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Impact of adopting quick response and agility on supply chain competition with strategic customer behavior

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Abstract. A growing trend towards computerization and competition in supply chains results in uncertainty and quick variability that make the decisions difficult for both levels of retailers and manufacturers. In this paper, two Bi-Level Stackelberg Models (BLSMs) are developed under non- and agile conditions in the presence of strategic customers. Our main novelty approach in this paper is to consider both levels competing with each other in a sequential game to determine the optimal production and order quantities and prices with and without agile abilities. In addition, both proposed models are simplified single-level using the Karush-Kuhn-Tucker (KKT) approach. Then, they are remodeled by a Robust Optimization (RO) technique due to existing uncertain parameters. To have a better assessment of the models' efficiency and applicability, they have been implemented in a real case and finally, the results are compared and analyzed.

1. Introduction

Todays, recent advances in technologies, internet access, and online shopping have led to lower demand and a wide variety of requirements [1]. Also, the importance of the consumers in supply chains has been recently recognized and all the members of a supply chain try to satisfy and keep their customers [2]. Thus, Quick Response (QR) is identified as a key factor in a company's success to meet the customer's requirements [3,4]. In addition, agility is known as a useful tool for achieving competitive advantages under constant and unexpected circumstances when the abilities make it possible for Agile Manufacturers (AMs) to react quickly to unforeseen circumstances, e.g., the consumers' demand and expectations [5].

Two main features of the agility are flexibility and quick production [6]. In this fast-changing world and unstable market, retailers would be faced with various problems in their orders [7]. These situations will result in either commodity shortage or clearance sales at the end of the sales season [3,4]. Hence, QR in retailing is a feature used to reduce the delivery time, improve the supply flexibility, and accelerate the logistics operations with technologies such as advanced information system [8–10]. QR has also been employed in different industries such as toys, bags and shoes, fashion, and other inconstant changing markets [8].

Consumers are generally divided into three groups

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in the literature; myopic, bargain-hunting, and strategic as they react to different circumstances [11,12]. In general, strategic consumers constitute the majority of the market; therefore, customers in this scientific work are considered as strategic ones. Strategic customers first assess the market situation and, then, decide whether to purchase the product at full price or not [3,4]. International marketing, increasing competition-based performance, and rapid technological and economic changes have led to increase in uncertainty [13]. Uncertainty and keen competition have greatly influenced decision-making at different levels of the supply chain in general. Therefore, considering the competition, uncertainty, and clearance sale would make the model more realistic.

Uncertainty has been modeled and solved using various approaches in the literature [14,15]. In this regard, Robust Optimization (RO) is identified as an efficient method in which the unknown values of parameters are considered and the model is solved and tested in various scenarios [16]. Furthermore, the market is highly variable in ordering quantity and demand types. Therefore, a considerable number of goods will go through clearance sales if the uncertainty is not taken into account.

According to the literature, very little attention has been drawn to the bi-level models in which both levels employ QR and agile systems. In contrast to favorable theoretical models and evaluation, there is a limited scope of research on such a mathematical model in reality with an appropriate case study. Contrary to previous works, in this paper, two bi-level models of the competitive supply chain with strategic consumers are proposed first. In the first model, the manufacturer and the retailer compete with each other conventionally (ordering and producing goods just before starting the sale's season). However, in the second one, the model is modified by adding QR and agility abilities. The problems were developed and formulated using Stackelberg Game (SG). Then, Bi-Level Stackelberg Models (BLSMs) would be the simplified single level with the Karush-Kuhn-Tucker (KKT) approaches. Due to the quick change and variability, the RO method is applied to address the uncertainty. Next, the models are implemented in the real case to illustrate the applicability and efficiency of the proposed models. Finally, the results and analysis of different models are presented.

The rest of this paper is organized as follows. The second section is devoted to the literature review and the gap discussion. In the third section, the problem and its modeling are explained. In the fourth section, the solution approaches are presented and discussed. Also, the results are given and analyzed in this section. Finally, conclusion and suggestions for further research are proposed in the last section.

2. Literature review

This work contains three major parts related to competitive supply chain, QR in supply chain, and agile production discussed as follows.

While demand, replacement Lead Time (LT), and product's life are widely fluctuated, long, and short, respectively, QR is highly useful [8,10,17]. Many papers were published in the areas of utilizing QR in supply chains [3,4,8,10,17] most of which were related to the reduction of delivery time and improvement of performance in uncertain situations and a few of them are close to our work. For instance, Yang et al. [4] studied the effect of QR on pricing and making a decision on the stock in decentralized and centralized supply chains with strategic consumers using revenue sharing. Cachon and Swinney [3] discussed separately the effects of QR on production: high changeability of capacity and product design for markets with unstable changes.

They also developed a model of the fashion market under uncertainty in demand with strategic consumers in order to decide what quantity and price to select for maximizing the profit. The application of QR in retail business considering a single product and non-deterministic demand was conducted by Cachon and Swinney [11]. In this work, a simultaneous game (Nash game) between the retailer and the consumer was proposed for optimizing the ordering quantity and price. Similarly, Li et al. [18] examined how a manufacturer could reduce LT for short lifetime products in a Bi-Level Supply Chain (BLSC) involving the retailer and manufacturer. They developed a theory for determining the ordering quantity, time, and price while the risk of members' behavior as well as extra costs for reducing LT were considered. The proposed model was evaluated using a numerical example. Also, Choi [19] investigated the value of QR considering the rational behavior of customers in the retail business of fashion products; accordingly, an inventory decision-making was mathematically formulated.

In a similar work, Dong and Wu [12] studied how strategic customers might affect the price and inventory in a QR system as well as increase in the yield obtained from some scenarios. Likewise, a simple Stackelberg model for two-period pricing with a price reduction in a BLSC involving a retailer and a manufacturer was presented by Zhang et al. [20]. In this study, three pricing scenarios were examined including QR, no QR, and limited QR. Regarding retailing problems, a newspaper supply chain inventory management model was proposed by Darwish et al. [21]. The retailers had two opportunities for ordering goods at the beginning and during the season after updating demand information using the Bayesian approach. The demand distribution and quantities were optimally determined. Recently, Khouja et al. [22] also optimized the order quantity for retailers to enhance profits using a retail off-price in non-deterministic situations. In this study, a newspaper model was developed for achieving optimal order quantity under different conditions (before and after solving demand uncertainty).

The intensity of global competition and the growing importance of customers have made manufacturers change their strategy from the efficient system to the responding one, thus giving priority to their consumers [23]. In this respect, agility plays a major role in competitive marketing and supply chain, and it also helps manufacturers supply suitable products at the right time [24]. Quick production response, as one of the most important features of agility, aims to reduce the LT and respond to the consumer's requirements [1,23]. To date, many papers that have investigated agility at different levels of supply chains have been published.

A conceptual framework was provided by Sindhwani and Malhotra [23] in which the interactions between different enablers of the agile manufacturing system were analyzed. The research sought to find a structural model for meeting customer's requirements. In the operations research, a scheduling problem in an order-based-production environment in various conditions was investigated by Lalmazloumian et al. [25]. They developed a multi-product, multi-period, and multi-level mixed-integer linear programming model and solved the proposed model by CPLEX. Also, Lago et al. [26] focused on the two major variables: the commodity design duration and LT. Thus, a continuous inventory-based sales model was developed; consequently, LT, time-to-market, design time, and sales' speed were assessed in unique circumstances. Recently, Mahmoodi [27] designed an agile supply chain network in which both production and supply quantities were optimized considering uncertain demand. The agility was taken into account to mitigate the demand uncertainty and improve network flexibility.

An increase in competition can make the supply chain more complicated because supply chains have different members and levels. In this case, game theory is a highly helpful method that analyzes a wide variety of possibilities where a player's decision can affect the others' payoff [28]. Therefore, many papers have been published in competitive situations in a BLSC. A bi-level rice supply chain was given by Cheraghalipour et al. [29] for minimizing the agricultural costs. The model was solved using two meta-heuristics and hybrid algorithms and a numerical example inspired by a real case was employed to demonstrate the model's applicability. Also, Giri et al. [30] developed a BLSC with a manufacturer and a retailer in centralized and decentralized situations. The model was optimized in terms of pricing and advertising strategies. In a decentralized situation, a supply chain with a retailer and some manufacturers were studied to investigate pricing coordination and cooperative advertising [31]. To address the problem, a multi-follower bi-level model was developed and, then, the model was solved by simulated annealing algorithm. The effects of positive relationship between the factors are clarified.

Another work surveyed the effects of manufacturer's social responsibility investment [32]. The proposed model contains two retailers and a manufacturer for a competitive supply chain and solved using backward induction method. The results proved that selling price was sensitive to the social cooperation effort. A bi-level mixed integer linear model for closed-loop supply chain was employed to collect more used products [33]. In this research, the government and private centers were taken as a leader and followers, respectively. Based on the assumptions, a network to increase their profits is designed considering the governmental policies. To solve the model, metaheuristic algorithms and min-max regret scenario-based RO approach were employed; consequently, an optimized network was proposed according to the results.

In other situations where consumers are sensitive to the prices, Seifbarghy et al. [34] obtained the optimal price and quality considering revenue sharing and Ren et al. [35] presented a Stackelberg model with a manufacturer and a retailer concerning make-to-order and deterministic demand. The findings of this work revealed that personalized products could boost profits in this specific matter. In addition, the effect of uncertain competition and demand on the Nash structure and supply chain profit was examined by Mahmoodi and Eshghi [36] using a numerical example. Taken risk into consideration, the green supply chain concept for the design of a lean and agile company under uncertainty and risk was developed by Golpira et al. [37] and a bi-level model was proposed in that sense. Then, the KKT approach is applied to convert the bi-level model to a single-level one. To validate the model application, the model was solved by a numerical example using a RO approach. Similarly, Yue and You [38] presented a BLSM in the decentralized supply chain for designing an optimized supply chain. The bi-level model was simplified at a single level using the KKT approach and evaluated through a case study. Another study was devoted to modeling supply chain competition under uncertainty [39]. The model was proposed first to determine the locations and number of distribution facilities, retailers' allocation, and selling price. Then, the model was modified by real assumptions of risk and failure probabilities. To address the uncertainty, they used a two-stage stochastic model and handled the models using a hybrid genetic algorithm.

Also, Shen et al. [40] presented a BLSC of supplier/manufacturer and retailer considering fashion goods with a short life cycle and uncertain demand in which the manufacturer and the retailer decided on the price and quantity of the order. Likewise, Ghasemy Yaghin et al. [41] proposed a model considering pricing integration, markdown pricing, and production programming in a BLSC involving a retailer and a manufacturer for several periods and products in a fuzzy situation. The model was solved by a fuzzy approach and its results were achieved using a numerical example. Under uncertain conditions, a new hybrid multi-criterion decision-making model in which AHP and G-TOPSSIS fuzzy were taken into consideration was developed by Tian et al. [42] for deriving weights of influence criteria and assessing automated components remanufacturing production patterns. To demonstrate its robustness, a sensitivity analysis was employed.

Another bi-level model is presented to reduce the demand satisfaction costs in the interdictor's attacking condition. In this regard, a new heuristic is designed and the model is optimized using the algorithm and CPLEX software [43]. In addition, a bi-level model for competitive supply chain for obtaining optimal inventory and pricing was presented by Mahmoodi [44]. A modified threshold-accepting algorithm was applied to solve the problem in which the efficiency of the modified algorithm against a differential evolution approach was proved in this matter. In another research area, Fatollahi-Fard et al. [45] proposed a two-stage stochastic programming approach and a Lagrangian relaxation-based algorithm to solve the model. Also, both upper and lower bounds of the problem were considered for improving a better performance. Kaviyani-Charati et al. [46] employed a RO method to cope with uncertainty and investigated the outputs through Mont-Carlo simulation. The efficiency of the RO approach was confirmed in this respect.

Despite the information provided above, Table 1 shows a summary of the literature review of other previous studies.

Table 1. Literature review on the subject areas.

Refs.	Number of level	Competition	Type of game	Agility for manufacturer	Uncertainty	Decision variable	Maximization	QR for retailer	Customer behavior	Type of uncertainty	Journal name
[3]	1	√	Simultaneously	×	√	Price and quantity	√	√	Strategic	Stochastic	MS
[4]	2	√	Sequential	×	×	Price and quantity	√	×	Strategic	Stochastic	Omega
[11]	1	√	Simultaneously	×	√	Price and quantity	√	√	Strategic, Myopic, and Bargain-hunting	Stochastic	MS
[12]	2	√	Simultaneously	×	√	Inventory and pricing	√	√	Strategic	Stochastic	IJPE
[17]	2	×	×	×	×	Risk analysis and sensitivity	√	√	-	Stochastic	DS
[18]	2	×	×	×	√	Time and quantity	√	√	-	Stochastic	CIE
[19]	2	×	×	√	√	Price and quantity	√	×	-	MOQ	ITIOR
[21]	2	×	×	×	√	Service level and inventory management	√	×	-	Normal probability distribution	IJPR
[25]	4	√	×	×	×	Quantity and inventory	√	×	-	RO	AOR
[34]	2	√	Sequential	×	×	Price and quality	√	×	-	-	IJPE
[35]	2	√	Sequential	×	×	Price	√	×	-	-	CIE
[47]	2	√	Sequential	×	√	Price, quantity and advertising	√	√	-	-	EJOR
[48]	2	√	×	×	√	Quantity	√	√	-	Stochastic	IEEE
[49]	2	√	Sequential	×	×	Production, advertising and investment	√	×	-	-	COR
[50]	2	√	Sequential	×	×	Production, quantity, and price	√	×	-	-	IJAMT
[51]	2	√	Sequential	×	×	Price, percent of reduce price, and quantity	√	×	-	-	IJCM
This paper	2	√	Sequential	√	√	Quantity and price	√	√	Strategic	RO	

2.1. Research gap and discussion

Most of the papers published in the field of QR and agility focus only on the retailer level. In other words, various features of QR in retailing were conceptually investigated with little attention to competitive and integrated situations. Thus, the optimal ordering quantity and price will be obtained under competitive circumstances. It is worth mentioning that a retailer with QR needs a manufacturer who can respond to the retailer at the right time. Besides, the effects of QR and agility on profits and clearance sales are investigated in comparison with the traditional supply chain using a real case study. The main aim of this study is to investigate the differences between conventional and modified models. In addition to the discussions, there is little attention to the features of responsiveness and agility in mathematical models in those papers working on a BLSC despite emphasizing the importance of the consumers' needs and personalized products in a conceptual way. With regard to the features of the fashion market and its uncertainty, a search through the literature illustrates that the studies that have employed the RO method are still limited and need to receive a greater focus. Thus, novel bi-level mathematical models for both supply chains are considered in which ordering and production quantities and prices are optimized.

Apart from that, customers play a crucial role in today's competitive world so that suppliers and retailers strive to attract customer's attention by providing better services and product quality and reasonable prices. Although the consumers' demand and behavior have been considered separately in the previous papers, we consider the mentioned items simultaneously in this work. In addition to a determination of the manufacturer's and retailer's strategy, QR and agility would be employed to achieve the strategic customer's satisfaction and elevate the supply chain members' profit. These characteristics are applied in this study using some assumptions to increase the satisfaction and profit of the supply chain members.

Also, customers usually seek products that ensure profit and satisfaction. For instance, in the smartphone industry, two competitors, namely Samsung and Apple, are struggling to gain a higher market share by presenting more advanced models. Taking two Samsung smartphone models 7 and 8 as an example; the customers reasonably decide whether to buy the new model after the introduction immediately or wait until buying it with a price reduction. In the meantime, the producer tries to introduce a new product to the market due to a decline in the demand and meeting customers' requirements and expectations. This can lead to attraction of more customers and satisfaction of customers' needs, consequently maximizing the producer's profit in this situation. The former example is an actual one that perfectly elaborates the application of our research finding in which an attempt is made to obtain the optimal price, production, and ordering quantity at two levels of the supply chain. Thus, a decoration industry is employed in this research work as a case study to prove its applicability and efficiency in reality.

The main contributions of this work are listed as follows:

1. Two BLSMs for two-echelon supply chain with strategic customers are developed;
2. Two different conditions with and without agile abilities are considered for developing the mathematical models;
3. To cope with the uncertain circumstance, a scenario-based RO approach is applied;
4. A real case study of Chandeliers industry is employed to demonstrate the applicability and efficiency of models.

In summary, two bi-level models are developed. The first model involves a manufacturer and a retailer without any agility; however, the second one comprises a manufacturer with the agility and a retailer with a QR feature which can produce and satisfy customers' demand in a timely manner. Additionally, the consumers' behavior is taken into account in both models and their requirements are considered in the second one. To tackle the uncertainty, the RO approach is employed to enhance the efficiency of the results under real conditions. Also, the manufacturer and the retailer compete with each other in a sequential SG.

3. The problem

Producers prefer efficient and expense-based approaches in which the wholesale with less manufacturing costs are preferred. In the ordering of traditional production systems, the retailer can only order once before the sale season due to the long LT [3,4,11]. Customization in the fashion market is high [52] and uncertainty in such markets is of great importance. Thus, it may result in the loss of the efficiency of the mathematical model in reality if the uncertainty is ignored. In such markets, quick changes in the customer's behavior and requirements are also observed. The detailed problems are discussed in the following two sub-sections.

3.1. The first problem

A bi-level problem is suggested containing a manufacturer and a retailer who offer strategic consumers only a product in the selling season with full and discount prices. Strategic consumers are the consumers who behave quite rationally with respect to purchasing commodities and select the time of their purchase upon assessing the situation [3,4,11].

Given its nature and considering the existing limitations, the manufacturer initially decides on the price and production quantity as the leader and then, the retailer offers his best strategies after observing the decisions of the leader. Some hypotheses are considered in this paper and listed as follows:

- The retailer has a limited capacity and his ordering quantity cannot exceed a certain limit;
- The manufacturer and the retailer are chosen as the leader and follower in the SG, respectively;
- The behavior of the strategic consumers influences the decisions of the players;
- The full and discount prices are considered for the retailer;
- Throughout the selling season, the price reduction occurs only once and the rest of the products are sold at the end of the selling season at a reduced price;
- The retailer has also budget limitations;
- The consumers are homogeneous and shortage is not allowed.

The notations used to describe the problem are:

Index

s Uncertainty scenarios for all $s \in S$

Parameters

C The production costs of each product for the manufacturer

S The reduced price for each product for the manufacturer

Cap The manufacturer's production capacity

α The selling commission for the retailer

ν The commodity value for the consumer

δ The discount factor of the price of each product for the retailer

D_s The consumer's demand for the retailer under scenario s

γ The percentage of the reduction of commodity value for the consumer during the time

B Budget limitation for the retailer

w_s Ordering capacity for the retailer under scenario s

Variables

P_l The manufacturer's price

Q_{ls} The production quantity for the manufacturer under scenario s

P_f The retailer's price

Q_{fs} The ordering quantity for the retailer under scenario s

3.1.1. Mathematical model

After giving some explanation and notations, the traditional model is proposed in the following.

$$\text{Max } \pi_{ls}(Q_{ls}, P_l) = \sum_s \Big((P_l - C) \,.Q_{fs} + (S - C) \,. (Q_{ls} - Q_{fs})^+ \Big), \tag{1}$$

s.t.:

$$Q_{ls} \le cap \qquad \forall s \in S, \tag{2}$$

$$Q_{ls} \ge Q_{fs} \qquad \forall s \in S, \tag{3}$$

$$\text{Max } \pi_{fs}(Q_{fs}, P_f) = \sum_s \Big((P_f - P_l) \,.D_S + (\delta.P_f - P_l) \,. (Q_{fs} - D_s) \Big), \tag{4}$$

s.t.:

$$(1 + \alpha) \,.P_l \le P_f, \tag{5}$$

$$P_f \le \frac{v.\,(1 - \gamma)}{1 - \delta}, \tag{6}$$

$$Q_{fs} \le w_s \qquad \forall s \in S, \tag{7}$$

$$P_l.Q_{fs} \le \beta \qquad \forall s \in S, \tag{8}$$

$$Q_{ls}, P_l, Q_{fs}, P_f \ge 0 \qquad \forall s \in S. \tag{9}$$

Constraint (1) shows the objective function of the leader. Constraint (2) guarantees that the production quantity will not exceed the manufacturer capacity. Constraint (3) guarantees that the manufacturer satisfies the consumer's order. Constraint (4) is the objective function of the follower. The price announced by the leader cannot exceed the follower's price shown in Constraint (5). Constraint (6) guarantees that the follower's price cannot exceed a certain limit. The retailer's capacity for sales is given in Constraint (7). Constraint (8) ensures that the total costs paid for the quantity of ordering the commodity will not exceed a certain limit. Finally, Constraint (9) shows the positivity of the variables.

As explained in the literature and based on the real assumptions and issues, the first problem is modified by adding the QR and agile ability to the retailer and the manufacturer, respectively. The second problem is fully described in the following sub-section.

3.2. The second problem

Instant changes in customer's demands and needs as well as the remaining commodities at the end of the selling season make decision-making really difficult for the retailers and the manufacturers in this highly competitive market. QR, as a strategy, uses new systems for reducing the inventory level and applies a quick reaction to the consumer's requirements and demand. The concept of QR with regard to [3,4,8,11] tries to reduce the inventory level and correctly anticipate the consumer's demand by reducing the LT. To order the goods required by the customers, the retailer needs a manufacturer who can respond properly to the ordering quantity in a reasonable time according to the consumer's requirements. The AM can quickly meet the retailers' demand and needs in an unstable market using useful information sharing [1,24]. In this problem, a bi-level model is developed in which the retailer and the manufacturer try to determine the price, ordering quantity, and production quantity considering strategic consumers to optimize the objective functions with agile abilities. Regarding the previous works [3,4,8,11], the retailer can order twice throughout the selling season once before the starting of the season and once after updating the demand during the season. The retailer and manufacturer should pay extra costs in order to use QR and agility per product unit.

In addition to the assumptions of the first problem, the following assumptions are added to this problem:

- There are two times throughout the selling season in that the retailer and the manufacturer can be supplied and the demand type cannot be the same (in terms of feature and quantity);
- Throughout the season, the requirements of the market and the customers change once;
- The innovations and changes in the product are applied in accordance with the consumers' demand and requirements under uncertainty;
- The cost added to a product production depends on the rate of innovation and change in the product;
- The value added to the product offered based on the changes in the market and the customers' requirements depends on the rate of innovation and changes in the product.

With regard to its real assumptions and agile abilities, this model is developed in the following.

3.2.1. Mathematical modeling

The general model for I $(i = 1, ..., I)$ products is shown as follows:

$$\text{Max } \pi_l(Q_{li}, P_{li}) = \sum_i \Big(\left(P_{li} - (C + n_i)\right).Q_{fi} + \left(S_i - (C + n_i)\right).\left(Q_{li} - Q_{fi}\right)^+ \Big), \tag{10}$$

s.t.:

$$Q_{li} \le cap_i \qquad \forall i \in I, \tag{11}$$

$$Q_{li} \le Q_{fi} \qquad \forall i \in I, \tag{12}$$

$$\text{Max } \pi_f(Q_{fi}, P_{fi}) = \sum_i \Big(\left(P_{fi} - P_{li}\right).D_i + \left(\delta_i.P_{fi} - P_{li}\right).\left(Q_{fi} - D_i\right) - C_Q.Q_{fi} \Big), \tag{13}$$

s.t.:

$$(1 + \alpha).P_{li} \le P_{fi} \qquad \forall i \in I, \tag{14}$$

$$P_{fi} \le \frac{(v + m_i).(1 - \gamma_i)}{1 - \delta_i} \qquad \forall i \in I, \tag{15}$$

$$Q_{fi} \le \omega_i \qquad \forall i \in I, \tag{16}$$

$$P_{li}.Q_{fi} \le \beta_i \qquad \forall i \in I, \tag{17}$$

$$Q_{li}, P_{li}, Q_{fi}, P_{fi} \ge 0 \qquad \forall i \in I. \tag{18}$$

It is assumed that the cost C for the first product and m_i, n_i, and C_Q would be zero in this sense. Considering two types of products, $i = 1, 2$ the description and mathematical model are given below:

Parameters

C	The cost of producing per product unit
S_1, S_2	The clearance price for product types 1 and 2 for the manufacturer
Cap_1, Cap_2	Production capacity for product types 1 and 2
α	The selling commission for the retailer
ν	The value of the product for the customers
δ_1, δ_2	The reduced rates of products' prices, types 1 and 2, for the retailer throughout time
D_{1s}, D_{2s}	Demand for products, types 1 and 2, under scenario s
γ_1, γ_2	The reduced rates of products' values, types 1 and 2, for the retailer throughout time
C_Q	The cost of QR adoption for the retailer

m_s The additional value added to the product for the customers under scenario s

n_s The extra cost added to the purchasing cost for the consumers under scenario s

w_{1s}, w_{2s} The ordering capacity of the product types 1 and 2 for the retailer under scenario s

b_1, b_2 The budget of the retailer for the product types 1 and 2

Variables

Q_{l1s}, Q_{l2s} The production quantity of the product types 1 and 2 for the manufacturer under scenario s

P_{l1} The first product price for the manufacturer

P_{l2s} The second product price for the manufacturer under scenario s

Q_{f1s}, Q_{f1s} The ordering product quantity types 1 and 2 for the retailer under scenario s

P_{f1} The first product price for the retailer

P_{f2s} The second product price for the retailer under scenario s

3.2.2. Mathematical model

The relations between the quantities and capacities are as follows:

Eq. (19) is shown in Box I, s.t.:

$$Q_{l1s} \leq cap_1 \qquad \forall s \in S, \tag{20}$$

$$Q_{l2s} \leq cap_2 \qquad \forall s \in S, \tag{21}$$

$$Q_{l1s} \geq Q_{f1s} \qquad \forall s \in S, \tag{22}$$

$$Q_{l2s} \geq Q_{f2s} \qquad \forall s \in S, \tag{23}$$

Eq. (24) is shown in Box II, s.t.:

$$(1+\alpha).P_{l1} \leq P_{f1}, \tag{25}$$

$$(1+\alpha).P_{l2s} \leq P_{f2s} \qquad \forall s \in S, \tag{26}$$

$$P_{f1} \leq \frac{v.(1-\gamma_1)}{1-\delta_1}, \tag{27}$$

$$P_{f2s} \leq \frac{(v+m_s).(1-\gamma_2)}{1-\delta_2} \qquad \forall s \in S, \tag{28}$$

$$Q_{f1s} \leq \omega_{1s} \qquad \forall s \in S, \tag{29}$$

$$P_{l1}.Q_{f1s} \leq \beta_1 \qquad \forall s \in S, \tag{30}$$

$$Q_{f2s} \leq \omega_{2s} \qquad \forall s \in S, \tag{31}$$

$$P_{l2s}.Q_{f2s} \leq \beta_2 \qquad \forall s \in S, \tag{32}$$

$$Q_{l1s}, P_{l1}, Q_{l2s}, P_{l2s}, Q_{f1s}, P_{f1}, Q_{f2s}, P_{f2s} \geq 0 \qquad \forall s \in S. \tag{33}$$

Constraint (19) shows the leader's objective function including costs, clearance sales, and sales. The production quantity of the products types 1 and 2 would not exceed its capacity, which is ensured by Constraints (20) and (21). Constraints (22) and (23) guarantee that the manufacturer satisfies the ordering quantity of the retailer. The follower's objective function is shown in Constraint (24). Constraints (25) and (26) demonstrate that the leader cannot announce a price higher than that of the follower. Constraints (27) and (28) ensure that the retail price cannot exceed a certain limit since customers are not disposed to incur extra expenses. The ordering capacity and available budget for the follower are limited by Constraints (29)–(32). Finally, Constraint (33) shows the positive variables.

$$\text{Max} \quad \pi_{ls}(Q_{l1s}, P_{l1}, Q_{l2s}, P_{l2s}) = \sum_s \begin{pmatrix} (P_{l1}-C).Q_{f1s} + (P_{l2s}-(C+n_s)).Q_{f2s} + (S_1-C).(Q_{l1s}-Q_{f1s})^+ \\ +(S_2-(C+n_s)).(Q_{l2s}-Q_{f2s})^+ \end{pmatrix}. \tag{19}$$

Box I

$$\text{Max} \quad \pi_{fs}(Q_{f1s}, P_{f1}, Q_{f2s}, P_{f2s}) = \sum_s \begin{pmatrix} (P_{f1}-P_{l1}).D_{1s} + (P_{f2s}-P_{l2s}).D_{2s} + (\delta_1.P_{f1}-P_{l1}).(Q_{f1s}-D_{1s}) \\ +(\delta_2.P_{f2s}-P_{l2s}).(Q_{f2s}-D_{2s}) - C_Q.Q_{f2s} \end{pmatrix} \tag{24}$$

Box II

4. Solution procedure

Several theories have been offered for solving linear bi-level programming problems [37,38,43,44,53–55]. Thus, this paper applies the KKT approach to convert the proposed bi-level models into single-level ones. In the following sub-section, the KKT method is briefly discussed and then, the models are linearized as the KKT's precondition. After that, they are simplified single levels; finally, the models are solved by scenario-based RO and its results are analyzed under some various conditions.

4.1. The KKT approach

The KKT approach is initially written for the lower level and, then, added to the upper one. The bi-level model is simplified into a single-level one. It is fully addressed in the literature of the KKT [37,38,54–57]. However, if the model contains any non-linear formula, they should be converted into linear one first. Then, the linear mathematical model can be turned to a single-level by the KKT approach. Therefore, the proposed models need to be linearized first.

4.2. Linearization

$P_f.Q_{fs}$ and $P_l.Q_{fs}$ formulas in the first model and $Q_{f1}.P_{l1}$, $Q_{f2s}.P_{l2s}$, $Q_{f1s}.P_{f1}$, $Q_{f2s}.P_{f2s}$ formulas in the second one are non-linear. Therefore, they should be changed into linear using the method suggested in [58].

Let's take the non-linear formula, $P_l.Q_{fs}$, in the first model. On the one side, the price per product for the manufacturer cannot be lower than its production costs. On the other side, the maximum price that the manufacturer can offer may not be higher than a certain limit owing to the nature of the problem. Thus, the high and low levels of the unit price in the first model are $\frac{v.(1-\gamma)}{(1+\alpha).(1-\delta)}$ and C, respectively. The limitation related to the two non-linear variables is shown as follows:

$$C \le P_l \le \frac{v.\left(1-\gamma\right)}{\left(1+\alpha\right).\left(1-\delta\right)}. \tag{34}$$

Similarly, for the second variable in this formula, we have:

$$0 \le Q_{fs} \le cap \qquad \forall s \in S. \tag{35}$$

Now, the non-linear formula is replaced with a new variable called y_{1s} and its associated constraints are:

$$y_{1s} = P_l.Q_{fs} \qquad \forall s \in S,$$

$$C \le P_l \le \frac{v.\left(1-\gamma\right)}{\left(1+\alpha\right).\left(1-\delta\right)} \xrightarrow{\times Q_{fs}} C.Q_{fs} \le P_l.Q_{fs}$$

$$\le \frac{v.\left(1-\gamma\right)}{\left(1+\alpha\right).\left(1-\delta\right)}.Q_{fs} \xrightarrow{y_{1s}=P_lQ_{fs}} C.Q_{fs} \le y_{1s}$$

$$\le \frac{v.\left(1-\gamma\right)}{\left(1+\alpha\right).\left(1-\delta\right)}.Q_{fs} \qquad \forall s \in S. \tag{36}$$

Moreover, the rest of non-linear formulas are similarly changed into linear, the details of which are shown in Appendix A. Regarding the previous explanations, the linearized models are simplified single-level ones using the KKT approach given in Subsection [53–57].

4.3. Single-level models

The bi-level models are transformed into single ones using KKT approach and presented into the following models.

4.3.1. First model

The objectives and constraints of this model are as follows:

$$\text{Max} \;\; \pi_{ls}\left(Q_{ls}, P_l\right) = \sum_s \Bigg(y_{1s} - C.Q_{fs} + \left(S-C\right). \left(Q_{ls} - Q_{fs}\right)^{+} \Bigg), \tag{37}$$

s.t.:

$$Q_{ls} \le cap \qquad \forall s \in S, \tag{38}$$

$$Q_{ls} \ge Q_{fs} \qquad \forall s \in S, \tag{39}$$

$$C.Q_{fs} \le y_{1s} \le \frac{v.\left(1-\gamma\right)}{\left(1+\alpha\right).\left(1-\delta\right)}.Q_{fs} \quad \forall s \in S, \tag{40}$$

$$\left(1+\alpha\right).P_l \le P_f, \tag{41}$$

$$P_f \le \frac{v.\left(1-\gamma\right)}{1-\delta}, \tag{42}$$

$$Q_{fs} \le w_s \qquad \forall s \in S, \tag{43}$$

$$P_l.Q_{fs} \le \beta \qquad \forall s \in S, \tag{44}$$

$$C.\left(1+\alpha\right).Q_{fs} \le y_{2s} \qquad \forall s \in S, \tag{45}$$

$$y_{2s} \le \frac{v.\left(1-\gamma\right)}{\left(1-\delta\right)}.Q_{fs} \qquad \forall s \in S, \tag{46}$$

$$\delta + U_4 - U_5 + U_8 = 0, \tag{47}$$

$$\left(1-\delta\right).D_s + U_1 - U_2 + U_7 = 0 \qquad \forall s \in S, \tag{48}$$

$$-U_3 - C.\left(1+\alpha\right).U_4 + \frac{v.\left(1-\gamma\right)}{\left(1-\delta\right)}.U_5 + U_6 = 0, \tag{49}$$

$$U_4.\left(C.\left(1+\alpha\right).Q_{fs} - y_{2s}\right) + U_5.\left(y_{2s} - \frac{v.\left(1-\gamma\right)}{\left(1-\delta\right)}.Q_{fs}\right) + U_8.\mathrm{y}_{2s} = 0 \qquad \forall s \in S, \tag{50}$$

$$U_1.\left((1+\alpha).P_l-P_f\right)+U_2.\left(P_f-\frac{v.(1-\gamma)}{1-\delta}\right)+U_7.P_f=0, \quad (51)$$

$$U_3.\left(Q_{fs}-w_s\right)+U_4.\left(C.(1+\alpha).Q_{fs}-y_{2s}\right)+U_5.\left(y_{2s}-\frac{v.(1-\gamma)}{(1-\delta)}.Q_{fs}\right)+U_6.Q_{fs}=0 \quad \forall s\in S, \quad (52)$$

$$y_{1s},y_{2s},U_1,\ldots,U_8,Q_{ls},P_l,Q_{fs},P_f\geq 0 \quad \forall s\in S. \quad (53)$$

4.3.2. Second model

The second model can also be reformulated as follows:

Eq. (54) is shown in Box III, s.t.:

$$Q_{l1s}\leq cap_1 \quad \forall s\in S, \quad (55)$$

$$Q_{l2s}\leq cap_2 \quad \forall s\in S, \quad (56)$$

$$Q_{l1s}\geq Q_{f1s} \quad \forall s\in S, \quad (57)$$

$$Q_{l2s}\geq Q_{f2s} \quad \forall s\in S, \quad (58)$$

$$C.Q_{f1s}\leq y_{1s}\leq\frac{v.(1-\gamma_1)}{(1+\alpha).(1-\delta_{1)}}.Q_{f1s} \quad \forall s\in S, \quad (59)$$

$$(C+n_s).Q_{f2s}\leq y_{2s}\leq\frac{(v+m_s).(1-\gamma_2)}{(1+\alpha).(1-\delta_2)}.Q_{f2s} \quad \forall s\in S, \quad (60)$$

$$(1+\alpha).P_{l1}\leq P_{f1}, \quad (61)$$

$$(1+\alpha).P_{l2s}\leq P_{f2s} \quad \forall s\in S, \quad (62)$$

$$P_{f1}\leq\frac{v.(1-\gamma_1)}{1-\delta_1}, \quad (63)$$

$$P_{f2s}\leq\frac{(v+m_s).(1-\gamma_2)}{1-\delta_2} \quad \forall s\in S, \quad (64)$$

$$Q_{f1s}\leq\omega_{1s} \quad \forall s\in S, \quad (65)$$

$$P_{l1}.Q_{f1s}\leq\beta_1 \quad \forall s\in S, \quad (66)$$

$$Q_{f2s}\leq\omega_{2s} \quad \forall s\in S, \quad (67)$$

$$P_{l2s}.Q_{f2s}\leq\beta_2 \quad \forall s\in S, \quad (68)$$

$$(1+\alpha).C.Q_{f1s}\leq y_{3s} \quad \forall s\in S, \quad (69)$$

$$y_{3s}\leq\frac{v.(1-\gamma_1)}{1-\delta_1}.Q_{f1s} \quad \forall s\in S, \quad (70)$$

$$(C+n_s).(1+\alpha).Q_{f2s}\leq y_{4s} \quad \forall s\in S, \quad (71)$$

$$y_{4s}\leq\frac{(v+m_s).(1-\gamma_2)}{(1-\delta_2)}.Q_{f2s} \quad \forall s\in S, \quad (72)$$

$$(1-\delta_1).D_{1s}+U_1-U_3+U_{11}=0 \quad \forall s\in S, \quad (73)$$

$$(1-\delta_2).D_{2s}+U_2-U_4+U_{12}=0 \quad \forall s\in S, \quad (74)$$

$$\delta_1+U_7-U_8+U_{13}=0, \quad (75)$$

$$\delta_2+U_9-U_{10}+U_{14}=0, \quad (76)$$

$$-U_5-(1+\alpha).C.U_7+\frac{v.(1-\gamma_1)}{1-\delta_1}.U_8+U_{15}=0, \quad (77)$$

$$-C_Q-U_6-(1+\alpha).(C+n_s).U_9+\frac{(v+m_s).(1-\gamma_2)}{1-\delta_2}.U_{10}+U_{16}=0 \quad \forall s\in S, \quad (78)$$

$$U_1.\left((1+\alpha).P_{l1}-P_{f1}\right)+U_3.\left(P_{f1}-\frac{v.(1-\gamma_1)}{1-\delta_1}\right)+U_{11}.P_{f1}=0, \quad (79)$$

$$U_2.\left((1+\alpha).P_{l2s}-P_{f2s}\right)+U_4.\left(P_{f2s}-\frac{(v+m_s).(1-\gamma_2)}{1-\delta_2}\right)+U_{12}.P_{f2s}=0 \quad \forall s\in S, \quad (80)$$

$$U_7.\left((1+\alpha).C.Q_{f1s}-y_{3s}\right)+U_8.\left(y_{3s}-\frac{v.(1-\gamma_1)}{1-\delta_1}.Q_{f1s}\right)+U_{13}.y_{3s}=0 \quad \forall s\in S, \quad (81)$$

$$\text{Max}\ \ \pi_{ls}\left(Q_{l1s},P_{l1},Q_{l2s},P_{l2s}\right)=\sum_s\begin{pmatrix} y_{1s}-C.Q_{f1s}+y_{2s}-(C+n_s).Q_{f2s}+(S_1-C).(Q_{l1s}-Q_{f1s})^+\\ +(S_2-(C+n_s)).(Q_{l2s}-Q_{f2s})^+\end{pmatrix}. \quad (54)$$

Box III

$$U_9.\left((C+n_s).(1+\alpha).Q_{f2s}-y_{4s}\right)$$
$$+U_{10}\left(y_{4s}-\frac{(v+m_s).(1-\gamma_2)}{(1-\delta_2)}.Q_{f2s}\right)$$
$$+U_{14}.y_{4s}=0 \qquad \forall s\in S, \tag{82}$$

$$U_5.(Q_{f1s}-w_{1s})+U_7.\left((1+\alpha).C.Q_{f1s}-y_{3s}\right)$$
$$+U_8.\left(y_{3s}-\frac{v.(1-\gamma_1)}{1-\delta_1}.Q_{f1s}\right)+U_{15}.Q_{f1s}=0$$
$$\forall s\in S, \tag{83}$$

$$U_6.(Q_{f2s}-w_{2s})+U_9.\left((C+n_s).(1+\alpha).Q_{f2s}-y_{4s}\right)$$
$$+U_{10}.\left(y_{4s}-\frac{(v+m_s).(1-\gamma_2)}{(1-\delta_2)}.Q_{f2s}\right)$$
$$+U_{16}.Q_{f2s}=0 \qquad \forall s\in S, \tag{84}$$

$$y_{1s},y_{2s},y_{3s},y_{4s},U_1,\ldots,U_{16},Q_{l1s},P_{l1},Q_{l2s},P_{l2s},$$
$$Q_{f1s},P_{f1},Q_{f2s},P_{f2s}\geq 0 \qquad \forall s\in S. \tag{85}$$

4.4. Reduction the single-level model

In this paper, the single-level models can be equalized in the simplest form due to the nature of the problems and the KKT approach [56]. Based on the problem, the value of variables would not be zero. For this purpose, it is proved that the limitations of stationarity and complementary slackness are always correct. Therefore, they can be removed from the single-level models, and the simplified models can be analyzed. For instance, the variable P_{f1} is not equal to zero; therefore, the dual variable associated with it is zero. Similarly, $U_{11},...,U_{16}$ should be zero for the second model. Considering Constraints (69) and (70) related to the equation, $y_{3s}=P_{f1}.Q_{f1s}$. In these constraints, if P_{f1} is equal to its upper limit, the upper limit of Constraint (70) is satisfied as well. With regard to the explanation provided before, the problems are mathematically modeled to maximize the profit. Thus, the manufacturer and the retailer seek the maximum price in this competition. In that regard, the price is equal to the upper limit and Constraints (69) and (70) will be as follows:

$$(1+\alpha).C.Q_{f1s}-y_{3s}\neq 0 \quad \text{and}$$

$$y_{3s}-\frac{v.(1-\gamma_1)}{(1-\delta_1)}.Q_{f1s}=0.$$

Hence, the value of U_7 should be zero, while the value of U_8 cannot be zero. In the following, given the constraint, $\delta_1+U_7+U_8+U_{13}=0$, and the value of U_{13} being zero, the value of U_8 is δ_1. Then, all constraints of stationarity and complementary slackness are calculated and found in the same way (Appendix B).

After going through some mathematical processes, a brief description of the RO method is provided for solving the models in the next sub-section.

4.5. Robust Optimization (RO)

Despite developing various RO methods, the scenario-base RO is utilized in this paper. The scenario-based RO fits the problem considered in this research. Mulvey believes that if a model is infeasible in reality under some scenarios, the model loses its efficiency. Consequently, Mulvey et al. [59] introduced a new model for the RO in which uncertainties were regarded as various scenarios with certain probabilities. This model shows the answers which would be the result of a tradeoff between the robustness of the model and the answer. An answer can be robust if it is close to the optimum under all scenarios. Similarly, a model can be robust when it remains feasible under all considered scenarios with high probability. For more information, readers are referred to these studies [59,60].

Robust models for the first and second mathematical models are presented below.

The first model:

Eq. (86) is shown in Box IV, s.t.:

$$\varsigma_{ls}=y_{1s}-C.Q_{fs}+(S-C).(Q_{ls}-Q_{fs})^{+}$$
$$\forall s\in S, \tag{87}$$

$$\varsigma_{ls}-\sum_{s'=1}^{S}\rho_{s'}.\varsigma_{ls'}+\theta_s\geq 0 \qquad \forall s\in S, \tag{88}$$

$$Q_{ls}-Z_{1s}\leq cap \qquad \forall s\in S, \tag{89}$$

$$Q_{ls}\geq Q_{fs}-Z_{2s} \qquad \forall s\in S, \tag{90}$$

$$C.Q_{fs}-Z_{3s}\leq y_{1s} \qquad \forall s\in S, \tag{91}$$

$$y_{1s}\leq\frac{v.(1-\gamma)}{(1+\alpha).(1-\delta)}.Q_{fs}+Z_{4s} \qquad \forall s\in S, \tag{92}$$

$$Q_{fs}=w_s+Z^{+}_{5s}-Z^{-}_{5s} \qquad \forall s\in S, \tag{93}$$

$$y_{1s}\leq\beta+Z_{6s} \qquad \forall s\in S, \tag{94}$$

$$C.(1+\alpha).Q_{fs}-Z_{7s}\leq y_{2s} \qquad \forall s\in S, \tag{95}$$

$$y_{2s}=\frac{v.(1-\gamma)}{(1-\delta)}.Q_{fs}+Z^{+}_{8s}-Z^{-}_{8s} \qquad \forall s\in S, \tag{96}$$

$$(1+\alpha).P_l=P_f, \tag{97}$$

$$\text{Max } w=\sum_{s=1}^{S}\rho_s.\varsigma_{ls}-\lambda .\left[\sum_{s}^{S}\rho_s.\left[\left(\varsigma_{ls}-\sum_{s'}^{S}\rho_{s'}.\varsigma_{ls'}\right)+2.\theta_s\right]\right]-\sum_{s=1}^{S}\rho_s .\left(\begin{array}{l}W_1.Z_{1s}+W_2.Z_{2s}+W_3.Z_{3s}+W_4.Z_{4s}+W_5.\left(Z_{5s}^{+}+Z_{5s}^{-}\right)+W_6.Z_{6s}\\+W_7.Z_{7s}+W_8.\left(Z_{8s}^{+}+Z_{8s}^{-}\right)\end{array}\right). \tag{86}$$

Box IV

$$P_f=\frac{v.(1-\gamma)}{1-\delta}, \tag{98}$$

$$Z_{1s},Z_{2s},Z_{3s},Z_{4s},Z_{5s}^{+},Z_{5s}^{-},Z_{6s},Z_{7s},Z_{8s}^{+},Z_{8s}^{-},y_{1s},y_{2s},$$

$$Q_{ls},P_l,Q_{fs},P\geq 0 \qquad \forall s\in S. \tag{99}$$

The second model:

Eq. (100) is shown in Box V, s.t.:

$$y_{1s}+y_{2s}-C.Q_{f1s}-(C+n_s).Q_{f2s}+(S_1-C).(Q_{l1s}-Q_{f1s})^{+}+(S_2-C-n_s).(Q_{l2s}-Q_{f2s})^{+}=\varsigma_{ls} \qquad \forall s\in S, \tag{101}$$

$$\varsigma_{ls}-\sum_{s'=1}^{S}\rho_{s'}.\varsigma_{ls'}+\theta_s\geq 0 \qquad \forall s\in S, \tag{102}$$

$$Q_{l1s}-Z_{1s}\leq cap_1 \qquad \forall s\in S, \tag{103}$$

$$Q_{l2s}-Z_{2s}\leq cap_2 \qquad \forall s\in S, \tag{104}$$

$$Q_{l1s}+Z_{3s}\geq Q_{f1s} \qquad \forall s\in S, \tag{105}$$

$$Q_{l2s}+Z_{4s}\geq Q_{f2s} \qquad \forall s\in S, \tag{106}$$

$$C.Q_{f1s}-Z_{5s}\leq y_{1s} \qquad \forall s\in S, \tag{107}$$

$$y_{1s}\leq\frac{v.(1-\gamma_1)}{(1+\alpha).(1-\delta_1)}.Q_{f1s}+Z_{6s} \qquad \forall s\in S, \tag{108}$$

$$(C+n_s).Q_{f2s}-Z_{7s}\leq y_{2s} \qquad \forall s\in S, \tag{109}$$

$$y_{2s}\leq\frac{(v+m_s).(1-\gamma_2)}{(1+\alpha).(1-\delta_2)}.Q_{f2s}+Z_{8s} \qquad \forall s\in S, \tag{110}$$

$$(1+\alpha).P_{l2s}=P_{f2s}+Z_{18s}^{+}-Z_{18s}^{-} \qquad \forall s\in S, \tag{111}$$

$$P_{f2s}=\frac{(v+m_s).(1-\gamma_2)}{1-\delta_2}+Z_{9s}^{+}-Z_{9s}^{-} \qquad \forall s\in S, \tag{112}$$

$$Q_{f1s}=\omega_{1s}+Z_{10s}^{+}-Z_{10s}^{-} \qquad \forall s\in S, \tag{113}$$

$$Q_{f2s}=\omega_{2s}+Z_{11s}^{+}-Z_{11s}^{-} \qquad \forall s\in S, \tag{114}$$

$$y_{1s}\leq\beta_1+Z_{12s} \qquad \forall s\in S, \tag{115}$$

$$y_{2s}\leq\beta_2+Z_{13s} \qquad \forall s\in S, \tag{116}$$

$$(1+\alpha).C.Q_{f1s}-Z_{14s}\leq y_{3s} \qquad \forall s\in S, \tag{117}$$

$$y_{3s}=\frac{v.(1-\gamma_1)}{1-\delta_1}.Q_{f1s}+Z_{15s}^{+}-Z_{15s}^{-} \qquad \forall s\in S, \tag{118}$$

$$\text{Max } \pi_{ls}(Q_{l1s},P_{l1},Q_{l2s},P_{l2})=\sum_{s=1}^{S}\rho_s.\varsigma_{ls}-\lambda.\left[\sum_{s}^{S}\rho_s.\left[\left(\varsigma_{ls}-\sum_{s'}^{S}\rho_{s'}.\varsigma_{ls'}\right)+2.\theta_s\right]\right]-\sum_{s=1}^{S}\rho_s.\left(\begin{array}{l}W_1.Z_{1s}+W_2.Z_{2s}+W_3.Z_{3s}+W_4.Z_{4s}+W_5.Z_{5s}+W_6.Z_{6s}+W_7.Z_{7s}+\\W_8.Z_{8s}+W_9.\left(Z_{9s}^{+}+Z_{9s}^{-}\right)+W_{10}.\left(Z_{10s}^{+}+Z_{10s}^{-}\right)+W_{11}.\left(Z_{11s}^{+}+Z_{11s}^{-}\right)\\+W_{12}.Z_{12s}+W_{13}.Z_{13s}+W_{14}.Z_{14s}+W_{15}.\left(Z_{15s}^{+}+Z_{15s}^{-}\right)+W_{16}.Z_{16s}^{+}\\W_{17}.\left(Z_{17s}^{+}+Z_{17s}^{-}\right)+W_{18}.\left(Z_{18s}^{+}+Z_{18s}^{-}\right)\end{array}\right) \tag{100}$$

Box V

$$(C+n_s).(1+\alpha).Q_{f2s}-Z_{16s}\leq y_{4s} \qquad \forall s\in S, \tag{119}$$

$$y_{4s}=\frac{(v+m_s).(1-\gamma_2)}{(1-\delta_2)}.Q_{f2s}+Z^{+}_{17s}-Z_{17s} \qquad \forall s\in S, \tag{120}$$

$$(1+\alpha).P_{l1}=P_{f1}, \tag{121}$$

$$P_{f1}=\frac{v.(1-\gamma_1)}{1-\delta_1}, \tag{122}$$

$$Z_{1s},\ldots,Z_{8s},Z^{+}_{9s},Z^{-}_{9s},Z^{+}_{10s},Z^{-}_{10s},Z^{+}_{11s},Z^{-}_{11s},Z_{12s}, Z_{13s},Z_{14s},Z^{+}_{15s},Z^{-}_{15s},Z_{16s},Z^{+}_{17s},Z^{-}_{17s},Z^{+}_{18s}, Z^{-}_{18s},Q_{l1s},P_{l1},Q_{l2s},P_{l2s},Q_{f1s},P_{f1},Q_{f2s},P_{f2s}, y_{1s},y_{2s},y_{3s},y_{4s}\geq 0. \tag{123}$$

As seen in the two models, the first part of the objective function in both models consists of the solution robustness part that seeks to optimize the mean profit for each scenario. The second part is to minimize the variance of the objective function related to the solution robustness, and the last part is also associated with the penalty function and model robustness. Constraints (88) and (102) are for linearization of the robust objective function.

A real case of a chandelier industry is investigated for evaluating the QR and agility performance in reality. In this case, the applicability and efficiency of the models are proved and a comparison between models is made.

4.6. Case study

The decoration and chandelier manufacturing company of Shomal began in Northern Iran in 1991. The second level of the supply chain is the decoration- and chandelier-shop Milad which has served as the pioneering retailer in this field for many years, selling luxury chandeliers and decorations in the North of Iran. In this case, the traditional model is primarily applied and then, the second model is implemented. The market for these types of products is highly unstable; consequently, quick changes are observed in this market. Notice that the manufacturer only produces conventional and almost predictable products with low variations in demand. In addition, the retailer does not have much interest in considering the variations of costumers' demands. The retailer's and manufacturer's strategies allow for the retailer order only once during the sales season. In this model, the optimal ordering and production quantities and prices for two levels of the supply chain will be obtained. For solving the model, the interview method and analysis of historical data are employed and then, certain values of parameters are shown in Table 2. Furthermore, the marketing and sales managers do not have accurate information about some parameters because of uncertain circumstances. Therefore, the values of non-deterministic parameters, different scenarios, and occurrence probability of each scenario are given in Table 3.

Table 2. Value of deterministic variables.

Parameter (P)	Value (V)
C	170,000
δ	70%
γ	70%
S	150,000
Cap	2,400
V	300,000
α	0.213
B	800,000,000

Table 3. The values of scenario (s)-dependent parameters.

s/p	1	2	3	4	5	6	7
D_s	1670	1780	1930	1520	2010	1745	1890
w_s	1900	1980	2040	1600	2100	1800	1950
ρ_s	0.09	0.15	0.23	0.08	0.22	0.10	0.13

Seven scenarios are considered for uncertain parameters whose values are reported along with the occurrence probability for each scenario. Concerning the information received by the experts in this area, different scenarios have pertained to each other.

After solving the model in the GAMS 24.0.1, the optimal production and order quantity are given in Table 4; the price and objective function regarding various scenarios for each level are given in the following.

The leader has chosen the best possible strategy with regard to the model constraints and the follower should accept that as its constraints are not violated in the leader's decision. Thus, the manufacturer should offer a strategy in that all follower constraints are fully satisfied. Regarding the nature of the problem and the supply chain, Table 4 presents the values of clearance sales for the manufacturer, the leader of the SG. Moreover, it is important to note that the leader could not propose any desired price due to the limitations and also, the follower would not accept the proposed price. If this is the case, the retailer would not order anything; therefore, the manufacturer should make a decision rationally.

Moreover, optimal prices are provided in Table 5. For the model nature, the manufacturer aims at a price that obtains maximum profit. The leader of the

Table 4. Optimal Solution (OS) of production and ordering quantity.

S/(OS)	1	2	3	4	5	6	7
Q_{ls}	1900	1980	2040	1600	2100	1800	1950
Q_{fs}	1900	1980	2040	1600	2100	1800	1950

Table 5. Optimal Price (OP) in the first model.

OP	V
Retailer	300,000
Manufacturer	247,320.692

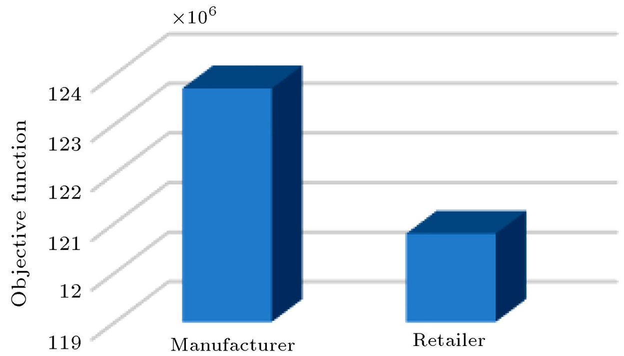

Figure 1. Objective function of the retailer and manufacturer for the first model.

Table 6. The values of certain parameters of the model.

Parameter (P)	Value (V)
C	170,000
δ_1	70%
δ_2	75%
γ_1	70%
γ_2	72%
s_1	60,000
s_2	170,000
V	300,000
α	0.213
β_1	400,000,000
β_2	400,000,000
Cap_1	1,600
Cap_2	1,300
C_Q	5,000

SG cannot offer his favorite price since otherwise, the follower may not order at all. Thus, this strategy is not preferred by the manufacturer. Similarly, the retailer's price cannot exceed a certain limit either because the customers already have a certain value on their mind for the goods. Thus, if the price is higher than their expectation, they will refuse to do any full-price purchase. This situation is also not favorable for the retailer. The mean values of the objective function for the retailer and the manufacturer when all scenarios are taken into consideration are presented in the following.

The values of the objective function for the manufacturer and retailer while two members of the supply chain take traditional approaches are shown in Figure 1. The objective function for the manufacturer is almost $2,000,000 more than that for the retailer since the manufacturer as the leader of the game has no clearance sale in the system. However, the retailer mostly encounters clearance sales which reduce his profits due to the nature of the market.

After implementing the first model in the real case, the second one is solved and its results are analyzed. For applying the model, the retailer and manufacturer can respond quickly and properly to their market upon accepting some additional costs so that they can meet customers' expectations and demands at the right time. The retailer can issue an order less than before considering the market demand using QR ability. He can also identify the market requirements and demands and update his information after starting the sale season and give the manufacturer his new order depending on the customers' demands and requirements [3,4,8,11]. The AM can recognize unpredictable changes in the market and satisfy them based on both information sharing among retailers and manufacturers and cutting-edge technology [1,24]. This study considered these matters and anticipated the related extra costs.

Having such capabilities necessitates paying some costs that can make them able to refill or produce an order based on consumer preferences and requirements. To gather the preferred data, an interview with the retailer and the manufacturer was conducted. The values of the parameters are shown in Table 6.

Subsequently, the parameters associated with the scenarios with their occurrence probabilities are presented in Table 7.

Given the values in Tables 6 and 7, the output of the second model is reported in the following tables.

Table 8 also shows production and order quantities for the retailer and manufacturer under different scenarios. The retailers can order twice during the sale season by incurring extra costs in which he could satisfy customer's demands and needs. Furthermore, they can boost profits by minimizing the clearance sales at the end of the sale season. Besides, the manufacturer has the ability to identify variation in

Table 7. Values of uncertain parameters depended to the scenario.

S/P	1	2	3	4	5	6	7
D_{1s}	1080	1180	1240	1040	950	1050	1180
D_{2s}	895	970	1076	869	835	998	963
n_s	30000	26000	20000	33000	38000	23000	27000
m_s	61000	51000	39000	65000	72000	48000	53000
w_{1s}	1200	1260	1310	1100	980	1120	1240
w_{2s}	950	1005	1100	900	870	1040	980
ρ_s	0.14	0.15	0.09	0.13	0.23	0.15	0.11

Table 8. The optimum quantity of production and order under different scenarios.

S/V	1	2	3	4	5	6	7
Q_{f1}	1200	1260	1310	1100	980	1120	1240
Q_{f2}	950	1005	1100	900	870	1040	980
Q_{l1}	1200	1260	1310	1100	980	1120	1240
Q_{l2}	950	1005	1100	900	870	1040	980

Table 9. The price of the first product.

Retailer	247,320.692
Manufacturer	300,000

the market by accepting extra costs and look for an appropriate response to the market requirements in a short time. In Table 8, the manufacturer can respond to the conventional and unconventional demands at the delivery time based on the market demands under each scenario.

Moreover, Table 9 shows the price of the first product which can receive before starting the season. In other words, the retailer orders a certain quantity of products and provides them with a price independent of the scenario.

The selling price of the second type pertains to the scenarios if the parameters associated with the demand for the product are considered uncertain. According to Table 10, the prices of the second type of product under different scenarios are not the same. This price is calculated using the product value for the customers and other important parameters in the pricing.

The average of the objective function for the second model concerning different scenarios is presented in Figure 2.

The average profit of the retailer is about $5.14e+6 higher than that of the manufacturer given in Figure 2. Although the costs for the retailer and manufacturer increase by using agility, they can present a better planning for the unstable market and offer products in proportion to the demands and instantaneous changes in the market, which would lead to the improvement of customer satisfaction and also, enhancement of the product value. The increase in the aforementioned value for the customers has persuaded them to pay greater costs for their desired product and this has led to increasing the profit of supply chain members. Thus, they have reduced the quantity of the products subjected to clearance sales. Now, the first

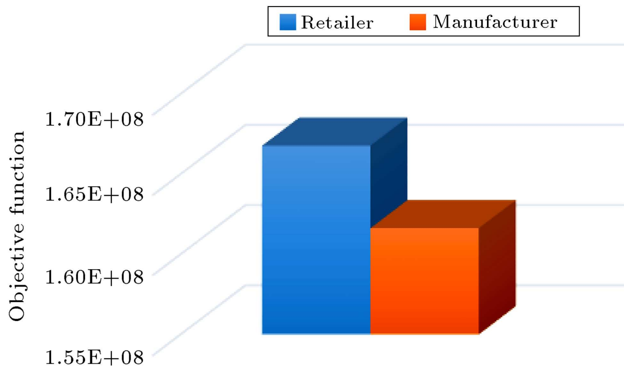

Figure 2. Average profit of the objective function for the second model.

Table 10. The price (Pr) of the second type product ($\times 10^2$).

S/Pr	1	2	3	4	5	6	7
P_{l2}	3333	3241	3130	3370	3435	3213	3259
P_{f2}	4043	3931	3797	4088	4166	3898	3954

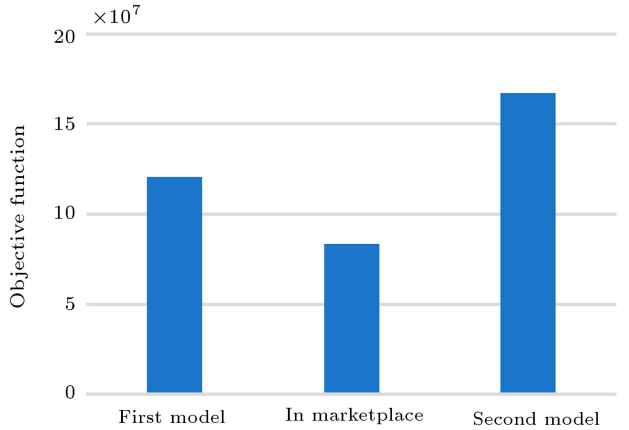

Figure 3. The retailer's profit function in the first model, real situation of the market, and the second model.

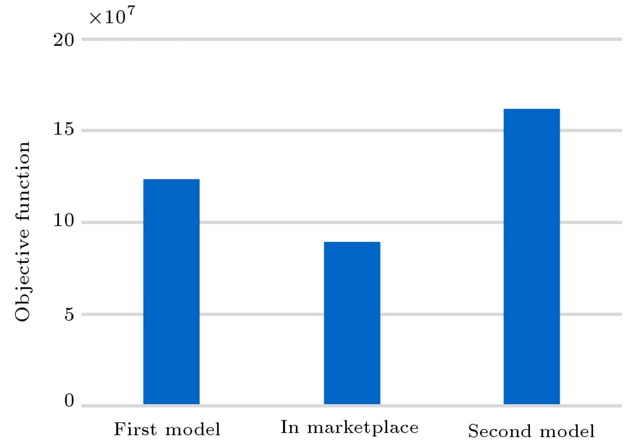

Figure 4. The manufacturer's profit function in the first model, real situation of the market, and the second model.

and second models and the real situation of the market in a similar situation are compared as follows.

With regard to Figures 3 and 4, the objective functions for the second model have been improved by the suggested tools. The retailer should look for two important actions in the world of fashion and luxury products: 1) to prevent the clearance sales of goods at the end of the sales season; and 2) to respond quickly and appropriately to the instant changes at the market level. Furthermore, the AM with the features such as quick production response and flexibility has the capacity to consider the newest demands in a timely fashion at the market level in the production and respond to the needs. Thus, the manufacturer could acquire such a capability by covering the cost so that customers' satisfaction could increase and profit be secured.

Through the use of QR, the retailer could reduce extra chandeliers and produce a smaller number of products; therefore, in this regard, strategic customers are more willing to buy chandeliers at the full price and even, pay higher prices for the ones that have satisfied their demands. The results of this model show that the retailer and manufacturer can enhance their profits by using useful information and up-to-date methods for production, ordering, and pricing systems. These modern methods have consequences; for instance: 1) By employing agility, the production level of the supply chain can react to the instantaneous variation in the needs and demands of the market at a certain time. Consequently, the value of the goods has risen for the customers and the manufacturer's profit is enhanced; 2) By taking the customers' requirements and behavior into consideration, the retailer can attract more potential customers and raise their willingness to buy at the full price; 3) Taking advantage of QR to cut down on both the waste of resources and the off-sales can bring about satisfaction for both customers and retailers because customers' needs would be satisfied as perfectly as possible and the retailer, on the other hand, could achieve a better profit in this sense; 4) These features in the manufacturing and retailing allow for a strategic planning to act better in response to uncertainty and sudden changes in the market.

Achievements of the second model have culminated in reducing delivery time, shortening LT, lowering prices, and higher customer satisfaction. To enhance customer satisfaction, the manufacturer tries to introduce a new product or a model based on their needs and demands and meet the quality standards. Introducing new products based on customers' needs has driven the supply chain members into providing concentrated and compatible programming and requiring sufficient processes with an integrated information system.

The supply chain members incurring additional costs to provide an integrated system for sharing information and having close relationships with customers could cut the total costs (such as the cost of obsolete products), reduce LT, enhance customers' satisfaction, identify immediate variations, and finally introduce products depending on the market needs.

Improving flexibility and managerial expertise, employing skilled workers, and providing an integrated information system in the supply chain would help the competitors to get the highest market share. Furthermore, the acceleration of responding and identifying market demands and variations using exact information from customers could satisfy their demands and requirements. Finally, utilizing advanced technology makes them able to react appropriately and quickly to various circumstances including both conventional and non-conventional demands. However, these capabilities can be acquired by devoting more effort, time, and also costs.

In Figures 5 and 6, the sensitivity analysis for the model robustness (ρ) is presented by the mean objective function derived from the first and second

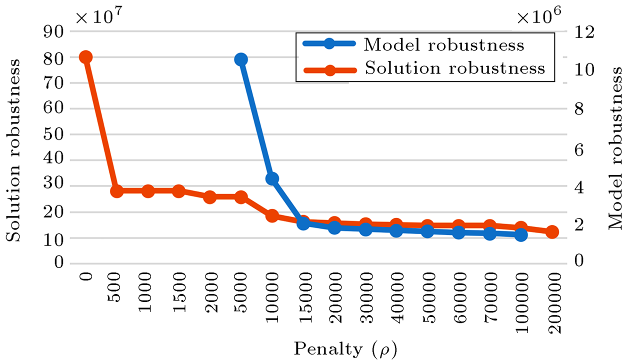

Figure 5. Trade-off between model and solution robustness in the first model.

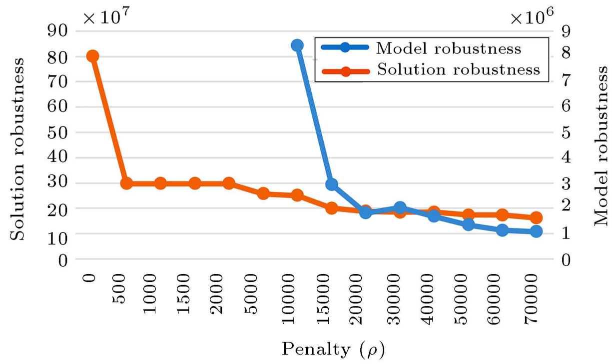

Figure 6. Trade-off between model and solution robustness in the second model.

model solutions. As can be seen in these figures, the average profit decreases; however, the model robustness primarily increases by increasing the penalty function ρ. Then, followed by a reduction and upon achieving values of 100,000 and 30,000 for the robustness of the first and second models, respectively, it remains steady.

4.6.1. Sensitivity analysis

In this section, the sensitivity of the model parameters is analyzed by tracking the changes in their values; consequently, variations in the average profit in various situations are measured and presented.

In Figure 7, the average objective function for the retailer is analyzed in a situation where the retailer has the QR ability and chooses the non-AM. In this way, the average profit increases in comparison to the first model in a situation where the cost of QR for the retailer is equal to, or less than, $1,500. However, the mean objective function for the retailer declines by increasing the QR costs and in such a situation, the application of QR is not economically reasonable.

Now, the mean objective function in which the retailer selects the AM is analyzed. The retailer's profits with different costs are presented in Figure 8. In this regard, the lower the QR costs, the greater the

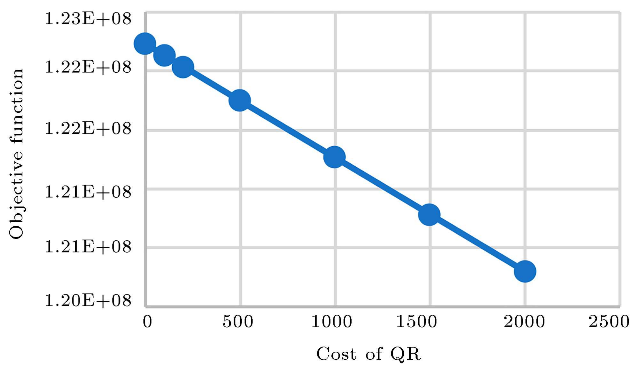

Figure 7. Average profit function of the retailer versus cost of quick response regardless of the manufacturer agility.

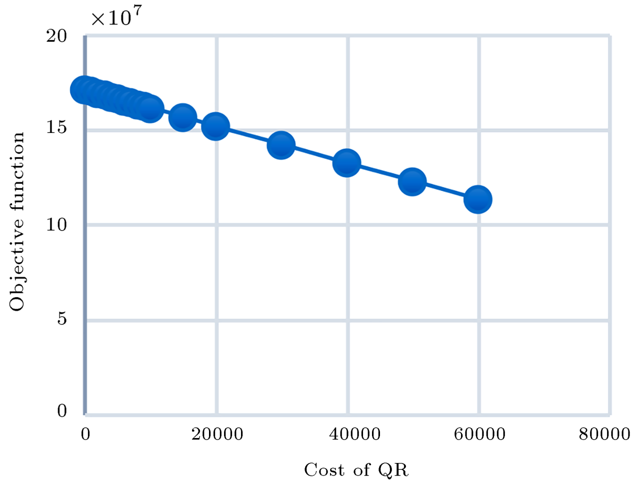

Figure 8. Analysis of the retailer's profit versus the changes in quick response costs.

profit. By increasing the costs up to $50,000 for the retailer, profit is earned more than that achieved in the first model. In this situation, if the QR costs rise from $5,000 to $50,000, utilizing this capability will be economically reasonable.

In Figure 9(a), the average profits are analyzed, while the costs of agility in the second scenario vary. As can be observed, by increasing its costs up to $83,000, the manufacturer earns more profit than that achieved by the first model. Afterwards, the profit decreases. Figure 9(b) shows the changes in mean profit with variations in the agility costs for all scenarios. The average profit increases as compared to the profit earned in the first model as the cost of agility is up to $40,000 in each scenario. Thus, these limited costs are economically reasonable for the manufacturer if other parameters are constant.

Figure 10 shows the mean profit variations as the second type of product is differently valued for the customers. If this parameter experiences a reduction of up to $50,000 compared with that of the case study while assuming that other parameters are constant, the

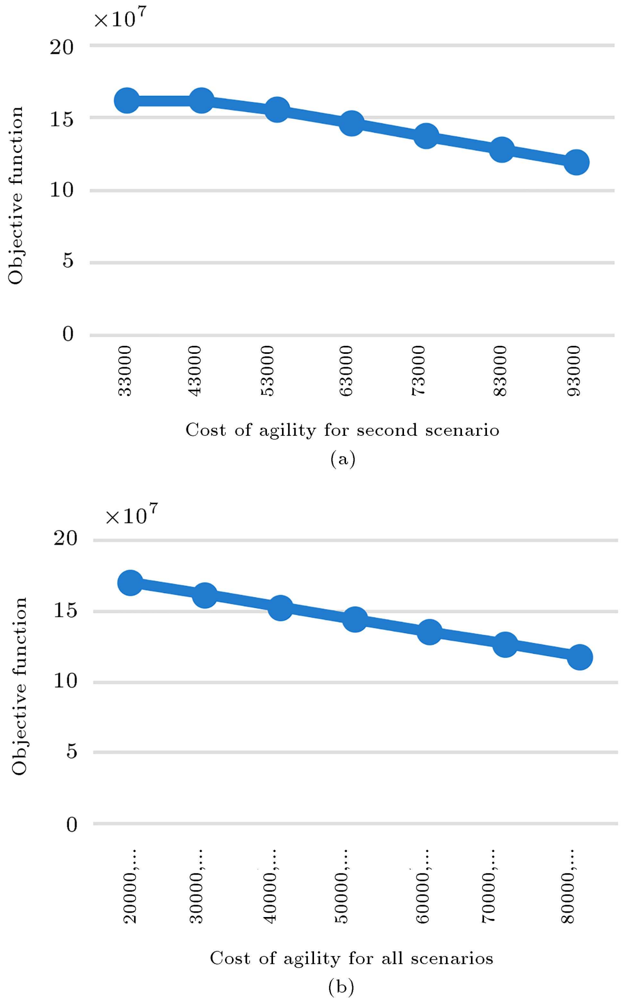

Figure 9. The manufacturer's average profit versus the variations of the second scenario (a) and all of the scenarios (b) for the agility costs.

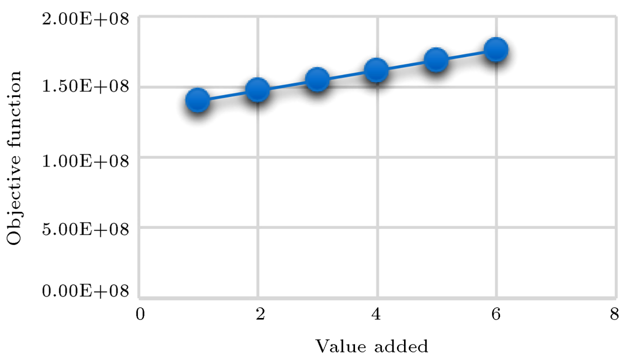

Figure 10. Variations of the manufacturer's average profit versus variations of the product value for the customers.

manufacturer's average profit will be more than that of the first model. However, the manufacturer can gain a greater amount of profit using agile capabilities.

The average profit changes in case of demand variation are given in Figure 11. This figure depicts economic justification in low demand situations. As illustrated earlier, the retailer's average profit moves further than that in the first model by the declining demand for the second type of product (around 390) in each scenario.

The average profit of the second product with the initial cost factor (up to 0.717) is greater than that in the first model, as demonstrated in Figure 12.

While the cost factor for the customers is reduced, changes in the retailer's profit are given in Figure 13. As observed, a decline in the cost up to 0.75 results in a greater profit for the retailer than that in the first model and this seems to be more economically reasonable.

In Figure 14, the retailer's average profit changes are illustrated as the QR costs are increasing in value in a situation in which there have been demand changes in each scenario. In this analysis, five different types of demand with distinctive values are taken into account and analyzed by various costs of the QR. For instance, the demands given in the first scenario are 573, 608, 445, 479, 686, 580, and 505, respectively. In this situation, the earnings economically justify the retailer to accept QR costs up to $10,000. The rest of the results are shown in Figure 14.

As shown in Figure 15, the retailer's average profit against variations in the QR costs is investigated in a situation where demands concerning a reduction in the product value and in price of the second product vary differently. The maximum objective function for the retailer is obtained through the initial price factor of 0.78 and QR cost of zero. According to this figure, a reduction in the demand and the price of the second product points to their significant role in the increase of the retailer's profit.

This study confirms that agile abilities are associated with customer satisfaction and profits. The previous discussions and results compared to real situations confirm the models' applicability and efficiency. In contrast to the case, more products would be sold to customers than to those in the real situation. Besides, the customers are convinced to pay more for the products in which their requirements would be met. Although the first model has not enjoyed any agile ability, the profit of the model was greater than that earned in reality. Since the proposed model considers market competition and the possibilities of all scenarios, it can provide decision-makers with better strategies and results. Regarding the second model, the clearance sales are noticeably reduced compared with the first model and reality; consequently, the observed decline in that amount could be attributed to the manufacturer's and retailer's profits. Differences between the scientific findings and reality can also influence the waste resources. In other words, natural resources such as wood, oil, and water are wasted as

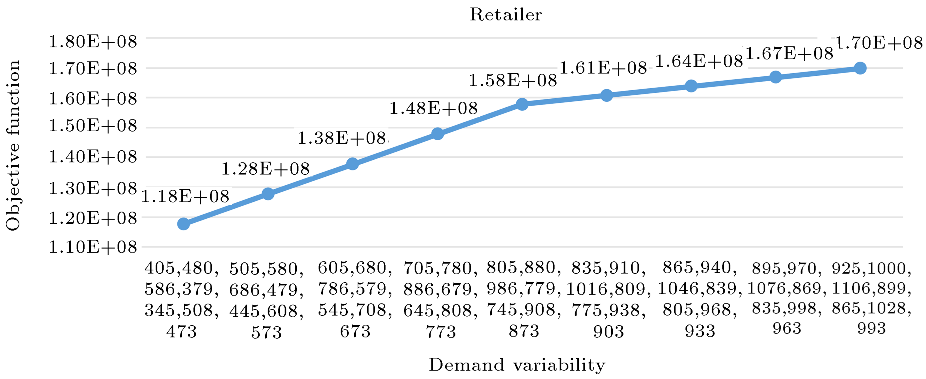

Figure 11. Variations in the average profit versus variations in the demand.

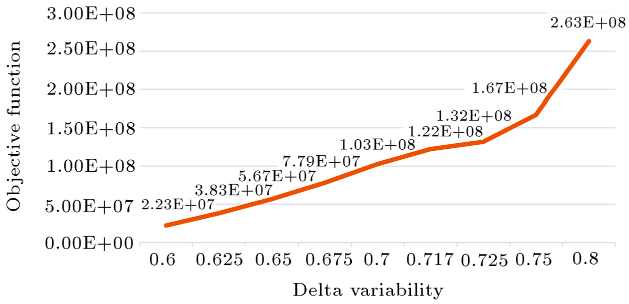

Figure 12. Variations in the retailer's average profit versus the percentage of price reduction of the second type product.

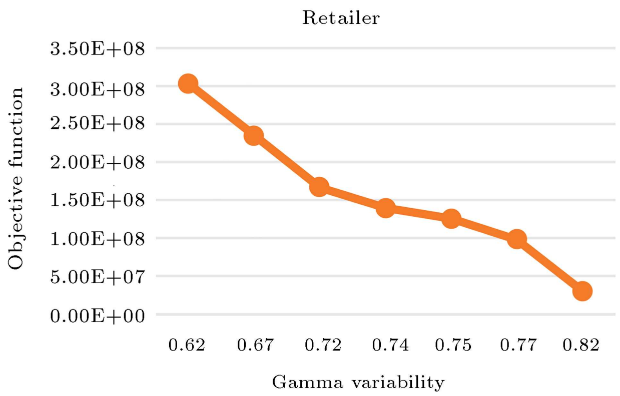

Figure 13. Variations of the retailer's average profit versus cost reduction for the customers.

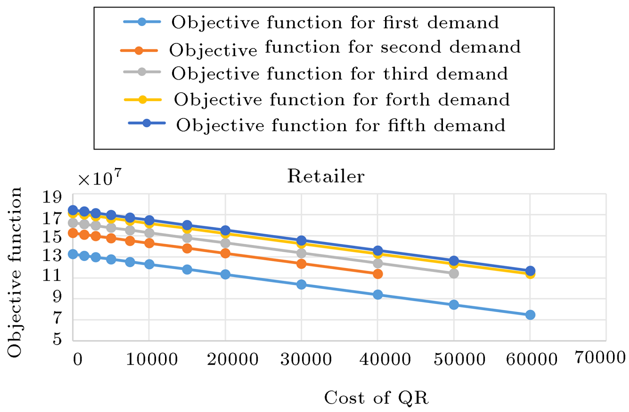

Figure 14. Variations of the average profit versus variations of the demand and costs of quick response.

the related products have become obsolete. Thus, these findings help practitioners to understand how to develop their work optimally and reduce their clearance sales. Last but not least, the outputs and discussions have important implications for developing an agile system.

The manufacturers require cutting-edge software (e.g., SAP and modular assembly), skilled and flexible workforce, and quick production system to develop products based on market variability. These measures can reduce natural resources waste so that manufacturers can recoup an amount of their investment in this regard. Also, the wholesale price will rise after optimizing their production quantity based on the market demand, which in turn translate into greater profits. In the retail business, retailers should record background information about customers' requirements, sales, and complaints. Besides, the integrated information system makes it possible for retailers to optimally adjust orders depending on the market demand. Thus, the clearance sales would be noticeably decreased and the retailers could enhance their earnings, although they need to employ a computerized database and system. The system could provide them with useful information on customers' demand, complaints, and sales figures; consequently, the available data analysis is valuable to improve service level and quality based on customer requirements and expectations. As such, the customers are satisfied and accordingly, a more market share is derived.

It would have been better if the supply chain members were trying to develop a more centralized system in the whole supply chain. In general, the competitive nature of supply chain may lead to a reduction in the members' profits due to the specific situations of competition. For a better explanation, the members have to reach a decision because of some limitations under competitive circumstances. There-

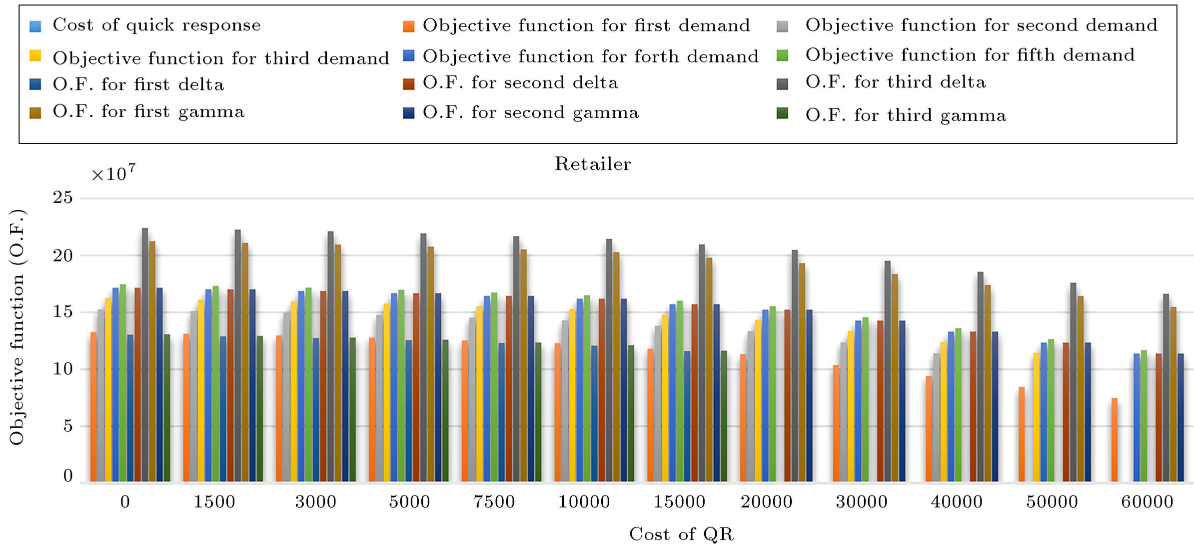

Figure 15. Comparison of the average profit with the demand variations, reductive factor of the product value, and price factor of the second type product versus variations of the quick response costs.

fore, good decisions are made if the supply chain has become more centralized using different contracts such as revenue sharing. In addition, retailers and manufacturers should facilitate a good communication with an integrated system (e.g., SAP). In this regard, the manufacturers can receive the required information on demand and expectations and then, will adopt a new approach in their production line to meet their inevitable demand.

5. Conclusion

Due to the high variability and inconsistency of the fashion market, it is clear that a successful retailer and a manufacturer are the ones who can adopt the right decisions and policies in line with the market needs and variations. Considering the customers' behavior, competitive situations, and the goods value, the method of ordering, pricing, and production should be improved.

Therefore, in this study, two Bi-Level Stackelberg Models (BLSMs) including the manufacturer and retailer were developed under uncertain circumstances to determine the optimal production and order quantities and price. Then, the proposed models were applied to the real case. In the first model, the traditional manufacturer, regardless of the market needs and variations, produces a certain volume of goods and the retailer also places an order for once due to the long Leud Time (LT). In this situation, the results improved slightly compared to what occurs in reality in terms of prices and clearance sales. However, in the second model, an Agile Manufacture (AM) introduced the products based on the instant variations in the market needs and demands considering the uncertainty supplied depending on the changes in the customers' needs.

The results of the proposed models demonstrate that the manufacturer and retailer can identify the market variations within a short time using their agile abilities. They are able to respond to these changes at the right time; accordingly, the customers will be more satisfied so that they will be persuaded to spend more money in the market. The additional costs of adopting the abilities would be incurred by each retailer and manufacturer considered in the model. However, the value of the second product is higher than that of the first one. The main reason is that the value of goods produced concerning the market variations will increase the customers' motivation toward paying more for buying a product.

There are many possible directions for future research. The presented model in this study could be developed by considering the simultaneous and sequential competition between the retailers and manufacturers, some of which may be agile. To ensure more explanation, firstly, the retailers and the manufacturers compete with each other at their levels (simultaneous game) and two levels (the dominant retailer and manufacturer) will sequentially compete for more profit Stackelberg Game (SG). Moreover, the proposed models can be solved by heuristic and metaheuristic algorithms to compare the obtained results with the ones found in this study. Therefore, a further study on the solution approach is suggested and the efficiency of the method is examined more.

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Appendix A

Here, the mentioned equations in the main manuscript are explained:

$$C.(1+\alpha) \le P_f \le \frac{v.(1-\gamma)}{(1-\delta)}, \tag{A.1}$$

$$0 \le Q_{fs} \le cap \qquad \forall s \in S, \tag{A.2}$$

$$\mathrm{y}_{2s} = P_f.\mathrm{Q}_{fs} \qquad \forall s \in S,$$

$$C.(1+\alpha) \le P_f \le \frac{v.(1-\gamma)}{(1-\delta)} \xrightarrow{\times Q_{fs}} C.(1+\alpha).Q_{fs}$$

$$\le P_f.Q_{fs} \le \frac{v.(1-\gamma)}{(1-\delta)}.Q_{fs} \xrightarrow{\mathrm{y}_{2s}=P_f.Q_{fs}} C.$$

$$(1+\alpha).Q_{fs} \le y_{2s} \le \frac{v.(1-\gamma)}{(1-\delta)}.Q_{fs}$$

$$\forall s \in S, \tag{A.3}$$

$$y_{3s} = P_{f1}.Q_{f1s} \qquad \forall s \in S,$$

$$(1+\alpha).C \le P_{f1} \le \frac{v.(1-\gamma_1)}{1-\delta_1}, \tag{A.4}$$

$$0 \le Q_{f1\mathrm{s}} \le Cap_1 \qquad \forall s \in S, \tag{A.5}$$

$$(1+\alpha).C \le P_{f1} \le \frac{v.(1-\gamma_1)}{1-\delta_1} \xrightarrow{\times Q_{f1s}} (1+\alpha).C.Q_{f1s}$$

$$\le P_{f1}.Q_{f1s} \le \frac{v.(1-\gamma_1)}{1-\delta_1}.Q_{f1s} \xrightarrow{y_{3s}=P_{f1}.Q_{f1s}}$$

$$(1+\alpha).C.Q_{f1s} \le y_{3s} \le \frac{v.(1-\gamma_1)}{1-\delta_1}.Q_{f1s}$$

$$\forall s \in S, \tag{A.6}$$

$$y_{1s} = P_{l1}.Q_{f1s} \qquad \forall \in S,$$

$$C \le P_{l1} \le \frac{v.(1-\gamma_1)}{(1+\alpha).(1-\delta_1)}, \tag{A.7}$$

$$0 \le Q_{f1\mathrm{s}} \le Cap_1 \qquad \forall s \in S, \tag{A.8}$$

$$C \le P_{l1} \le \frac{v.(1-\gamma_1)}{(1+\alpha).(1-\delta_1)} \xrightarrow{\times Q_{f1s}} C.Q_{f1s}$$

$$\le P_{l1}.Q_{f1s} \le \frac{v.(1-\gamma_1)}{(1+\alpha).(1-\delta_1)}.Q_{f1s}$$

$$\xrightarrow{y_{1s}=P_{l1}.Q_{f1s}} C.Q_{f1s} \le y_{1s}$$

$$\le \frac{v.(1-\gamma_1)}{(1+\alpha).(1-\delta_1)}.Q_{f1s} \qquad \forall s \in S, \tag{A.9}$$

$$C+n_s \le P_{l2s} \le \frac{(v+m_s).(1-\gamma_2)}{(1+\alpha).(1-\delta_2)} \xrightarrow{\times Q_{f2s}} (C+n_s)$$

$$.Q_{f2s} \le P_{l2s}.Q_{f2s} \le \frac{(v+m_s).(1-\gamma_2)}{(1+\alpha).(1-\delta_2)}$$

$$.Q_{f2s} \xrightarrow{y_{2s}=P_{l2s}.Q_{f2s}} (C+n_s).Q_{f2s} \le y_{2s}$$

$$\le \frac{(v+m_s).(1-\gamma_2)}{(1+\alpha).(1-\delta_2)}.Q_{f2s} \qquad \forall s \in S, \tag{A.10}$$

$$(C+n_s).(1+\alpha) \le P_{f2s} \le \frac{(v+m_s).(1-\gamma_2)}{(1-\delta_2)}$$

$$\xrightarrow{\times Q_{f2s}} (C+m_s).(1+\alpha).Q_{f2s} \le P_{f2s}.Q_{f2s}$$

$$\le \frac{(v+m_s).(1-\gamma_2)}{(1-\delta_2)}.Q_{f2s} \xrightarrow{y_{4s}=P_{f2s}.Q_{f2s}}$$

$$(C+n_s).(1+\alpha).Q_{f2s} \le y_{4s}$$

$$\le \frac{(v+m_s).(1-\gamma_2)}{(1-\delta_2)}.Q_{f2s} \qquad \forall s \in S. \tag{A.11}$$

Appendix B

Here, the mentioned equations in the main manuscript for the first and second models are explained:

First model

$$U_5.\left(C.\left(1+\alpha\right).Q_{f\mathrm{s}}-y_{2\mathrm{s}}\right)=0 \qquad \forall s\in S, \tag{B.1}$$

$$U_6.\left(y_{2s}-\frac{v.\left(1-\gamma\right)}{\left(1-\delta\right)}.Q_{fs}\right)=0 \qquad \forall s\in S, \tag{B.2}$$

$$U_9.\mathrm{y}_{2\mathrm{s}}=0 \qquad \forall s\in S, \tag{B.3}$$

$$U_1.\left(\left(1+\alpha\right).P_l-P_f\right)=0, \tag{B.4}$$

$$U_2.\left(P_f-\frac{v.\left(1-\gamma\right)}{1-\delta}\right)=0, \tag{B.5}$$

$$U_8.P_f=0, \tag{B.6}$$

$$U_3.\left(Q_{fs}-w_s\right)=0 \qquad \forall s\in S, \tag{B.7}$$

$$U_5.\left(C.\left(1+\alpha\right).Q_{fs}-y_{2s}\right)=0 \qquad \forall s\in S, \tag{B.8}$$

$$U_6.\left(y_{2s}-\frac{v.\left(1-\gamma\right)}{\left(1-\delta\right)}.Q_{fs}\right)=0 \qquad \forall s\in S, \tag{B.9}$$

$$U_7.Q_{fs}=0 \qquad \forall s\in S, \tag{B.10}$$

Second model

$$U_1.\left(\left(1+\alpha\right).P_{l1}-P_{f1}\right)=0, \tag{B.11}$$

$$U_3.\left(P_{f1}-\frac{v.\left(1-\gamma_1\right)}{1-\delta_1}\right)=0, \tag{B.12}$$

$$U_{11}.P_{f1}=0, \tag{B.13}$$

$$U_2.\left(\left(1+\alpha\right).P_{l2s}-P_{f2s}\right)=0 \qquad \forall s\in S, \tag{B.14}$$

$$U_4.\left(P_{f2s}-\frac{\left(v+m_s\right).\left(1-\gamma_2\right)}{1-\delta_2}\right)=0 \qquad \forall s\in S, \tag{B.15}$$

$$U_{12}.P_{f2s}=0 \qquad \forall s\in S, \tag{B.16}$$

$$U_7.\left(\left(1+\alpha\right).C.Q_{f1s}-y_{3s}\right)=0 \qquad \forall s\in S, \tag{B.17}$$

$$U_8.\left(\mathrm{y}_{3\mathrm{s}}-\frac{v.\left(1-\gamma_1\right)}{1-\delta_1}.\mathrm{Q}_{\mathrm{f1s}}\right)=0 \qquad \forall s\in S, \tag{B.18}$$

$$U_{13}.y_{3s}=0 \qquad \forall s\in S, \tag{B.19}$$

$$U_9.\left(\left(C+n_s\right).\left(1+\alpha\right).Q_{f2s}-y_{4s}\right)=0 \qquad \forall s\in S, \tag{B.20}$$

$$U_{10}.\left(y_{4s}-\frac{\left(v+m_s\right).\left(1-\gamma_2\right)}{\left(1-\delta_2\right)}.Q_{f2s}\right)=0 \quad \forall s\in S, \tag{B.21}$$

$$U_{14}.y_{4s}=0 \qquad \forall s\in S, \tag{B.22}$$

$$U_5.\left(Q_{f1s}-w_{1s}\right)=0 \qquad \forall s\in S, \tag{B.23}$$

$$U_7.\left(\left(1+\alpha\right).C.Q_{f1s}-y_{3s}\right)=0 \qquad \forall s\in S, \tag{B.24}$$

$$U_8.\left(y_{3s}-\frac{v.\left(1-\gamma_1\right)}{1-\delta_1}.Q_{f1s}\right)=0 \qquad \forall s\in S, \tag{B.25}$$

$$U_{15}.Q_{f1s}=0 \qquad \forall s\in S, \tag{B.26}$$

$$U_6.\left(Q_{f2s}-w_{2s}\right)=0 \qquad \forall s\in S, \tag{B.27}$$

$$U_9.\left(\left(C+n_s\right).\left(1+\alpha\right).Q_{f2s}-y_{4s}\right)=0 \qquad \forall s\in S, \tag{B.28}$$

$$U_{10}.\left(y_{4s}-\frac{\left(v+m_s\right).\left(1-\gamma_2\right)}{\left(1-\delta_2\right)}.Q_{f2s}\right)=0 \quad \forall s\in S, \tag{B.29}$$

$$U_{16}.Q_{f2s}=0 \qquad \forall s\in S. \tag{B.30}$$

Biographies

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