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RESEARCH PAPER

Two-Level Supply Chain Quality Improvement Through a Wholesale Price Coordination Contract on Pricing, Quality, and Services

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ABSTRACT

Nowadays, competitive market creates the necessity of quality improvement at different levels of supply chains (SCs). This paper contributes to the SC coordination literature and proposes a bilateral wholesale price (BWP) contract for optimizing pricing and quality improvement decisions in different echelons of a cell phone SC. The SC comprises a manufacturer who deals with determining the product quality and a retailer who seeks an optimal strategy for price, after-sales service, and service level in a periodic review inventory system. First, the decentralized model is investigated, where each member makes decisions individually. Afterwards, a benchmark is obtained for the whole system optimality through centralization. To convince the members to choose the benchmark decisions, the BWP contract is proposed and is shown to be capable of simultaneous coordination of the decisions. The analyses showed that in a market which is sensitive to quality, service, and price, the application of BWP facilitates greater investing in such quality improvements while the members' profitability is guaranteed in comparison to the traditional case. Moreover, this application can increase the SC service level, since it enables the members to hold more safety stock even under high inventory costs. Overall, the proposed coordination model for pricing, quality, after-sales service, and service level leads to the optimal performance of the SC and its members while it is beneficial for the customers.

KEYWORDS: *Quality improvement, Supply chain coordination, Pricing, Service, Periodic review inventory system, Bilateral wholesale price contract.*

1. Introduction

Supply Chain (SC) is a set of entities connected with streams of materials from upstream entities to downstream ones and financial and information flow from downstream entities to upstream ones. One of the main indicators of the effectiveness of this system is the level of demand that the SC faces. In today's market, product price, product quality, after-sales service, promotional efforts, etc. are the well-known factors that affect product demand. Moreover, the percentage of customers whose demands are met within a given period (i.e., the service level of the SCs) can be another important indicator of the system performance in the market. Analyzing such factors and proper management of the related operations, especially in the competitive markets with stochastic demands, can have great impacts on the success of the SC business. Proper management of these systems highly depends on the interactions between the entities within the system. Generally, many decisions in the SCs, especially those related to *product price*, *product quality*, and *services*, are made individually by each SC entity. Each entity's decision on one of these factors may either positively or negatively affect the others' profitability. One approach to improving this individual decision-making structure is considering the whole SC viewpoint so as to achieve a globally optimal performance. However, such a consideration may not result in mutual profits of the SC members. In fast-changing markets, the relationship among the firms is becoming closer. Thus, to improve all members' profit and achieve mutually beneficial goals and the globally optimal performance of the

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SCs, a coordination mechanism can play a critical role in generating such outcomes [1]. The necessity of applying a coordination model is much more realized when considering such interdependent decisions as retailers' services, inventory replenishment, product quality, and service level improvement, which can determine the level of a qualified SC. For the coordination purposes, many contracts are developed in the related literature, such as discount ([2], [3], [4], [59]), credit period contract ([5], [6]), two-part tariff contract ([60],[61]), collaborative models ([7], [8], [9]), cost sharing ([10], [11], [12]), and combined contracts ([62]). *Product quality* denotes a set of product features, more of which increase consumer product price and also marginal costs [13]. Putting product price aside, product quality plays the most important role in consumers' purchasing behaviors [46]. Some of the most well-known companies, such as Tylenol, Coca-Cola, Starbucks, and Porsche invest in their product quality in order to guarantee the best possible service or product received by the customers [58]. Besides product quality, service level is another competitive decision in today's market [48], which can bring customers' satisfaction [47]. Since the similarity of the products is increasing, it is a notable issue for the firms to enhance their differentiation from other competitors by investing in service efforts such as repairing, upgrading products over many years, and providing pre-sales services and after-sales services [20]. Between these services, the last one belongs to a set of most prominent factors, which keep customers and their satisfaction with products. In other words, after-sales service is a strategy for firms to promote their competitiveness [20]. For example, Apple Inc. provides after-sales services through its retailers by considering wholesale price contracts for them. Samsung also considers such services, mostly through its authorized downstream. Amazon, an online retailer, provides insurance services, called "Amazon Prime." Suning, a Chinese electronic product retailer, is presenting after-sales services for customers [21]. Services are costly for their providers and a longer service period increases this cost [17]. However, customers prefer products with more extended service periods. Hence, it is important to determine a desirable level of investment in services. In recent years, among SC owners, optimizing inventory, decreasing operating expenses, and improving service levels are becoming more popular points [24]. The safety stock is an acute factor in the uncertain situation, which specifies the SC service level [25]. Service level is described as an amount of demand, which is met by the retailer in a determined period [25] and positively affects the SC performance in competitive environments. Besides, the improvement of the service level can change the pricing strategies [26]. On the other hand, Liu et al. suggested that, under certain situations, the increased service level reduces the total service capacity [26]. Since the service level mitigates the impacts of unexpected events, it is necessary to set an inventory level according to the additional safety stock [27]. The low level of safety stock leads to shortage on the retailer side and reduces all members' market share [28] while additional safety stock terminates additional costs [25]. Therefore, upstream members make their efforts to convince the downstream ones to improve the service level and, in turn, mitigate shortage risks [29]. Generally, in decentralized SCs, the downstream member (e.g., retailer) specifies the safety stock level, while, in reality, this affects upstream member's profit, as well. Thus, the coordination of such decisions is very critical. The problem in the current study is investigated based on the challenges of a real case study related to a cell phone SC, where a manufacturer sells his product via a retailer. In the highly competitive market of cell phones, among a wide variety of cell phone types, one of the most important issues that the manufacturer deals with is the quality of its product. The retailer of this SC faces handling the service level and pricing, which are the other determining factors of the business success. Such decisions as the product quality, service, and price highly depend on each other; thus, lack of a proper scheme for integrated decision-making on these issues causes a financial problem for the company and leads to conflicts between the decision-makers in the current situation of the company. For instance, considering a high-qualified service for a product with a low-quality level results in high costs for the retailer, while it increases the product demand. Therefore, finding an effective method for making these decisions in an integrated manner in order to both reduce the conflicts and maintain the positive effects of them on demand is of high importance for the company. The current structure of decision-making in this SC is decentralized, where both the manufacturer and retailer decide separately with the aim of optimizing their own performance regardless of each other's profits.

On the other side, a centralized structure (integrated structure) leads to losses for one of the members. Accordingly, the company seeks a proper management strategy to resolve the challenges of finding an optimal decision-making structure for such interdependent decisions in order to reduce the conflicts between the decision-makers in determining quality, pricing, service level, and after-sales service decisions. Motivated by the challenges of the above real case and according to the research gaps, the current paper contributes to the literature on SC coordination by finding optimal decisions on pricing, after-sales service, quality, and service levels so that both the entire SC and its members' performance are optimized. More precisely, this study investigates decisions related to SC quality improvement at two levels of the SC. To find the optimal decisions, three different decision-making models are investigated and, finally, a coordination model is proposed to apply a bilateral wholesale price to convince the SC members to give up single decision-making and accept the centralized structure, which results in the global optimum for the whole system's performance and its members. In the next section, proper description of the real case problem under investigation is represented. After that, in Section 3, the decentralized, centralized, and coordinated structures are modeled. Section 4 represents the model evaluation based on the case data. Finally, Section 5 provides conclusions of the paper and some suggestions for future research.

2. Literature Review

In this section, the related literature is reviewed considering quality improvement in the SC along with service and periodic review inventory decisions.Studying quality decisions along with pricing and other related decisions in supply chains (SCs), where each decision is made by the corresponding entity regardless of the other entities' profit, has gained academics' attention and practitioners. For instance, Ma et al. considered the demand as a function of quality, price, and promotional efforts and proposed a combined coordination contract for finding their optimal values [14]. Seifbarghy et al. applied a revenue-sharing policy for calculating the best decisions on pricing and quality within a two-echelon SC [15]. Jerath et al. studied the interchange of quality, inventory, pricing, and vertical channel interactions [13]. Yoo and Cheong studied quality enhancement through reward policies offered by a buyer to a supplier and investigated the effects of this strategy on SC operations [16]. Hosseini-Motlagh et al. proposed a coordination contract to find the optimal amounts of quality along with competitive warranty decisions [17]. Zhang et al. studied the relations between an upstream member's quality decisions and the downstream member's selection of revenue-sharing mechanisms [18]. In a study by Sarkar et al., quality improvement and safety factor were imported into their model as dependent variables, while they were directly influenced by customer satisfaction [19]. Li et al. considered a two-echelon supply chain, where the supplier offered core components with a certain quality level to the downstream manufacturer [49]. They investigated optimal pricing and quality decisions considering fairness preferences of the members and their bargaining powers. These studies have all studied quality improvement in the production level along with pricing and inventory decisions. Besides the product quality, after-sales service is another important factor that affects product demand and is interlinked with the product quality decisions [17]. From a theoretical viewpoint, investigating service decisions in SCs and finding the optimal amount of investment in services have become more popular in recent years. Habibi and Tarokh investigated competition among two service providers offering the same web service in which a monopoly service provider offered a complementary service to their services. Each provider decided on service level and pricing for the service level [50]. Wu investigated a SC including two manufacturers bundling their products with services (warranty and advertisement) and a retailer that sold the products and decided on the sales price [51]. Li et al. proposed a service commitment policy in a manufacturer-retailer system, and showed that a cost-sharing strategy can enhance their profits [20]. Wei et al. investigated the best strategies for pricing and warranty service under four different game structures [22]. Rezapour et al. developed an integrated model for designing an effective production schedule and determined the optimal service level and after-sales service [23]. Dan et al. studied warranty service decision of a manufacturer in a dual-channel SC consisting of a manufacturer and a retailer that competed on offering free value-added service to customers [52]. Xia et al. examined service-level and distribution channel decisions for two competing SCs with a focus on how service competition affected the channel structure [53]. Although these studies have considered optimization of service decisions in SC systems, studies considering service decisions along with quality and pricing decisions are scarce; for instance, Yuen and Chan investigated the impact of the retailer's service level and product quality on customers loyalty [54]. Modak et al. considered optimization of warranty service period, pricing, and quality decisions under the decentralized and centralized models [55]. Hosseini-Motlagh et al. proposed the optimization of warranty service and green quality under a competitive situation [17]. Similar to these studies, this study aims to optimize service and quality decisions; however, different from them, this study considers simultaneous coordination of pricing, service, and quality decisions while considering the effect of service level decisions under a periodic review inventory system. Replenishment decision of a SC member is one of the factors that affects the responsiveness and performance of the SC and needs to be coordinated [42]. In comparison with other inventory systems, under the periodic review inventory systems, there is a need to hold more safety stock in order to increase the service level of the SC [56]. This imposes costs on the system. Accordingly, the optimization of safety stock decisions has attracted the attention of academia in recent years. Johari et al. coordinated pricing and periodic review inventory decisions (i.e., safety stock and review period) using a quantity discount coordination model [30]. In another study, Johari et al. proposed a coordination model based on different modes of transportation for coordinating review period, safety stock, and pricing [31]. Nematollahi et al. proposed the coordination of a two-level pharmaceutical SC and service level by applying a multi-objective collaborative decision-making structure, in which visit interval of the pharma-distributor specified the review period duration of the pharma-retailer's inventory method [8]. Hosseini-Motlagh et al. investigated the coordination of periodic review replenishment decisions along with advertising in a competitive situation [32]. They showed that the coordination model reduced the risks of such decisions even under competition. Hosseini-Motlagh et al. explored coordination among the members of a two-echelon socially responsible SC with promotional effort, corporate social responsibility, and periodic review replenishment decisions [10]. In order to optimize inventory policies, using periodic-review base-stock policy, Sakulsom and Tharmmaphornphilas proposed a two-phase heuristic method by which the first phase involved determining the initial ordering policy and the second phase involved determining the safety stock [57]. Similar to these studies, the current study aims to optimize safety stock decision in a periodic review system by considering safety stock as a decision variable. However, the aim of this study is to optimize this decision variable along with other factors that affect the quality of services in the SCs, i.e., service and quality decisions.A summary of the reviewed literature is provided in Table 1. Based on the reviewed literature, one can conclude that the simultaneous coordination of quality, pricing, after-sales service, and service level, which are interrelated decisions, has not yet been investigated. Although the optimization of each single decision, or at most two of the three decisions, has been considered in the previous literature, for instance, Ma et al., Seifbarghy et al., Jerath et al., Mai et al., Yoo and Cheong, and Zhang et al., which have coordinated quality and pricing decisions [14],[15],[13],[33],[16],[18] and Hosseini-Motlagh et al. who have investigated the coordination of quality and service decisions [17], these studies have not considered coordination of quality, pricing, and service decisions simultaneously. Moreover, most of the papers in the context of SC quality improvement (e.g., [14], [16], and [18]) have considered improvements in the production level (i.e., product quality improvement); however, one can consider SC quality improvement in other layers of the SC, as well. To be more precise, the service level and after-sales services can be other signs of the quality of SC performance. Accordingly, the optimization of service level and after-sales services has been widely considered in the previous literature (as in [50], [20], and [8]). However, they all have considered the quality improvement in one layer of the SC, i.e., production or sales level and not simultaneously in both layers. Moreover, regarding the service level improvement in the periodic review inventory systems, to the best of our knowledge, only Nematollahi et al. investigated the coordination of service level decisions [29],[8]; however, they have not considered the coordination of these decision along with other important factors as price, quality, and, service decisions, which the current study aims to do.

Overall, based on the above research gaps, the main contributions of this paper can be expressed as follows: (a) proposing SC quality improvement in two levels of the SC, i.e., production level and sales level, simultaneously; (b) developing a bilateral wholesale price contract to simultaneously coordinate pricing, quality, after-sales service, and service level within a periodic review inventory system.

3. Problem Definition

This paper considers the challenges of a real case of a two-echelon cell phone supply chain (SC), including a manufacturer and a retailer, namely MEC and CLPH, respectively. Due to confidentiality reasons, these artificial names are chosen for the SC members. In the investigated case study, MEC produces a new type of cell phone, and the competitive market of the cell phone makes it critical for MEC to consider the quality level of this product. MEC sells its cell phones in the market through CLPH. CLPH decides on the price, after-sales service, and service level of this cell phone. To reduce shortages, it is important for CLPH to increase its service level in the market. It applies a periodic review inventory system for its replenishment decisions and needs to determine the optimal decision on safety stock in this system, which is a determining factor of its service level. CLPH places orders at constant intervals to MEC and receives orders after a constant lead time. Since lead time does not exceed the length of inventory review interval, there is always no more than one order in each cycle. The shortages on the CLPH side are fully backordered. However, it tends to increase its service level to remain competitive in the market. MEC invests in SC quality improvement at the production level, and CLPH considers SC quality improvement strategies at the sales level.Considering a higher quality level or providing a qualified service for the customers has benefits for both MEC and CLPH, as well as the whole SC, since it increases demand. However, only the corresponding decision-maker incurs the costs of such decisions. In the current situation, MEC and CLPH individually determine the optimal level of their decisions so that their own profitability is optimized. This kind of decision-making does not necessarily lead to the best performance of the entire SC. This is due to the fact that product quality, service, and price are interrelated decisions, and the current decision-making structure of the SC ignores such an interrelation. This, in turn, may cause the SC to miss a great amount of marginal profit. For instance, if the cell phone produced by MEC is not of high quality and CLPH offers a long service period and a high price for this product, this not only leads to high service cost for CLPH, but also has negative effects on the company's credibility in the market. On the other hand, if CLPH holds little amounts of safety stock, due to the fact that the market demand is stochastic, its service level may become low in the market, which reduces MEC's profit, as well. Overall, a challenge for the whole company is to maintain its market share in the competitive situation and find the optimal quality improvement strategy at different levels of its SC. Another challenge is to find a proper decision-making structure to determine the optimal values of pricing, quality, after-sales service, and safety stock level in such a way that both MEC and CLPH profits, as well as the whole SC's profit, are optimized.To resolve the company's challenges, in this paper, three different structures of decision-making are investigated. First, the decentralized model in which MEC and CLPH decide separately to maximize their own profit is determined through a Retailer-Stackelberg game with CLPH as the leader and MEC as the follower. Second, the centralized model is investigated in which the SC is considered as an integrated unity with a central decision-maker, who determines the pricing, quality, after-sales service, and safety stock decisions with the aim of optimizing the whole SC profit. The centralized decisions may not necessarily be acceptable by MCE or CLPH. Thus, to convince MEC and CLPH to choose these decisions, a bilateral wholesale price (BWP) coordination mechanism is proposed. Afterward, to examine the model applicability, the model is run based on the company data, and a comprehensive sensitivity analysis is performed, as well. The notations used for the parameters and decisions variables are provided in Table 2.

4. Model Formulation

This study investigates the decentralized, centralized, and coordinated decision-making models. The optimum amounts of decision variables are determined under these structures. In the case under realization, it is assumed that the service level, after-sales services, and sales price are endogenous variables determined by the retailer (CLPH), and quality is the manufacturer’s (MEC’s) endogenous decision variable; therefore, according to the explanation offered by Chen at al. on endogenous selling prices, they are determined considering demand sensitivity to these variables [63].

Tab. 1. A brief view of the reviewed literature.

Reference	Decisions						Demand function	Supply chain structure			Coordination mechanism	Inventory system
	Pricing	Quality	Service	Order Quantity	Replenishment in (*R,T*) system	Other		Decentralized	Centralized	Coordinated		
Habibi and Tarokh [50]	✓		✓				Deterministically Dependent on Price and Service quality	✓			------	------
Yuen and Chan [54]		✓	✓				------				------	------
Wu [51]	✓		✓				Deterministically Dependent on Price and Service	✓			------	------
Ma et al. [14]	✓	✓					Deterministically Dependent on Price, marketing efforts, and quality	✓	✓	✓	Combination of two-part tariff and quality cost-sharing contracts	------
Li et al. [20]	✓		✓	✓			Stochastic with IFR Dependent on retailer's service level commitment.	✓	✓	✓	Cost-sharing mechanism	------
Wei et al. [22]	✓		✓				Deterministically Dependent on price and warranty	✓			------	------
Seifbarghy et al. [15]	✓	✓					Deterministically Dependent on price and quality	✓	✓	✓	Revenue-sharing contract	------
Modak et al. [55]	✓	✓	✓				Deterministically Dependent on price, warranty, and quality	✓	✓		------	------

Tab. 1. (continued)

	Decisions							Supply chain structure				
Reference	Pricing	Quality	Service	Order Quantity	Replenishment in (R,T) system	Other	Demand function	Decentralized	Centralized	Coordinated	Coordination mechanism	Inventory system
Rezapour et al. [23]			✓	✓			Stochastic Dependent on pre-sales and after-sales service levels and warranty length	✓	✓		------	Newsboy
Jerath et al. [13]	✓	✓		✓			Random variable	✓	✓	✓	Wholesale price contract	Newsvendor
Johari et al [30]	✓				✓		Stochastic, Dependent on price	✓	✓	✓	Quantity discount	Periodic review
Johari et al [31]	✓				✓		Stochastic, Dependent on price	✓	✓	✓	Lead time crashing	Periodic review
Hosseini-Motlagh et al. [17]		✓	✓				Deterministically Dependent on quality and competitive warranty services	✓	✓	✓	Multilateral compensation-based wholesale price contract	------
Mai [33]	✓	✓					Deterministically Dependent on product quality (regarding probability of failure, value of usage, and repair cost)	✓		✓	Extended warranty contracts	------
Yoo and Cheong [16]	✓	✓					Deterministically Dependent on price and quality	✓	✓	✓	Reward contracts	------

Tab. 1. (continued)

Reference	Decisions						Demand function	Supply chain structure			Coordination mechanism	Inventory system
	Pricing	Quality	Service	Order Quantity	Replenishment in (R,T) system	Other		Decentralized	Centralized	Coordinated		
Li et al. [49]	✓	✓	✓				Deterministically Dependent on Price and quality	✓	✓		------	------
Dan et al. [52]			✓				Deterministically Dependent on warranty and value-added service	✓			------	------
Hosseini-Motlagh et al. [10]		✓			✓	✓	Stochastically Dependent on social responsibility and promotional efforts	✓	✓	✓	Cost-sharing contract	periodic review
Hosseini-Motlagh et al. [32]					✓	✓	Stochastically Dependent on competitive advertising	✓	✓	✓	Lead time crashing	periodic review
Nouri et al. [42]					✓	✓	Stochastically Dependent on innovation and promotional efforts	✓	✓	✓	Compensation-based wholesale price contract	periodic review
Nematollahi et al. [8]					✓		Stochastic with Normal distribution	✓	✓	✓	Multi-Objective collaborative decision-making	Periodic review
Zhang et al. [18]	✓	✓					Deterministically Dependent on quality and price	✓		✓	Revenue-sharing Fixed-fee scheme	------
Sarkar et al. [19]		✓			✓	✓	Stochastic With unknown distribution		✓		------	Continuous review

Tab. 1. (continued)

Reference	Decisions: Pricing	Quality	Service	Order Quantity	Replenishment in (R,T)	Other	Demand function	Supply chain structure: Decentralized	Centralized	Coordinated	Coordination mechanism	Inventory system
Xia et al [53]	✓		✓				Deterministically Dependent on price and services	✓			------	------
Sakulsom and Tharmmaphornphilas [57]	✓				✓		Seasonal, deterministic in the first phase Stochastic in the second phase		✓		------	Periodic review
Current study	✓	✓	✓		✓		Stochastic with Normal distribution Dependent on quality, price, and service	✓	✓	✓	Bilateral wholesale price contract	Periodic review

4-1. Decentralized

In the decentralized structure, each supply chain (SC) member only cares about his/her own benefit optimization without considering the other members' benefit [34], [35]. To model this structure, a game-theory approach is used, because CLPH's decisions affect MEC's decisions. This is due to [36], which mentions that the game theory is used in a situation that the decision of each player influences that of other players. Since CLPH is more powerful in the market than MEC, a Stackleberg pattern (as in [45]) is used, in which CLPH and MEC are the leader and the follower, respectively. To solve the game model, backward induction is applied. Accordingly, at first, MEC's problem is solved by considering CLPH's decisions on price, service level, and after-sales service, leading to a primary q_m, which is MEC's response to these decisions.

4-1-1. Manufacturer (MEC) model

The profit function of MEC under the decentralized model is:

$$\pi_m(q_m) = (w-c)(D_0+\alpha q_m+\beta s_r-\theta p_r) - \frac{v}{nT} - \frac{1}{2}\gamma {q_m}^2 - h_m\left[\frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)T}{2}\right]\left[\frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)}{PR}(2-n)+(n-1)\right] \quad (1)$$

The first term in the above equation is the revenue for MEC and next terms include setup cost per period, cost of quality investment, and holding cost, respectively. MEC uses a lot-for-lot policy for its replenishment purpose, in which the production multiplier n is constant and deterministic. The holding cost is adopted from Joglekar [37], which represents the average inventory as $\frac{DT}{2}[\frac{D}{P}(2-n)+(n-1)]$, and the cost of quality investment is adopted from [14].

Proposition 1. *MEC's profit function is concave over q_m and the primary amount of q_m is*:

$${q_m}^{primary} = \frac{\alpha\left[(w-c)-hm\left[(2-n)\frac{T}{PR}(\mathrm{D}_0+\beta s_r-\theta \mathrm{p}_r)+\frac{\mathrm{T(n-1)}}{2}\right]\right]}{\gamma+hm\left[(2-n)\frac{\alpha^2 T}{PR}\right]} \quad (2)$$

Proof. Refer to "Appendix 1"

Based on the primary q_m, CLPH's problem is solved. The problem is formulated in the following subsection.

Tab. 2. Notations

Decision variables	
s_r	Retailer's level of after-sales service (unit)
p_r	Per unit retail price ($/unit)
$\mathrm{q_m}$	Level of product quality (unit)
$\mathrm{R_r}$	Order-up-to level (unit)
Parameters	
$\mathrm{D_0}$	Primary market size (unit/year)
$\mathrm{A_r}$	Unit ordering cost for the retailer ($/order)
$\mathrm{h_r}$	Inventory holding cost per unit for the retailer ($/unit)
$\mathrm{h_m}$	Inventory holding cost per unit manufacturer ($/unit)
L	Lead time, given (year)
y	Demand in protection interval ($T + L$), following a Normal distribution as $Normal(D(\mathrm{T}+\mathrm{L}), \sigma\sqrt{\mathrm{T}+\mathrm{L}})$
T	Length of a review period (year)
n	Production multiplier for the manufacturer ($n \in Z^+$)
w	Wholesale price offered by the manufacturer to the retailer per unit ($/unit)
v	Manufacturer's setup cost per setup ($/setup)
c	Manufacturer's production cost per item ($/item)
π	Shortage cost per unit for the retailer ($/unit)
α	Demand sensitivity to quality level (unit)
β	Demand sensitivity to the level of after-sales service (unit)
θ	Demand sensitivity to retail price (unit)
γ	Cost efficiency coefficient of investment in product quality ($/unit)
σ	Standard deviation of demand within protection interval
δ	Cost coefficient of after-sales service per unit service, per unit demand ($/unit service/unit demand)
λ	Cost coefficient of after-sales service independent of demand ($/unit service)
PR	Manufacturer's production rate per

	year (unit/year)
d	Coordination parameter (discount/surcharge)
d_{min}	The lower limit of the coordination parameter
d_{max}	The upper limit of the coordination parameter
$d_{sharing}$	The exact value of the coordination parameter

4-1-2. Retailer (CLPH) model

Here, the CLPH's problem is formulated, and the optimal values of its decisions on pricing, service level, and after-sales service are calculated. CLPH profit function is:

$$\pi_r(R_r, s_r, p_r) = (p_r - w - \delta s_r)(D_0 + \alpha q_m + \beta s_r - \theta p_r) - \frac{A_r}{T} - h_r\left[R_r - (D_0 + \alpha q_m + \beta s_r - \theta p_r)L - \frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)T}{2}\right] - \frac{1}{2}\frac{\lambda s_r^2}{T} - \frac{1}{T}\pi E(y - R_r)^+ \quad (3)$$

which expresses CLPH's revenue minus ordering cost, holding cost, service cost, and its shortage cost. The service cost is adopted from [38] and [39]. Moreover, as proposed by Vijayan and Kumaran, the holding cost in the periodic review inventory system is $h_r\left[R_r - DL - \frac{DT}{2}\right]$ [40]. Accordingly, this study considers CLPH's holding cost as $h_r\left[R_r - (D_0 + \alpha q_m + \beta s_r - \theta p_r)L - \frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)T}{2}\right]$. As explained before, we have assumed a Normal distribution $(N(D(T+L), \sigma\sqrt{T+L}))$ for the demand within the protection interval $(T+L)$. Accordingly, the order-up-to level, R_r, will be equal to $D(T+L) + k_r\sigma\sqrt{T+L}$. Moreover, according to [41], the shortage quantity in each period is:

$$E(y - R_r)^+ = \int_{R_r}^{\infty}(y - R_r)\, f_y d_y = \sigma\sqrt{T+L}\, U(k_r) \quad (4)$$

where $U(k_r)$ is equal to $f_z(k_r) - k_r[1 - F_z(k_r)]$. $f_z(k_r)$ and $F_z(k_r)$ are standard Normal probability and cumulative distribution functions, respectively. In these functions, subscript z is used instead of subscript y to imply that the normal distribution of y is changed into the standard form of the Normal distribution. Besides, due to the fact that order-up-to level R_r is equal to $D(T+L) + k_r\sigma\sqrt{T+L}$, for simplicity, safety factor k_r can be considered as one of CLPH's decisions instead of R_r. Such an assumption is made in [29]. Accordingly, the corresponding service level (SRL) can be obtained as $F_z(k_r)$, which is adopted from [29]. Based on this consideration, the profit function of retailer is converted to the following equation:

$$\pi_r(k_r, s_r, p_r) = (p_r - w - \delta s_r)(D_0 + \alpha q_m + \beta s_r - \theta p_r) - \frac{A_r}{T} - \frac{1}{2}\frac{\lambda s_r^2}{T} - h_r\left[\frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)T}{2} + \sigma\sqrt{T+L}\right] - \frac{\pi\sigma\sqrt{T+L}}{T}U(k_r) \quad (5)$$

CLPH tries to optimize the values of price, safety factor, and after-sales service. To calculate these optimal values, the following proposition holds.

Proposition 2. *CLPH's profit function is concave over k_r, s_r, and p_r.*

Proof. Refer to "Appendix 2".

s_r^*, p_r^*, and k_r^* are used to denote the optimum amounts of CLPH's decisions under the decentralized model, which are calculated based on the first-order derivative of Equation (5) *w.r.t.* s_r^*, p_r^*, and k_r^* as follows:

$$s_r^* = \frac{1}{2\,\delta\beta(1-M\alpha)+\frac{\lambda}{T}-\frac{N_1N_2}{2\theta(1-M\alpha)}}\Bigg[D_0\left(\frac{N_1}{2\theta(1-M\alpha)} - \delta\right) + w\left(\frac{N_1}{2\theta(1-M\alpha)}\theta - \beta\right) + M\alpha\left(w\beta - \frac{w\theta N_1}{2\theta(1-M\alpha)} + h_r\frac{T}{2}\left(\beta - \frac{N_1}{2\theta(1-M\alpha)}\theta\right)\right) - h_r\frac{T}{2}\left(\beta - \frac{N_1}{2\theta(1-M\alpha)}\theta\right) + \left(\frac{\alpha^2}{F}\left((w-c) - \frac{Th_m(n-1)}{2}\right) - M\alpha D_0\right)\left(\frac{N_1}{2\theta(1-M\alpha)} - \delta\right)\Bigg] \quad (6)$$

where $M = \frac{h_m\alpha(2-n)\frac{T}{PR}}{\gamma+hm\left[(2-n)\frac{\alpha^2T}{PR}\right]}$, $N_1 = -\alpha\delta M\theta + \theta\delta + (1-M\alpha)\beta$, $N_2 = \beta - M\alpha\beta + \delta\theta(1-M\alpha)$, and $F = \gamma + h_m\left[(2-n)\frac{\alpha^2T}{PR}\right]$.

$$p_r^* = \frac{1}{2\theta(1-M\alpha)-\frac{N_2N_1}{2\,\delta\beta(1-M\alpha)+\frac{\lambda}{T}}}\Bigg[D_0\left(1 - \frac{N_2}{2\,\delta\beta(1-M\alpha)+\frac{\lambda}{T}}\delta\right) + w\left(\theta - \frac{N_2}{2\,\delta\beta(1-M\alpha)+\frac{\lambda}{T}}\beta\right) + M\alpha\left(-w\theta + \frac{w\beta N_2}{2\,\delta\beta(1-M\alpha)+\frac{\lambda}{T}} - h_r\frac{T}{2}\left(\theta - \beta\frac{N_2}{2\,\delta\beta(1-M\alpha)+\frac{\lambda}{T}}\right)\right) +$$

$$h_r \frac{T}{2}\left(\theta - \beta \frac{N_2}{2\,\delta\beta(1-M\alpha)+\frac{\lambda}{T}}\right) + \left(\frac{\alpha^2}{F}\left((w-c) - \frac{Th_m(n-1)}{2}\right) - M\alpha D_0\right)\left(1 - \frac{N_2}{2\,\delta\beta(1-M\alpha)+\frac{\lambda}{T}}\delta\right)\Bigg] \quad (7)$$

$$k_r^* = F_z^{-1}\left(1 - \left(\frac{h_r T}{\pi}\right)\right) \quad (8)$$

According to Equation (8), the corresponding service level is $SRL^* = F_z(k_r^*) = 1 - \left(\frac{h_r T}{\pi}\right)$.
After determining the optimal decisions of retailer on pricing, after-sales service, and service level, MEC determines the optimal level of product quality as follows:

$$q_m^* = \frac{\alpha\left[(w-c) - h_m\left[(2-n)\frac{T}{PR}(D_0+\beta s_r^* - \theta p_r^*) + \frac{T(n-1)}{2}\right]\right]}{\gamma + h_m\left[(2-n)\frac{\alpha^2 T}{PR}\right]} \quad (9)$$

The above optimal decisions are derived in such a way that MEC's and CLPH's single profit is optimized, while the entire system optimality is not guaranteed. To calculate pricing and the three quality improvement decisions, the centralized model is formulated in next subsection.

4-2. Centralized model

Here, profit optimization of the entire SC is considered, and the best values of decision variables are simultaneously calculated. The profit function to be optimized in this structure is the sum of both members' profit function:

$$\pi_{sc}(k_r, s_r, p_r, q_m) = \pi_r + \pi_m = (p_r - c - \delta s_r)(D_0 + \alpha q_m + \beta s_r - \theta p_r) - \frac{A_r}{T} - h_r\left[\frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)T}{2} + k_r\sigma\sqrt{T+L}\right] - \frac{1}{2}\frac{\lambda s_r^2}{T} - \frac{1}{T}\pi\sigma\sqrt{T+L}\,U(k_r) - \frac{v}{nT} - \frac{1}{2}\gamma q_m^2 - h_m\left[\frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)T}{2}\right]\left[\frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)}{PR}(2-n) + (n-1)\right] \quad (10)$$

To ensure the concavity of this function, the following proposition is defined:
Proposition 3. The SC's profit function is concave over k_r, q_m, s_r, and p_r under the following conditions:

$$((\lambda/T) + 2\delta\beta + H\beta^2)(2\theta + H\theta^2) - (\beta + \delta\theta + H\theta\beta)^2 > 0 \quad (11)$$

$$\left(2\delta\beta + \frac{\lambda}{T} + H\beta^2\right)(\alpha + H\alpha\theta)^2 + (\beta + \delta\theta + H\theta\beta)^2(\gamma + H\alpha^2) + (\alpha\delta + H\alpha\beta)^2(2\theta + H\theta^2) \leq \left(2\delta\beta + \frac{\lambda}{T} + H\beta^2\right)(2\theta + H\theta^2)(\gamma + H\alpha^2) + \big(2(\alpha\delta + H\alpha\beta)(\alpha + H\alpha\theta)(\beta + \delta\theta + H\theta\beta)\big) \quad (12)$$

where $H = h_m T\frac{(2-n)}{PR}$.
Proof. see "Appendix 3".
By simultaneously solving the following equations, the optimal values of k_r, q_m, s_r, and p_r under the centralized model are calculated.

$$\frac{\partial\pi_{sc}}{\partial k} = 0 \rightarrow -h_r\sigma\sqrt{T+L} - \frac{1}{T}\pi\sigma\sqrt{T+L}\,(F_z(k_r) - 1) = 0 \quad (13)$$

$$\frac{\partial\pi_{sc}}{\partial p_r} = 0 \rightarrow (D_0 + \alpha q_m + \beta s_r - 2\theta p_r) - \theta(c + \delta s_r) + \frac{h_r}{2}\theta T + h_m\theta T\left(\frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)(2-n)}{PR} + \frac{n-1}{2}\right) = 0 \quad (14)$$

$$\frac{\partial\pi_{sc}}{\partial s_r} = 0 \rightarrow -\delta(D_0 + \alpha q_m + \beta s_r - \theta p_r) + \beta(p_r - c - \delta s_r) - \frac{\lambda s_r}{T} - \frac{h_r}{2}\beta T - h_m\beta T\left((D_0 + \alpha q_m + \beta s_r - \theta p_r)\frac{(2-n)}{PR} + \frac{n-1}{2}\right) = 0 \quad (15)$$

$$\frac{\partial\pi_{sc}}{\partial q_m} = 0 \rightarrow (p_r - c - \delta s_r)\alpha - \frac{h_r\alpha T}{2} - \gamma q_m - h_m\alpha T\left[(2-n)\frac{(D_0+\alpha q_m+\beta s_r-\theta p_r)}{PR} + \frac{(n-1)}{2}\right] = 0 \quad (16)$$

Suppose that $H' = \left(2\delta\beta + \frac{\lambda}{T} + \beta^2 H\right) - \frac{1}{F}(\alpha\delta + H\alpha\beta)^2$, $H'' = (2\theta + \theta^2 H) - \frac{1}{F}(\alpha + \alpha\theta H)^2$, $H''' = (\alpha + \alpha\theta H)\frac{-1}{F}(\delta\alpha + \alpha H\beta) + \beta + \theta\delta + \theta\beta H$, $O' = -C\alpha - h_m\left[(2-n)\frac{\alpha T}{PR}D_0 + \frac{\alpha T(n-1)}{2}\right]$, $B_1 = (\alpha + \alpha\theta H)\frac{1}{F}\big((-\delta)\alpha - \alpha H\beta\big) + \beta + \theta\delta + \theta\beta H$, and $Z = -(\delta + \beta H)\frac{\alpha}{F}(\alpha + H\alpha\theta) + \delta\theta + \beta + \theta H\beta$, the optimal values of decision variables are:

$$k_r^{**} = F_z^{-1}\left(1 - \frac{\mathrm{Th_r}}{\pi}\right) \rightarrow SRL^{**} = F_z(k_r^{**}) = 1 - \left(\frac{hrT}{\pi}\right) \quad (17)$$

$$p_r^{**} = \frac{B_1\left(-(\delta+H\beta)\frac{\alpha}{F}\left(-\frac{h_r\alpha T}{2}+O\right)-\delta D_0-\beta c-\frac{h_r}{2}\beta T-h_m\beta T\left(D_0\frac{(2-n)}{PR}+\frac{n-1}{2}\right)\right)}{\left((2\theta+\theta^2 H)-\frac{1}{F}(\alpha+H\alpha\theta)^2\right)\mathrm{H}'+B_1((\delta+\beta H)\frac{\alpha}{F}(\alpha+H\alpha\theta)-\delta\theta-\beta-\beta\theta H)} + \frac{D_0+\theta c+\frac{h_r}{2}\theta T+h_m\theta T\left(\frac{D_0(2-n)}{PR}+\frac{n-1}{2}\right)+(\alpha+\alpha\theta H)\frac{1}{F}\left(-\frac{h_r\alpha T}{2}+O\right)}{(2\theta+\theta^2 H)-\frac{1}{F}(\alpha+H\alpha\theta)^2+B_1\frac{(\delta+\beta H)\frac{\alpha}{F}(\alpha+H\alpha\theta)-\delta\theta-\beta-\beta\theta H}{\mathrm{H}'}} \quad (18)$$

$$s_r^{**} = \frac{D_0+\theta\left(c+\frac{h_r}{2}T\right)+\left(H\theta D_0+h_m\theta T\frac{n-1}{2}\right)(\alpha+\alpha\theta H)\frac{1}{F}\left(O'+\frac{h_r\alpha T}{2}\right)}{H''H'-H'''Z} - \frac{(\delta+\beta H)\frac{\alpha}{F}(O'+\frac{h_r\alpha T}{2})+\delta D_0+c\beta+\frac{h_r}{2}\beta T+\beta T\left(D_0\frac{(2-n)}{PR}+\frac{n-1}{2}\right)}{\mathrm{H}'-\frac{H'''Z}{H''}} \quad (19)$$

$$q_m^{**} = \frac{\left(\alpha+\mathrm{h_m}(2-n)\frac{\alpha T}{PR}\theta\right)p^{**}}{\gamma+\mathrm{h_m}\left[(2-n)\frac{\alpha^2 T}{PR}\right]} - \frac{c\alpha+\left(\delta\alpha+\mathrm{h_m}(2-n)\frac{\alpha T}{PR}\beta\right)s^{**}-\frac{\mathrm{h_r}\alpha\mathrm{T}}{2}-\mathrm{h_m}\left[(2-n)\frac{\alpha T}{PR}\mathrm{D_0}+\frac{\alpha\mathrm{T}(\mathrm{n}-1)}{2}\right]}{\gamma+\mathrm{h_m}\left[(2-n)\frac{\alpha^2 T}{PR}\right]} \quad (20)$$

The centralized decision-making model on product quality, pricing, and service decisions optimizes the whole SC profit; however, it does not necessarily mean that both MEC and CLPH meet their own optimum benefits. This structure may even cause losses for one of them. Accordingly, it may refuse to choose centralized decisions and tend to choose decisions of the decentralized structure. Hence, for motivating all members to accept the centralized model, a bilateral wholesale price (BWP) coordination contract is developed in the following.

4-3. Coordinated model: BWP contract

As explained in the previous section, the centralized model may cause losses for some SC members, while it is optimal for the whole SC. Accordingly, to encourage all SC members in integrated decision- making, an incentive mechanism is required [42]. For this purpose, in this section, a bilateral wholesale price (BWP) coordination contract is suggested. According to this contract, MEC offers a wholesale price equal to dw, instead of w. According to the scenarios that may occur under the centralized model, parameter d can be between zero and one ($0 \le d \le 1$) or be greater than one ($d \ge 1$); Scenario I: under the centralized model, MEC incurs losses and CLPH gains profit in comparison to the decentralized structure. Scenario II: CLPH incurs losses and MEC gains profit in the centralized structure in comparison to the decentralized one. For achieving coordination through BWP contract, in scenario I, the wholesale price should be increased, and in scenario II, it should be reduced. In fact, parameter d makes the coordination contract a flexible and bilateral contract that considers both scenarios. It is notable that another scenario will be developed in which both SC members gain profits in the centralized structure in comparison to the decentralized one. In this situation, just the extra profits of the integrated decision-making are divided between the two members. The proposed BWP coordination model will be acceptable to both members if and only if it leads to at least their decentralized profits. Accordingly, the conditions of CLPH and MEC to participate in the coordinated model are derived.

4-3-1. Retailer (CLPH) condition

CLPH's condition to accept BWP contract is represented by the following equation:

$$TP_r^{co}(k_r^{**},T^{**},p_r^{**},s_r^{**},dw) \ge TP_r^{dc}(T^*,k_r^*,p_r^*,s_r^*) \quad (21)$$

Based on the above inequality, the upper bound of the coordination parameter is calculated:

$$d_{max} = \frac{\begin{array}{c}(p_r^{**}-\delta s_r^{**})N_3+\frac{\mathrm{A_r}}{\mathrm{T}}+\mathrm{h_r}\left(\left[\frac{N_4\mathrm{T}}{2}\right]-\left[\frac{N_3\mathrm{T}}{2}\right]\right)\\ -(p_r^*-\mathrm{w}-\delta s_r^*)N_4-\frac{\mathrm{A_r}}{\mathrm{T}}-\frac{\lambda}{2}\left(\frac{{s_r^{**}}^2}{\mathrm{T}}-\frac{{s_r^*}^2}{\mathrm{T}}\right)-\frac{\pi\sigma}{T}\left(\sqrt{\mathrm{T+L}}\,U(k_r^{**})-\sqrt{\mathrm{T+L}}\,U(k_r^*)\right)\end{array}}{\mathrm{w}N_3} \quad (22)$$

where $N_3 = (D_0 + \alpha q_m^{**} + \beta s_r^{**} - \theta p_r^{**})$ and $N_4 = (D_0 + \alpha q_m^* + \beta s_r^* - \theta p_r^*)$.

If $d > d_{max}$, CLPH may not accept the coordination scheme, since it cannot achieve its minimum profit. Similarly, MEC's condition for taking part in BWP scheme can be derived.

4-3-2. Manufacturer (MEC) condition

MEC's condition to accept the coordination contract is:

$$TP_m^{co}(q_m^{**}, dw) \geq TP_r^{dc}(q_m^{*}) \quad (23)$$

Based on the above inequality, the lower bound of the coordination parameter is calculated:

$$d_{min} = \frac{(w-c)N_4 + cN_3 + \frac{1}{2}\gamma {q_m^{**}}^2 + h_m\left[\frac{N_3 T}{2}\right]\left[\frac{N_3}{PR}(2-n)+(n-1)\right]}{wN_3} - \frac{\frac{1}{2}\gamma {q_m^{*}}^2 + h_m\left[\frac{N_4 T}{2}\right]\left[\frac{N_4}{PR}(2-n)+(n-1)\right]}{wN_3} \quad (24)$$

For any value of d belonging to interval $[d_{min}, d_{max}]$, coordination will be achieved. Since the SC members are of different market powers, it is anticipated that the dominant member achieves more profits than the other member. In the next section, a profit-sharing policy is applied, which takes the SC members' bargaining power into account. Accordingly, the exact value of parameter d can be calculated.

4-3-3. Profit-sharing strategy

Here, to specify each member's surplus profit under the BWP contract, the exact value of d is calculated based on their bargaining powers. Parameter ψ denotes the CLPH's bargaining power. Accordingly, 1-ψ is related to MEC's. Thus, the profits of members in the coordinated model are calculated as follows:

$$TP_r^{co}(k_r^{**}, p_r^{**}, s_r^{**}, dw) = TP_r^{dc}(k_r^{*}, p_r^{*}, s_r^{*}) + \psi dev \quad (25)$$

$$TP_m^{co}(q_m^{**}, dw) = TP_r^{dc}(q_m^{*}) + (1-\psi)dev \quad (26)$$

where

$$dev = TP_{sc}^{cnt}(k_r^{**}, p_r^{**}, s_r^{**}, q_m^{**}) - TP_{sc}^{dc}(k_r^{*}, p_r^{*}, s_r^{*}, q_m^{*})$$

By solving the first equation, the exact value of d, namely $d_{sharing}$, is obtained as follows:

$$d_{sharing} = \frac{1}{wN_3}\left[(p_r^{**} - \delta s_r^{**})N_3 - \frac{A_r}{T} - \frac{1}{2}\frac{\lambda {s_r^{**}}^2}{T} - h_r\left[\frac{N_3 T}{2}\right] - \frac{\pi\sigma\sqrt{T+L}}{T}U(k_r^{**}) - (p_r^{*} - w - \delta s_r^{*})N_4 + \frac{A_r}{T} + \frac{1}{2}\frac{\lambda {s_r^{*}}^2}{T} + h_r\left[\frac{N_4 T}{2}\right] + \frac{\pi\sigma\sqrt{T+L}}{T}U(k_r^{*}) - \psi dev\right] \quad (27)$$

by selecting the coordination parameter as equal to $d_{sharing}$, the surplus profit is shared among CLPH and MEC according to their bargaining powers.

5. Numerical Experiment and Sensitivity Analysis

In order to better examine the model applicability, it is run based on the data of the investigated cell phone supply chain (SC) case. The data used to run the model are represented in Table 3. Some parameters are estimated based on the experts' opinions; for instance, the parameters representing demand sensitivity to quality, price, and service are estimated as $\alpha = 14$, $\theta = 35$, and $\beta = 12$, respectively. The unit for costs and prices is $/unit.

The current decisions and the model results on profits under the case data are shown in Table 4. As shown in this table, the centralized structure results in a higher level of product quality, a lower product price, and higher level of services in comparison to the decentralized structure. The SC's profit in the centralized model is $21827.084, which has improved by about 10.45% in comparison with the decentralized model. The manufacturer's (MEC's) profit under this model has improved, whereas the retailer's (CLPH's) profit has decreased in comparison to the decentralized structure. This is because of higher services and lower prices that CLPH must offer under the centralized model. Thus, CLPH may prefer traditional decision-making rather than the centralized one. Accordingly, the cell phone SC will not reach its optimal profit, and the 10.45% increase in its profitability will be lost. The same occurs for MEC's profit. Thus, to maintain the profit improvement, MEC decides to offer a reduced wholesale price to CLPH as a coordination contract. This strategy leads to profit improvements for both MEC and CLPH compared to the decentralized model. The improvements are 14.22% and 6.45% for CLPH and MEC, respectively. Moreover, the cell phone SC reaches its centralized profit. Overall, by applying the proposed bilateral wholesale price (BWP) contract, MEC and CLPH can enhance their quality improvement strategies (i.e., product quality improvement and level of services), while their profits increase. Therefore, the proposed contract is both economically and socially profitable.

In the following, a set of sensitivity analysis tests is carried out by considering some pivotal parameters so as to examine the proposed model under different channel structures.

In Fig. 1(a), the changes in the level of quality investment with respect to the changes in demand sensitivity to quality are examined. As this parameter grows, i.e., the customers become more sensitive to the product quality, MEC invests more in the product quality level. The investment under BWP contract is much more than the investment under the decentralized structure. Accordingly, one obvious conclusion will be the fact that MEC's profit under BWP contract is lower than that in the decentralized structure. However, according to Fig. 1(b), the coordination model (BWP contract) leads to more profits for MEC in comparison to the decentralized model. This implies the great advantage of the proposed coordination model in encouraging MEC to increase the quality of products while making more profits. Figs. 2. (a), (b) show the changes in product price and after-sales service with respect to an increase in demand sensitivity to quality, respectively. The figures demonstrate that whenever demand sensitivity to quality investment grows, the product price and after-sales service take more values under both decentralized and coordination models. However, as is demonstrated in Fig. 2. (a), the product price under BWP contract is much less than its value under the decentralized model. Moreover, from Fig. 2. (b), it can be seen that CLPH invests more in after-sales service under BWP contract compared to individual decision-making. Thus, under the proposed BWP contract, CLPH sells the cell phone with a lower price and higher level of after-sales service compared to the decentralized model. Accordingly, one can expect that CLPH makes less profit under the BWP contract in comparison to the decentralized structure. However, the great point is that the BWP coordination contract leads to more profits for CLPH compared to individual decision-making regardless of the higher services and lower prices offered by CLPH under the contract. The above results show that the BWP contract is also beneficial for the customers since they can buy products with higher levels of services and lower prices. Fig. 3. shows the changes in after-sales services under different amounts of demand sensitivity to services. It shows a growing divergence between the level of after-sales services in the decentralized model and that in the coordinated model with respect to increasing service elasticity coefficient of demand. In other words, with an increase in demand sensitivity to services, the BWP coordination model creates a faster growth in after-sales services rather than the decentralized one. In Fig.4. (a), the changes in CLPH's profit with respect to demand sensitivity to services are examined, and the positive relationship between them is shown. From the figure, it is concluded that whenever demand sensitivity to services heightens and the market becomes more sensitive to services, the BWP coordination model facilitates investing to a greater degree in the services, leading to more profits for CLPH compared to the decentralized one. This is due to MEC's offer of lower wholesale prices for CLPH. Although the profit of MEC under the BWP contract is lower than its profit under the centralized structure, it is still more than that of the individual decision-making structure (Fig. 4. (b)). Generally, under the situations where demand sensitivity to services grows, the application of the BWP coordination model is profitable for the whole SC, as well (Fig. 4. (b)). Fig. 5. (a) shows that whenever shortage cost increases, as expected, CLPH tries to hold more values of safety stock to maintain its service level in the market. This is the same under the coordination model with a difference that CLPH makes more profits under the coordination model in comparison to individual decision-making one, while it holds the same amount of safety stock as the decentralized model. Thus, under BWP contract, CLPH can maintain its service level while its profit undergoes little decrease. In Fig. 5. (b), it is observed that the graph of CLPH profit in the coordination structure is above all other graphs. Moreover, under the conditions with high shortage costs, the proposed contract results in less profit loss for the whole cell phone SC rather than the decentralized model (Fig. 5. (c)). Fig. 6. (a) shows the effect of changes in holding cost on CLPH profit. As can be seen, according to this change, CLPH profit decreases under all structures. However, the amount of decrease under the coordination structure is less than the others, which shows the model's economic benefits. From Fig. 6. (b), as expected, by increasing retailer's holding cost, CLPH decreases the amount of safety stock to hold. This act may increase its shortage costs and, thus, reduce its service level and profits. However, as Fig. 6. (a) clearly shows, this reduction under the coordinated structure is much less than the other structures. This implies the model applicability under different economic conditions of the market, and shows that the model can be used as an efficient management strategy for reducing the risks of shortages.

Tab. 3. Case data

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
D_0	3000	γ	60	w	44	σ	1000
α	14	λ	54	c	30	π	1.9
β	12	A_r	350	v	100	L	2
θ	35	h_r	5	PR	1000	T	33
δ	0.1	h_m	1	n	2	ψ	0.7

Tab. 4. Results of implementing the model based on case data

Structure	q_m	p_r	s_r	k_r	R_r	SRL	π_r	π_m	π_{sc}
Decentralized	3.256	65.688	0.305	0.712	30475.54	0.76	10164.716	9596.861	19761.577
Centralized	6.797	59.444	0.414	0.712	39897.54	0.76	9537.957	12289.127	21827.084
Coordination	6.797	59.444	0.414	0.712	39897.54	0.76	11610.571	10216.513	21827.084

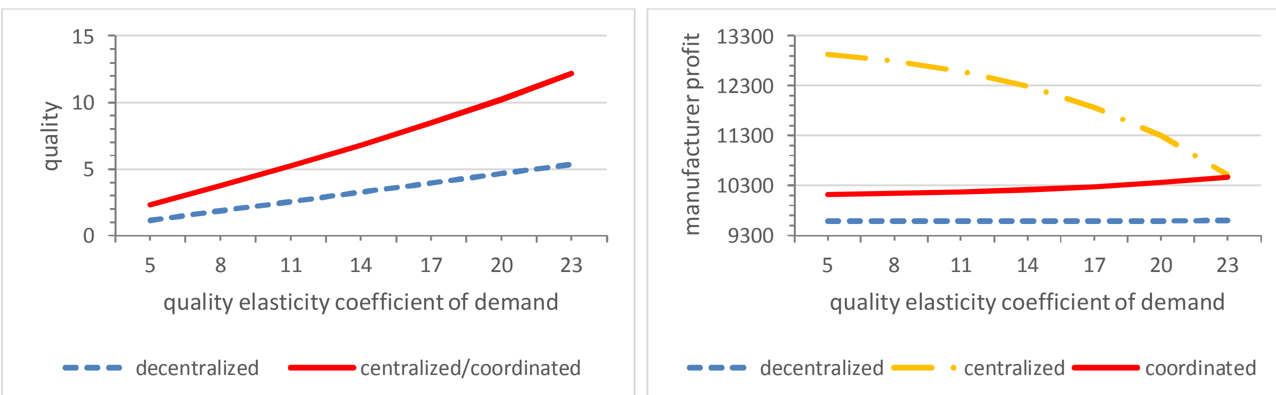
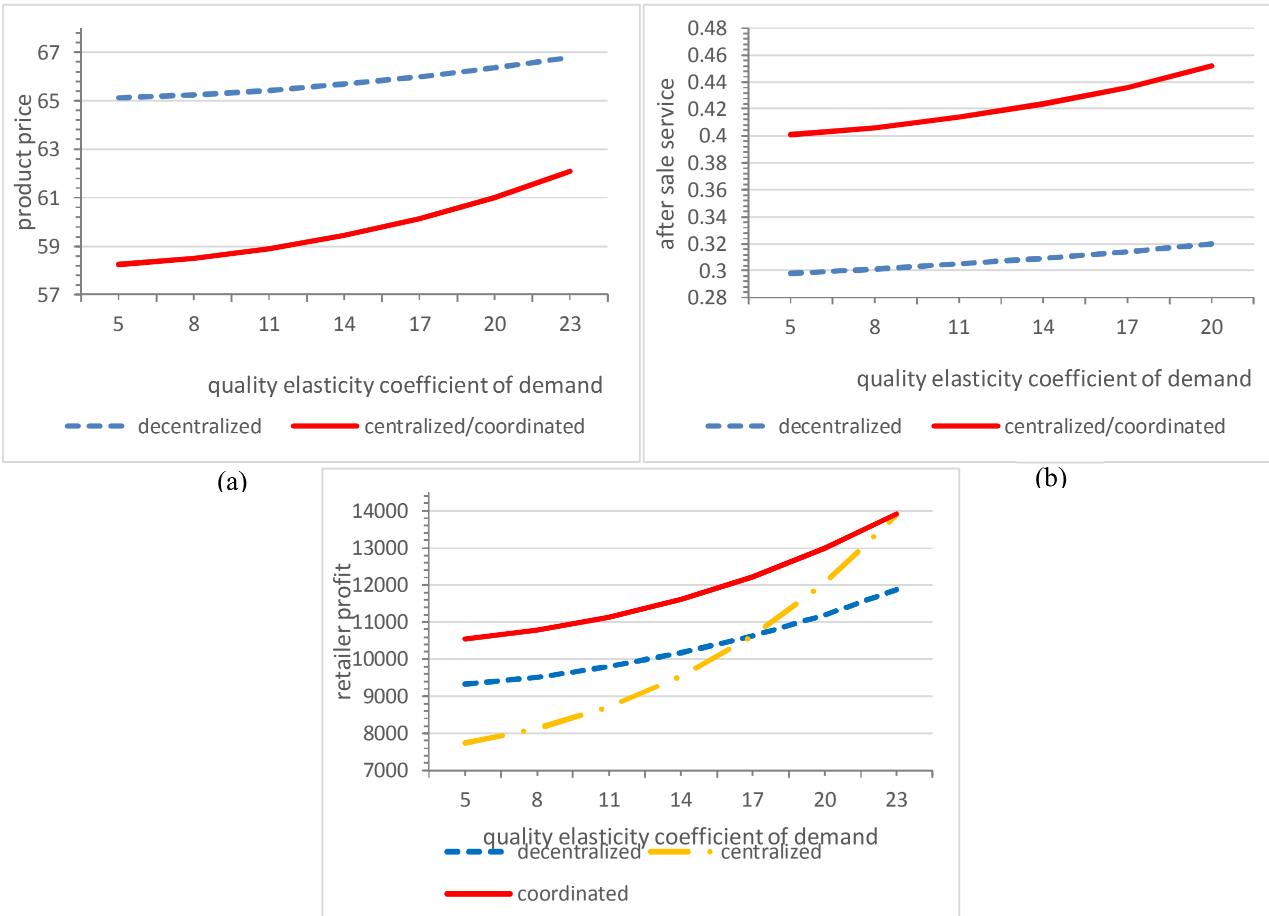


Fig. 1. the effect of changes in demand sensitivity to quality on: (a) the level of quality investment and (b) MEC profit under different structures

6. Conclusion

Supply chain (SC) coordination is an innovative policy searching for a strategy to eliminate the deficiencies of the decentralized structure [43]. In this study, a coordination model was proposed across a manufacturer-retailer SC of a real cell phone case. Due to the competitive market of cell phones, the company seeks optimal quality-improvement strategies at different levels of its SC. It invests in quality improvement in the production level and sales level. Accordingly, to investigate these strategies, the SC demand function is considered to be dependent on the product quality, after-sales service, and price. In the investigated case, the manufacturer (MEC) decides on the investment in product quality level. The retailer (CLPH) decides on after-sales service and the price. Moreover, it decides on safety stock level under a periodic review inventory model in order to enhance its service level in the market. Since MEC and CLPH's decisions are interrelated, their profitability is influenced by each other's decisions. In the current situation, MEC and CLPH make individual decisions to improve their own profit regardless of the other's profits. This does not lead to the optimal quality improvement strategy for the SC. Accordingly, this study considered the centralized model in which a central decision-maker determines the pricing, quality, after-sales service, and safety stock decisions to optimize the whole SC performance. However, based on the scenarios which may occur under the centralized model, these centralized decisions may not be acceptable to MEC or CLPH. Thus, a bilateral wholesale price (BWP) contract is proposed to coordinate the SC and motivate MEC and CLPH to choose the centralized decisions. The results of the model showed that the BWP contract could effectively coordinate the cell phone SC members and enhance their profits compared to the case, where they make individual decisions. Moreover, the comprehensive sensitivity analyses led to the following managerial implications.



(a) (b) (c)

Fig. 2. The effect of quality elasticity coefficient of demand on: (a) product price, (b) after-sales service, and (c) retailer profit.

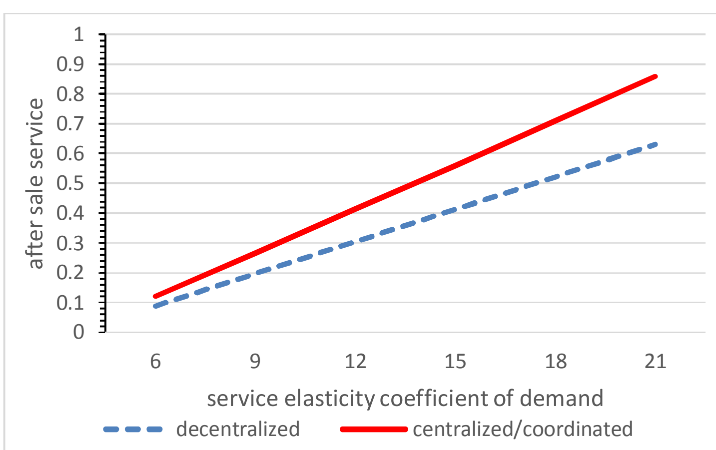


Fig. 3. Changes of after-sales services w.r.t. demand sensitivity to service

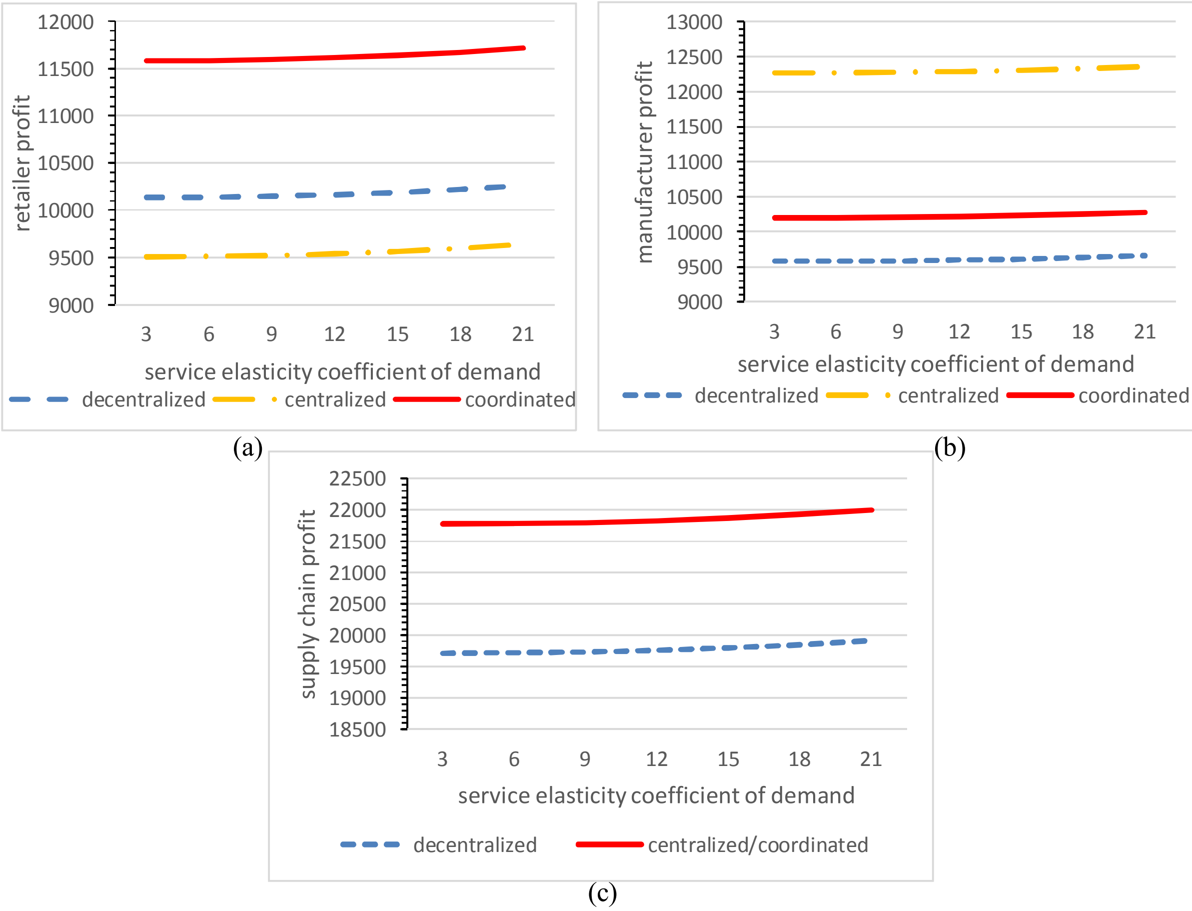


Fig. 4. The effect of changes in demand sensitivity to services on (a) retailer profit, (b) manufacturer profit, and (c) SC profit

- The coordinated model provides the possibility that none of the members not only bears cost, but also makes more profits in comparison to the decentralized model. The model provides the SC members with flexibility to increase after-sales services, reduce the product price, and increase the product quality while they make more profits compared to the other decision-making models. As explained in the literature, pricing policies can effectively influence the firm’s losses [44]. Applying the BWP contract could adjust decisions on pricing, as well as other decisions, in such a way that the firms incur less losses.
- Under the proposed BWP coordination contract, CLPH can provide a higher service level in the market even under high levels of shortage costs. This is because of the fact that, under the BWP contract, if CLPH is incurred by losses, it can buy products with a lower wholesale price from MEC. This may compensate it for high costs of holding more safety stocks. Thus, the model is highly applicable in reducing the risks of shortages.
- When customers are highly sensitive to the product quality, the investment in product quality goes up. Under the BWP contract, this investment is higher than the decentralized one. However, the profit for MEC in the coordination model is still more than the decentralized structure. Thus, the BWP contract enables MEC to enhance its strategy on SC quality improvement in the production level.
- Whenever demand sensitivity to quality investment takes more values, the product price and after-sales service increase, since they are dependent on the product quality. However, the product price in the coordinated model is very lower than that in the decentralized one. Moreover, CLPH invests more in after-sales service under the coordinated structure rather than the decentralized structure. However, despite the expectations, the BWP coordination contract

provides a more profitable situation for CLPH rather than the decentralized structure. Accordingly, the BWP contract creates a good advantage for the customers, as well. In fact, the BWP model improves their buying power through enabling the retailer in price reduction; moreover, they will receive greater after-sales services. Hence, the coordination model with BWP contract provides a more profitable condition for all SC members and the customers.

- Since, in one scenario, under the BWP contract, the manufacturer proposes a lower wholesale price to the retailer in a highly sensitive market to the services, investing more in the services leads to more profits for the retailer compared to the decentralized one. Even though the manufacturer's profit under the coordination structure is lower than that under the centralized one, it still makes more profits than the profit made in the decentralized structure. The same occurs under the other scenario, where the market is more sensitive to quality and the retailer pays a more amount of wholesale price to the manufacturer to enable him to invest more in product quality.
- The BWP contract is flexible and can coordinate the investigated SC under different scenarios that happen under the centralized structure. Moreover, the surplus profit can be divided between MEC and CLPH considering their bargaining powers in the market, making the contract be more similar to real-world situations. For further research, one extension can be considering a three-echelon SC including suppliers, manufacturers, and retailers, since the effect of raw materials provided by the suppliers on the product quality cannot be ignored. This paper did not model competitive situations, since the aim of the paper was to enhance strategies for quality improvement in production and sales level by considering the related decisions. One interesting topic for the future can be considering multiple retailers and different game structures to model the competition among them.

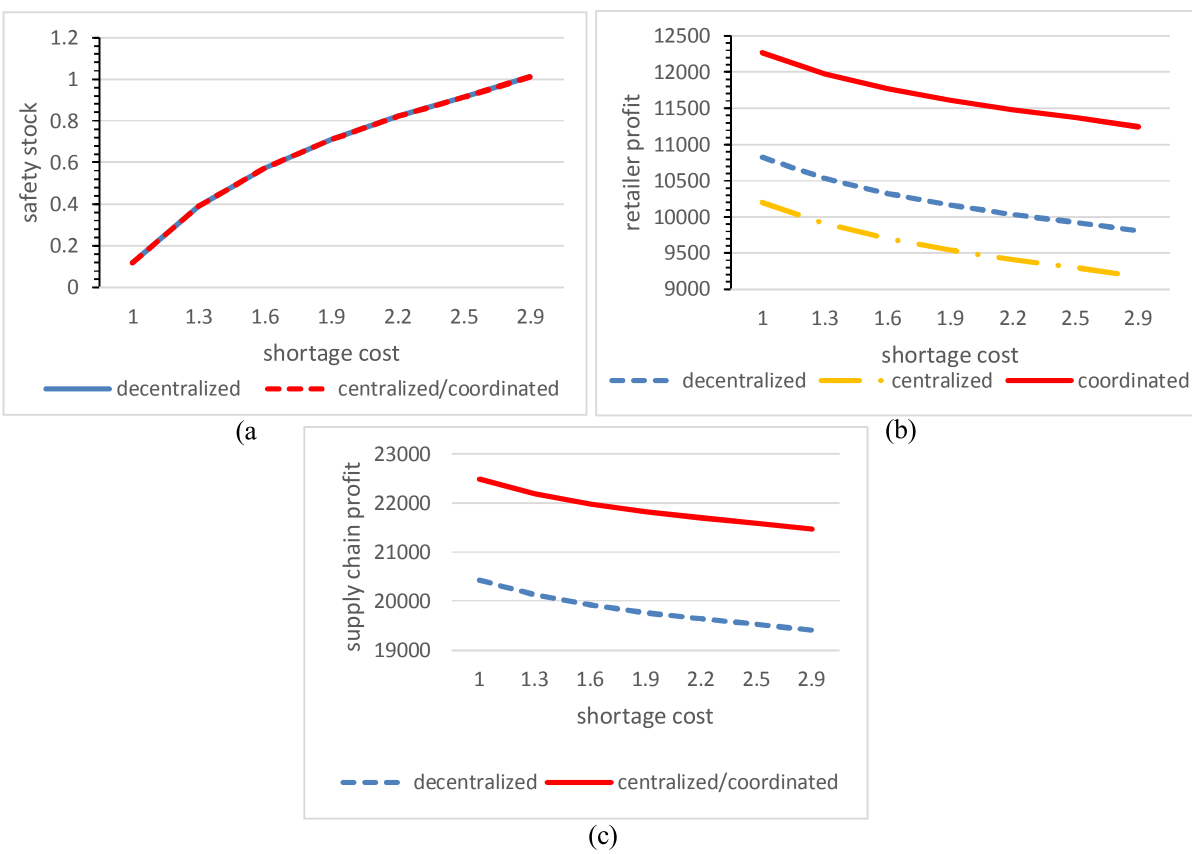
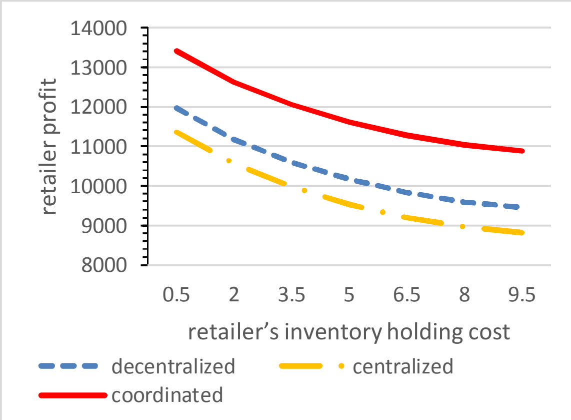
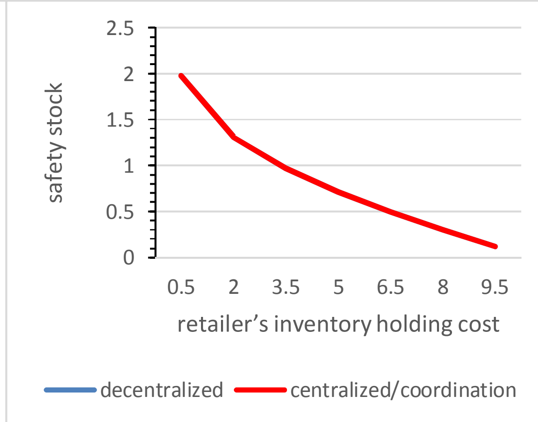


Fig. 5. The effect of shortage cost on: (a) safety stock, (b) retailer profit, and (c) SC profit



(a)



(b)

Fig. 6. The effect of retailer's inventory holding cost on (a) retailer profit and (b) safety stock

Appendix

Appendix 1. Analyzing the concavity of manufacturer's (MEC's) profit function

For proving concavity of the manufacturer's profit function over q_m, the second-order derivative of π_m must be calculated, and is shown that it is negative. The following equation, which is always negative, completes the proof.

$$\frac{\partial^2\pi_m}{\partial {q_m}^2} = -\gamma - hm\left[(2-n)\frac{\alpha^2 T}{PR}\right] < 0 \tag{1}$$

Appendix 2. Analyzing the concavity of retailer's (CLPH's) profit function

The Hessian's matrix of $\pi_r(k_r, s_r, p_r)$ is:

$$H\big(\pi_r(k_r, s_r, p_r)\big) = \begin{bmatrix} \frac{\partial^2\pi_r}{\partial {k_r}^2} & \frac{\partial^2\pi_r}{\partial s_r \partial k_r} = 0 & \frac{\partial^2\pi_r}{\partial p_r \partial k_r} = 0 \\ \frac{\partial^2\pi_r}{\partial k_r \partial s_r} = 0 & \frac{\partial^2\pi_r}{\partial {s_r}^2} & \frac{\partial^2\pi_r}{\partial p_r \partial s_r} \\ \frac{\partial^2\pi_r}{\partial k_r \partial p_r} = 0 & \frac{\partial^2\pi_r}{\partial s_r \partial p_r} & \frac{\partial^2\pi_r}{\partial {p_r}^2} \end{bmatrix} \tag{2}$$

The first, second, and third principle minors are calculated as follows:

$$H_1 = \frac{\partial^2\pi_r}{\partial {k_r}^2} < 0 \Rightarrow -\frac{1}{T}\pi\sqrt{T+L}f_z(k_r) < 0 \tag{3}$$

$$H_2 = \begin{vmatrix} \frac{\partial^2\pi_r}{\partial {k_r}^2} & 0 \\ 0 & \frac{\partial^2\pi_r}{\partial {s_r}^2} \end{vmatrix} > 0 \Rightarrow \frac{\partial^2\pi_r}{\partial {k_r}^2}.\frac{\partial^2\pi_r}{\partial {s_r}^2} > 0 \tag{4}$$

$$\frac{\partial^2\pi_r}{\partial {s_r}^2} = -2\delta\beta - \gamma < 0 \tag{5}$$

$$\frac{\partial^2\pi_r}{\partial {p_r}^2} = -2\theta < 0 \tag{6}$$

$$\frac{\partial^2\pi_r}{\partial s_r \partial p_r} = \frac{\partial^2\pi_r}{\partial p_r \partial s_r} = \delta\theta + \beta \tag{7}$$

$$H_3 = \begin{vmatrix} \frac{\partial^2\pi_r}{\partial {k_r}^2} & 0 & 0 \\ 0 & \frac{\partial^2\pi_r}{\partial {s_r}^2} & \frac{\partial^2\pi_r}{\partial p_r \partial s_r} \\ 0 & \frac{\partial^2\pi_r}{\partial s_r \partial p_r} & \frac{\partial^2\pi_r}{\partial {p_r}^2} \end{vmatrix} < 0 \Rightarrow \frac{\partial^2\pi_r}{\partial {k_r}^2}\begin{vmatrix} \frac{\partial^2\pi_r}{\partial {s_r}^2} & \frac{\partial^2\pi_r}{\partial p_r \partial s_r} \\ \frac{\partial^2\pi_r}{\partial s_r \partial p_r} & \frac{\partial^2\pi_r}{\partial {p_r}^2} \end{vmatrix} = \frac{\partial^2\pi_r}{\partial {k_r}^2}\left(\left(\frac{\partial^2\pi_r}{\partial {s_r}^2}.\frac{\partial^2\pi_r}{\partial {p_r}^2}\right) - \left(\frac{\partial^2\pi_r}{\partial p_r \partial s_r}.\frac{\partial^2\pi_r}{\partial s_r \partial p_r}\right)\right) < 0 \tag{8}$$

$$\left(\frac{\partial^2\pi_r}{\partial s_r^2}.\frac{\partial^2\pi_r}{\partial p_r^2}\right)-\left(\frac{\partial^2\pi_r}{\partial p_r\partial s_r}.\frac{\partial^2\pi_r}{\partial s_r\partial p_r}\right)>0 \Rightarrow (4\,\delta\beta\theta+2\theta\gamma)-(\delta\theta+\beta)^2>0 \Longrightarrow if\ \ (\delta\beta\theta+2\theta\gamma)>(\delta\theta+\beta)^2 \quad (9)$$

As can be seen, H_1 is always negative, H_2 is always positive, and H_3 is negative under the condition represented in Equation (9). Thus, under this condition, the above Hessian matrix is negative definite; thus, the concavity is proved.

Appendix 3. Analyzing the concavity of the supply chain's profit function

For the concavity of $\pi_{sc}(k_r,s_r,p_r,q_m)$ over k, s, p, and q, the Hessian matrix of $\pi_{sc}(k_r,s_r,p_r,q_m)$ must be negative definite. The Hessian matrix of $\pi_{sc}(k_r,s_r,p_r,q_m)$ is:

$$H\big(\pi_{sc}(k_r,s_r,p_r,q_m)\big)=\begin{bmatrix}\frac{\partial^2\pi_{sc}}{\partial k_r^2} & \frac{\partial^2\pi_{sc}}{\partial k_r\partial s_r} & \frac{\partial^2\pi_{sc}}{\partial k_r\partial p_r} & \frac{\partial^2\pi_{sc}}{\partial k_r\partial q_m}\\ \frac{\partial^2\pi_{sc}}{\partial s_r\partial k_r} & \frac{\partial^2\pi_{sc}}{\partial s_r^2} & \frac{\partial^2\pi_{sc}}{\partial s_r\partial p_r} & \frac{\partial^2\pi_{sc}}{\partial s_r\partial q_m}\\ \frac{\partial^2\pi_{sc}}{\partial p_r\partial k_r} & \frac{\partial^2\pi_{sc}}{\partial p_r\partial s_r} & \frac{\partial^2\pi_{sc}}{\partial p_r^2} & \frac{\partial^2\pi_{sc}}{\partial p_r\partial q_m}\\ \frac{\partial^2\pi_{sc}}{\partial q_m\partial k_r} & \frac{\partial^2\pi_{sc}}{\partial q_m\partial s_r} & \frac{\partial^2\pi_{sc}}{\partial q_m\partial p_r} & \frac{\partial^2\pi_{sc}}{\partial q_m^2}\end{bmatrix} \quad (10)$$

The first, second, third, and fourth principle minors are calculated as follows:

$$H_1=\frac{\partial^2\pi_{sc}}{\partial k_r^2}<0 \Rightarrow -\frac{1}{T}\pi\sqrt{T+L}f_z(k_r)<0 \quad (11)$$

$$H_2=\left[\left(\frac{\partial^2\pi_{sc}}{\partial k_r^2}.\frac{\partial^2\pi_{sc}}{\partial s_r^2}\right)-\left(\frac{\partial^2\pi_{sc}}{\partial s_r\partial k_r}.\frac{\partial^2\pi_{sc}}{\partial k_r\partial s_r}\right)\right]=\left(-\frac{1}{T}\pi\sqrt{T+L}f_z(k_r)\right)\left(-2\delta\beta-\frac{\lambda}{T}-hm\left[(2-n)\frac{\beta^2T}{PR}\right]\right)>0 \quad (12)$$

$$H_3=\frac{\partial^2\pi_{sc}}{\partial k_r^2}\begin{vmatrix}\frac{\partial^2\pi_{sc}}{\partial s_r^2} & \frac{\partial^2\pi_{sc}}{\partial s_r\partial p_r}\\ \frac{\partial^2\pi_{sc}}{\partial p_r\partial s_r} & \frac{\partial^2\pi_{sc}}{\partial p_r^2}\end{vmatrix}=\left(-\frac{1}{T}\pi\sqrt{T+L}f_z(k_r)\right)\left[\left(\left(-\left(2\theta+h_m\left[(2-n)\frac{\theta^2T}{PR}\right]\right)\right).\left(-2\delta\beta-\frac{\lambda}{T}-h_m\left[(2-n)\frac{\beta^2T}{PR}\right]\right)\right)-\left(\delta\,\theta+\beta+h_m\left[(2-n)\frac{\beta\theta T}{PR}\right]\right)^2\right]<0 \quad (13)$$

The third principle minor is negative if the following condition is satisfied.

$$if\ \left(\delta\,\theta+\beta+h_m\left[(2-n)\frac{\beta\theta T}{PR}\right]\right)^2<\left(\left(\left(2\theta+h_m\left[(2-n)\frac{\theta^2T}{PR}\right]\right)\right).\left(2\delta\beta+\frac{\lambda}{T}+h_m\left[(2-n)\frac{\beta^2T}{PR}\right]\right)\right) \quad (14)$$

$$H_4=\frac{\partial^2\pi_{sc}}{\partial k_r^2}\begin{vmatrix}\frac{\partial^2\pi_{sc}}{\partial s_r^2} & \frac{\partial^2\pi_{sc}}{\partial s_r\partial p_r} & \frac{\partial^2\pi_{sc}}{\partial s_r\partial q_m}\\ \frac{\partial^2\pi_{sc}}{\partial p_r\partial s_r} & \frac{\partial^2\pi_{sc}}{\partial p_r^2} & \frac{\partial^2\pi_{sc}}{\partial p_r\partial q_m}\\ \frac{\partial^2\pi_{sc}}{\partial q_m\partial s_r} & \frac{\partial^2\pi_{sc}}{\partial q_m\partial p_r} & \frac{\partial^2\pi_{sc}}{\partial q_m^2}\end{vmatrix}=\frac{\partial^2\pi_{sc}}{\partial k_r^2}\left[\frac{\partial^2\pi_{sc}}{\partial s_r^2}\begin{vmatrix}\frac{\partial^2\pi_{sc}}{\partial p_r^2} & \frac{\partial^2\pi_{sc}}{\partial q_m\partial p_r}\\ \frac{\partial^2\pi_{sc}}{\partial p_r\partial q_m} & \frac{\partial^2\pi_{sc}}{\partial q_m^2}\end{vmatrix}-\frac{\partial^2\pi_{sc}}{\partial p_r\partial s_r}\begin{vmatrix}\frac{\partial^2\pi_{sc}}{\partial s_r\partial p_r} & \frac{\partial^2\pi_{sc}}{\partial q_m\partial p_r}\\ \frac{\partial^2\pi_{sc}}{\partial s_r\partial q_m} & \frac{\partial^2\pi_{sc}}{\partial q_m^2}\end{vmatrix}+\frac{\partial^2\pi_{sc}}{\partial q_m\partial s_r}\begin{vmatrix}\frac{\partial^2\pi_{sc}}{\partial s_r\partial p_r} & \frac{\partial^2\pi_{sc}}{\partial p_r^2}\\ \frac{\partial^2\pi_{sc}}{\partial s_r\partial q_m} & \frac{\partial^2\pi_{sc}}{\partial p_r\partial q_m}\end{vmatrix}\right]=\left(-\frac{1}{T}\pi\sqrt{T+L}f_z(k_r)\right)\left[\left(-\left(2\delta\beta+\frac{\lambda}{T}+H\beta^2\right)(2\theta+H\theta^2)(\gamma+H\alpha^2)\right)+\left(\left(2\delta\beta+\frac{\lambda}{T}+H\beta^2\right)(\alpha+H\alpha\theta)^2\right)+\left((\beta+\delta\theta+H\theta\beta)^2(\gamma+H\alpha^2)\right)-\left(2(\alpha\delta+H\alpha\beta)(\alpha+H\alpha\theta)(\beta+\delta\theta+H\theta\beta)\right)+\left((\alpha\delta+H\alpha\beta)^2(2\theta+H\theta^2)\right)\right]\geq 0 \quad (15)$$

According to the above calculations, the entire SC profit function is concave over all decision variables under the following conditions:

$$\left(\left(2\delta\beta+\frac{\lambda}{T}+H\beta^2\right)(\alpha+H\alpha\theta)^2\right)+\left((\beta+\delta\theta+H\theta\beta)^2(\gamma+H\alpha^2)\right)+\left((\alpha\delta+H\alpha\beta)^2(2\theta+H\theta^2)\right)\leq\left(\left(2\delta\beta+\frac{\lambda}{T}+H\beta^2\right)(2\theta+H\theta^2)(\gamma+H\alpha^2)\right)+\left(2(\alpha\delta+H\alpha\beta)(\alpha+H\alpha\theta)(\beta+\delta\theta+H\theta\beta)\right) \quad (16)$$

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