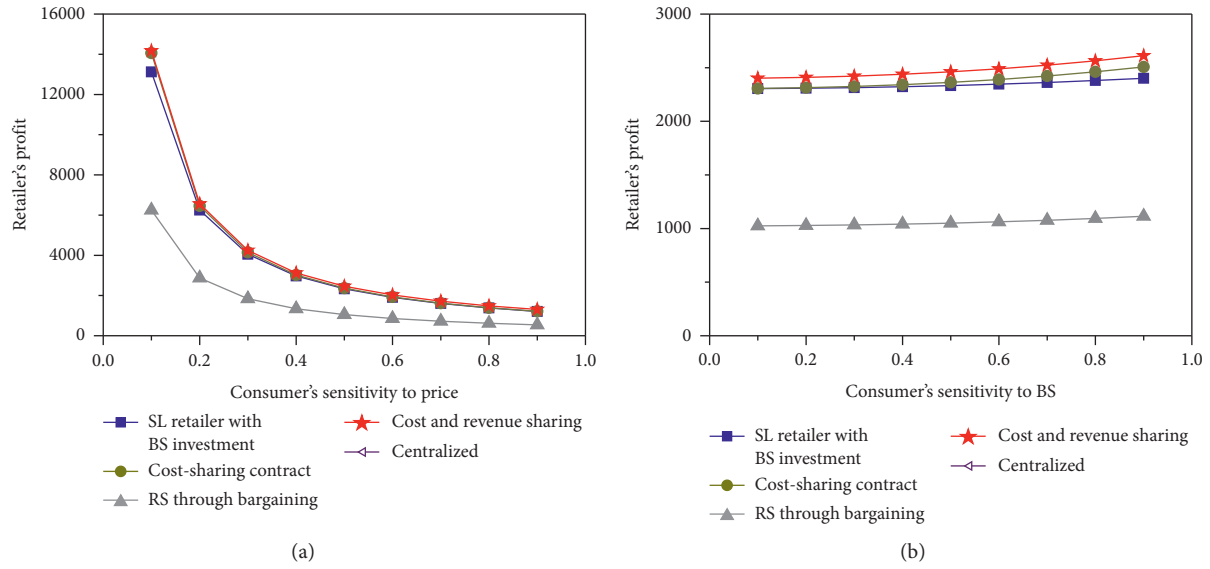


FIGURE 1: (a) The effect of optimal  $b$  on the expected profits of the retailers. (b) The effect of optimal  $\beta$  on the expected profits of the retailers.

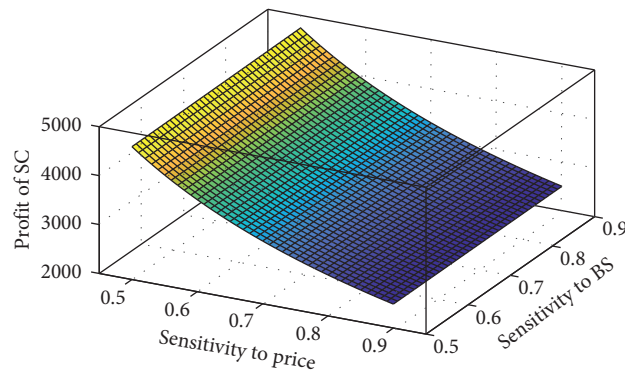


FIGURE 2: The effects of consumers' sensitivity  $b$  and  $\beta$  on SC profit.

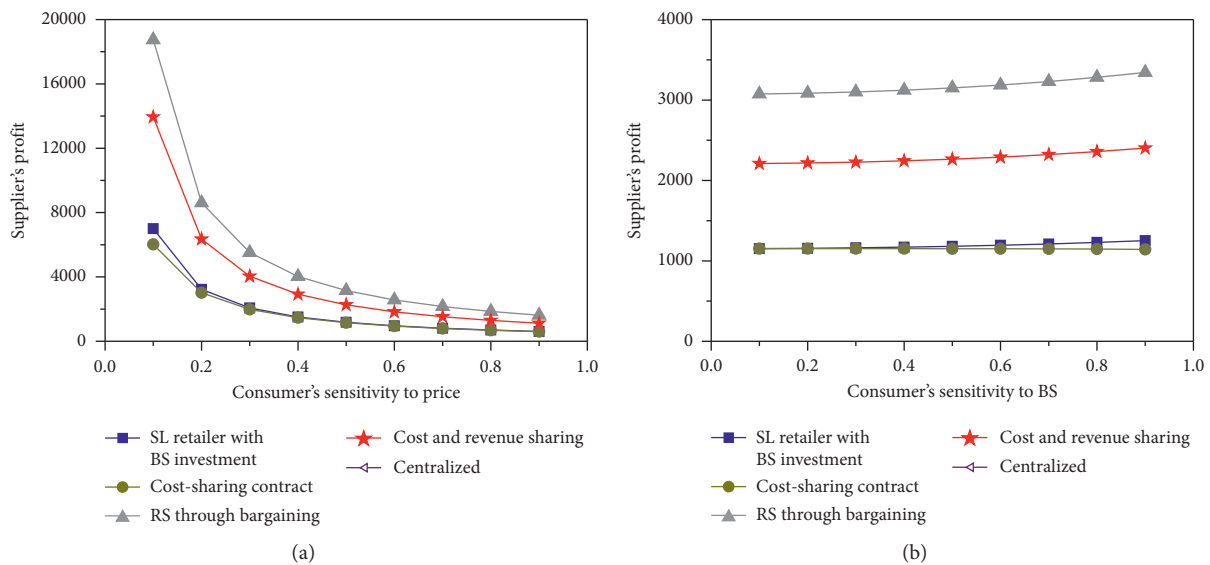


FIGURE 3: (a) The effect of optimal  $b$  on the expected profits of the suppliers. (b) The effect of optimal  $\beta$  on the expected profits of the suppliers.



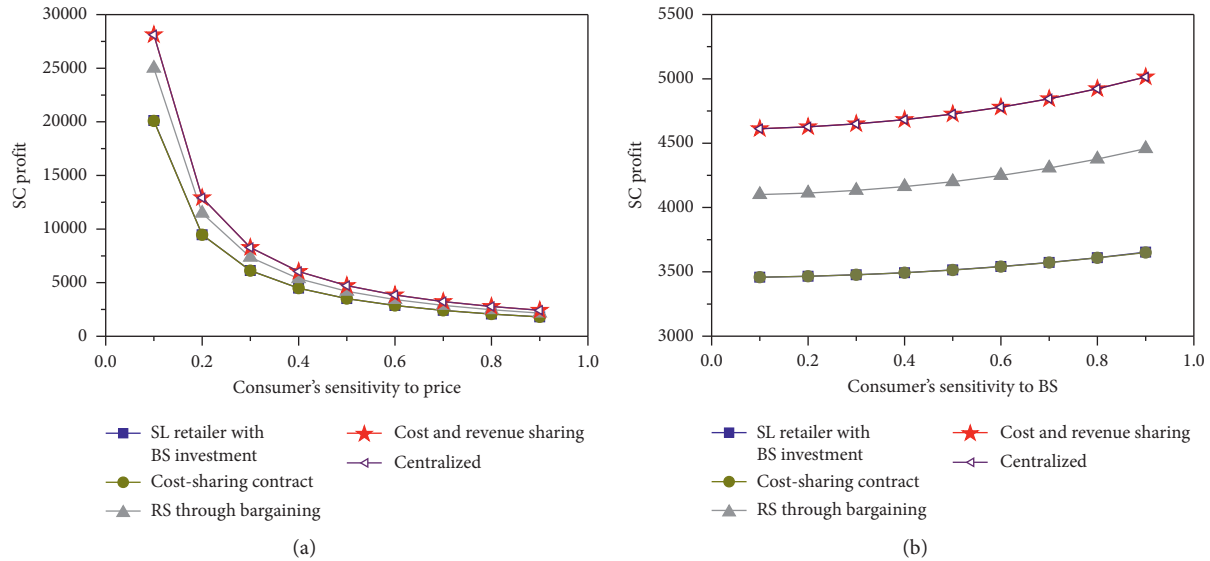


FIGURE 4: (a) The effect of optimal  $b$  on the expected profits of the SCs. (b) The effect of optimal  $\beta$  on the expected profits of the SCs.

cost-sharing model under retailer SL; a bargaining RS model under retailer SL; the cost and revenue-sharing model under retailer SL. The paper constructs a SC model based on product proper lifecycle information sharing effort cost coefficient, consumer's price sensitivity coefficient with the decision-making behaviors, and expected profits of SC members. With the help of game theory, the Nash equilibrium solution of the SC under different circumstances is obtained. Total SC profit of the five models is solved by reverse induction method, and the results are compared and analysed. Our study is providing incentives to the upstream SC by proper sharing of its cost and revenue simultaneously. In addition, cost and revenue-sharing coordination mechanism will give sustainability to building long-term relationships between the members of decentralized SC. Our future research will focus on investigation of the models in different industries with uncertain demand to understand the impact of the product and process information sharing via BS. Future research could focus on the global distribution of demand to minimize the risk among multiple competing members.

### Data Availability

The analysis of this study is based on secondary data, including online databases, digital libraries, books, and journals. The sources of the reviewed papers are mainly from different scientific resources (i.e., Research Gate, Elsevier, IEEE, and EI publishers).

### Conflicts of Interest

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

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