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A behavior-based pricing model in retail systems using game theory approach

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Abstract

Demand fluctuations, customer's behavior and price of products can greatly impact on distribution systems. Here, pricing decisions in a distribution system is focused considering customer behavior in a competitive market. A behavior-based bi-level model is proposed to present the Stackelberg competition among the wholesalers and retailers in a distribution system under two distinct scenarios. The defined scenarios attempt to focus on profit and utility maximization for the distribution system and customers, respectively. In addition, behavior-based price discrimination is used in the current paper considering retail prices and customer geographical zones in the market. The developed model is finally carried on an industrial case problem to derive sensitivity analyses and compare different scenarios to get managerial insights.

Keywords: Behavior-based price discrimination, game theory, retail systems, Stackelberg competition, revenue management

1- Introduction

Lately, business enterprises can concentrate on marketing, pricing strategies, and customer behaviors by information technology and recording purchase history. Implementing web beacons, cookies and data broker assist vendors and also managers follow customer preferences, precisely. In addition, firms aim price discrimination using customer geographical zone, perceived quality and acceptable prices (Batarfi, Jaber et al. 2019). Traditional distributions are replaced with online shopping and delivering systems using smart phones and mobile application implementing information technology and internet networks. Hence, enterprises can easily determine previous customers and propose discriminated prices under online channels and purchase histories (Choe, King et al. 2017).

Moreover, investigating purchase histories and derived information intensify competition among entities to chain more market share. Thisse and Vives (1988) stated that prisoner's dilemma may be the consequence of access to customer information and disturb previous market share and profitability. Banks, restaurants, web retailers, and supermarkets are some common examples of firms delivering products or services under behavior-based price discrimination models (Esteves and Cerqueira 2017). It can be also mentioned that most of the aforementioned industries suffers from intensity of competition and ease of entrance for new-comer competitors in the market. Therefore, developing a joint optimization model for finding the market equilibriums and conquering in competition considering customers' behavior seems necessary. Presenting a new competitive behavior-based price discrimination model capable of delivering optimal values both in traditional and online distribution systems is a crucial challenge.

The current paper attempts to develop this field of study for addressing the importance of competition in competitive market while configuring behavior-based pricing model using customer purchase history.

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Given the lack of researches in this area, the current paper is amongst the first modeling attempts seek to jointly focus on competition and customers' behavior. Here, a bi-level pricing model is presented to demonstrate the formed competition in a distribution system using behavior-based price discrimination. Afterwards, a numerical case problem is used in a distribution system considering both vertical competition among the wholesalers and retailers and also horizontal competition among the retailers based on customer geographical locations and the proposed retail prices offering to customers.

The reminder of this paper is organized as follows: Section 2 reviews the related literature. Then, section 3 presents problem definition and the mathematical modelling for different scenarios. Afterwards, section 4 describes the solution method. Section 5 discusses the research analyses on parameters and model structure. And finally, section 6 gives a survey for future research directions and includes conclusions on behavior-based pricing in distribution systems.

2- Literature review

In this section, the related literature on competitive pricing and also behavior-based price discrimination models are reviewed to derive more insights about pricing decisions in competitive markets and also the effects of customer behavior in the modelling attempts.

The horizontal competition shows competition among the same tier or level of a supply chain. Probing into the literature show that the most relevant studies focus on competition and pricing, simultaneously. Huang, Huang et al. (2011) presented a multi-level uncoordinated game and derived Nash equilibrium for finding the optimal prices and inventory decisions in a supplier selection problem. Alaei and Setak (2014) noticed the vertical competition as the main coordination strategy for sharing the costs among supply chain entities to enhance the profit and gain more market share. Sajadieh and Larsen (2015) studied a bi-level problem in a two-level supply chain using stackelberg competition under stochastic revenue and demand. Markovian process is implemented to solve the aforementioned uncoordinated model. Shou, Huang et al. (2009) developed an uncertain competition model, and similarly Wu, Baron et al. (2009) developed two other distinct competing supply chains. Mahmoodi and Eshghi (2014) presented competitive supply chains and determined the optimal prices of the proposed probabilistic structures. More recently, (Ghomi-Avili, Tavakkoli-Moghaddam et al. 2020) defined a competitive supply chain network design problem with pricing decisions under uncertainties disruption risks. Supply disruption and the consequent results in pricing decisions are also examined by (Gupta, Ivanov et al. 2021). Yousefi, Rezaee et al. (2019) studied another type of competitive pricing models focusing on supplier-selection problem. Jabarzare and Rasti-Barzoki (2020) focused on quality and price in a dual-manufacturing channel and used coordination contracts to solve the model.

Behavior-based pricing is mainly related to pricing decisions evaluating customer surplus, preferences, interests, geographical zone and the other effective factors (Das, Hanouna et al. 2009). Thus, investigating the customer behavior and presenting the most suitable demand functions demonstrating the consumer sensitivity to different factors may bring noticeable improvements (Tianhu, Jumpei et al. 2017). As mentioned, defining the appropriate demand function using exact coefficients capable of evaluating demand elasticity is one of the main challenges in behavior-based price discrimination (BBPD) models studied by (Caves, Eakin et al. 2000). Then, Nero (1999) attempted to tackle this problem. Similarly, Anderson and De Palma (2000) tried to solve the hoteling game considering global competition with a specific approach using correct demand elasticity. To apply the above method, it is suitable to use price behavior-based price discrimination model. The BBPD models are generally categorized in two distinct groups: "brand preference" and "switching costs" strategies.

The first strategy named as "brand preference" is about offering discriminated prices by the brands. Some practitioners worked specially on this strategy are Chen and Pearcy (2010) and Gu and Wenzel (2009) who aimed to define the most compatible demand function in the existing preference structure using customer reactions and the elasticity of customers to the offered prices. Later on, Esteves and Cerqueira (2017) developed a BBPD model for optimizing the retail prices based on market fluctuations. But, it lacks some main factors in a market such as competition, disruption risks, uncertainties and business structure. In the second strategy knowing as "switching cost", there is no choice in the first stage of purchasing. Customers face the same retailers or distributors. Composedly, in the second level they may switch to different costs by purchasing form another suppliers. Chen (2005) and Ali (2019) studied the switching cost method and worked on the purchase history of consumers to analyze the interests and preferences. In addition, Li, Chu et al. (2020) proposed a two-period model considering different online coupons to design a discount structure in supply chain management problems. Discriminative pricing can be also used across with environmental issues in supply chain management problems. More recently, Liu, Lin et al. (2020) considered customer's sensitivity to environmental issues in a sustainable supply chain. Similarly, (Chen, Su et al. 2021) worked on how entities can implement discriminative pricing to improve environmental effectiveness in carbon emission trading schemes. The body of review efforts prove that most of the current papers target price discrimination concepts in a single level of a supply chain as it is also confirmed by (Jena, Sarmah et al. 2019). In addition, the published papers ignore considering competition among different tiers and distribution characteristics while evaluating the customer surplus which may result in sub-optimal equilibriums and end up to lower profits. Thus, the current paper aims to model the behavior-based pricing problem in a distribution system capable of finding the market equilibriums for different competitors applying game theory under external and internal competition.

3- Problem definition

In this paper, a distribution channel is considered for finding the best delivered prices, market share of entities and demanded quantities under asymmetric competition. Studying the features of distribution channel show that it includes two main levels, the wholesalers and the retailers. The proposed structure is depicted in figure 1. The distribution channel is composed of two different levels capable of delivering a single type of a product to customers. Wholesalers and the retailers are the leader and followers of distribution channel due to the asymmetric competition among them representing in Stackelberg form. Moreover, another type of competition as long as vertical form among the wholesaler and retailers is developed in horizontal mode among retailers and wholesalers individually to attract more buyers.

Here, competitive behavior-based pricing is presented applying game theory. The bi-level programming approach is used to show the Stackelberg competition among the wholesalers and the retailers, more precisely. In the proposed bi-level model, the first level involves the leader (wholesalers) and the second level includes the follower optimal decisions. The leader problem aims to maximize the wholesalers' profit. And, the second level targets to maximize the follower profit using BBPD. Therefore, a two-stage programming approach is used in the second level to find the optimal prices. The behavior-based pricing procedure in this paper follows the following steps; (i) a uniform pricing model will be applied in the first stage, (ii) considering the customer reactions in the previous step, discriminated prices will be obtained for each customer. Finally, the model can deliver the optimal wholesale and retail prices (note that each retailer is capable of proposing distinct prices to his own and rival's customers in case of discrimination), quantity of purchased product by each retailer from the wholesalers and the total fulfilled demand by each retailer.

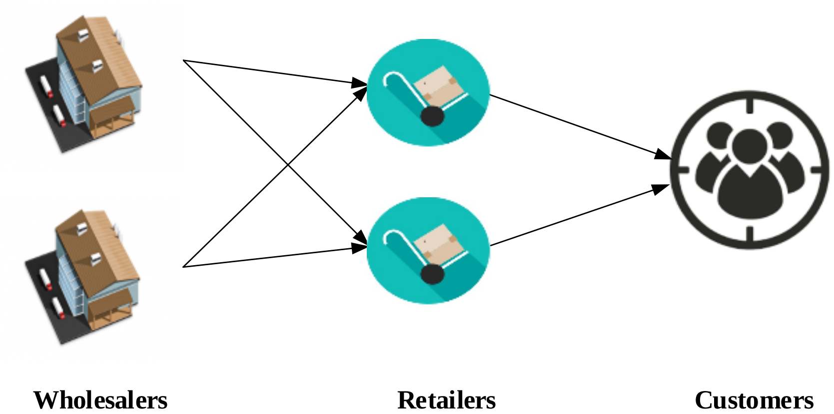

Fig 1. The proposed model structure

3-1- Assumptions

The following assumptions are made in the current paper:

- Two wholesalers and two retailers are considered in a distribution system which delivers a single-type of product to customers.
- The Stackelberg competition is used to present asymmetric vertical competition among the wholesalers and retailers.

- Bi-level programming is used to model the vertical competition (the upper and lower level models involve wholesalers and retailers optimal decisions, respectively).
- The horizontal competition is considered among retailers based on proposed retail prices and customer geographical zones.
- Behavior-based pricing is used to solve the lower level discriminative problem considering the offered retail prices and the location of customers.
- The horizontal competition is assumed among wholesalers based on proposed wholesale prices.
- Retailers A and B are located at the extreme points of the interval $[0,1]$.
- The location of each customer in the interval $[0,1]$ describes his relative preference for buying product from the retailers
- All the entities compete uncooperatively.
- All demand is fulfilled by the wholesalers through retailers.
- The locations and capacity of wholesaler and retailers are predefined and also fixed.

3-2- Mathematical modelling

Now, the competitive behavior-based pricing model is formulated in a bi-level form as follows. The following sets, parameters and decision variables are applied through this paper.

Sets	
i	Set of wholesalers, $i = \{1,2\}$
j	Set of retailers, $j = \{A, B\}$
Parameters	
C_i	Product total cost for wholesaler i
cap_i	Capacity of wholesaler i for providing product
I	Customer income in two period of purchasing and consumption
tr	Unit transportation cost
α	Marginal profit of each wholesaler
δ	Common discount factor offered by retailers $\in [0,1]$
ε	Price coefficient in demand function $\in [0,1]$
L^P	Lower bound for wholesale price
U^P	Upper bound for wholesale price
S^Q	Upper bound for the amount of products Q_{ij}
Decision Variable	
P_i	Wholesale price
$\Pr_j$	Retail price of retailer j
Q_{ij}	Total amount of product from wholesaler i to retailer j
D_j	Total demand of retailer j

Now, for modelling the proposed problem two scenarios can be considered. The first scenario is about the situation where the wholesale price follows mark-up pricing principles and need not any special mathematical optimization and can be evaluated considering a specific marginal profit. But, the follower problem should be modeled for finding the optimal equilibrium by applying the wholesale price. The second scenario involves the optimization of both leader and follower problem in a bi-level form considering behavior-based price discrimination for the retailers.

3-2-1- Scenario 1: Mark-up pricing

Consider a supply chain responsible for distributing a single type of product to market including two wholesalers and two retailers in two periods of purchase and consumption. Supply chain members do not have the same authority in the proposed market, and the wholesalers are assumed to be the leader and the retailers A and B are considered as the market followers. In this scenario, the wholesalers adopt mark-up pricing strategy while the retailers enter a behavior-based pricing model. As stated before, there exists two periods of consumption. In each period, there is a mass of normalized one customer trying to buy one product from either retailer A or B but not from both. It is assumed that the retailers A and B are located at the extreme points of the interval $[0,1]$. Moreover, customers are uniformly scattered in the defined interval. The location of each customer in the interval $[0,1]$ describes his relative preference for buying product from the retailers and the customer brand preference does not change in two periods. Therefore, $D_A(x) = x$ shows the distance of customer located at $x \in [0,1]$ from retailer A. similarly, $D_B(x) = 1 - x$ defines the distance of customer from retailer B. In addition, $tr > 0$ (unit transportation cost in linear form and independent of purchased quantity) is defined to show how customers dislike purchasing less preferred brand. Customers can purchase more than one unit of product. Thus, the purchased amount of products by each customer depends on each retailer proposed price. Therefore, the utility of a customer in x (u_j) trying to buy product from retailer A or retailer B, is considered as follows (Esteves and Reggiani 2014):

$$u_j = I + V(\Pr_j) - trD_j(x) \qquad j = \{A, B\} \tag{1}$$

$$V(\Pr_j) = v - \Pr_j^{1-\varepsilon} / 1 - \varepsilon \qquad j = \{A, B\} \tag{2}$$

Utility of each customer purchasing product from retailers is formulated in equation(1). It represents the customer surplus minus transportation costs while I is the total income when customer locating at $D_j(x)$ purchases product from retailer j under price P_j. In addition, all customers certainly purchase in two periods due to the high defined reservation value v in equation(2).

Here, the indifferent customer is located at $x = \dfrac{1}{2} + \dfrac{\Pr_B^{1-\varepsilon} - \Pr_A^{1-\varepsilon}}{2tr(1-\varepsilon)}$ (Ziari and Sajadieh 2021). Therefore, the retailer A and B total demand conditional on the market share can be written as follows:

$$D_A = x.\Pr_A^{-\varepsilon} \tag{3}$$

$$D_B = (1-x).\Pr_B^{-\varepsilon} \tag{4}$$

Now, each retailer's profit can be derived:

$$\pi_A = x.\Pr_A^{-\varepsilon}.\Pr_A = x.\Pr_A^{1-\varepsilon} \tag{5}$$

$$\pi_B = (1-x).\Pr_B^{-\varepsilon}.\Pr_B = (1-x).\Pr_B^{1-\varepsilon} \tag{6}$$

Before formulating the mathematical modeling, it is essential to summarize the two periods of behavior-based discrimination pricing efforts among the market followers. The first period involves uniform pricing strategy, which means that each of the retailers quotes the same price. In the second period, considering the customers brand preference by purchase history, different prices will be

charged by the retailers to their own and rival customers. Now, the first scenario modeling effort can be described as follows:
Upper Level (as Leader)

$$\mathrm{P}_i = C_i \times (1+\alpha) \tag{7}$$

Lower Level (as Followers)

$$Max\ Z_A = x \times (\mathrm{Pr}_A^{1-\varepsilon}) - \sum_i P_i \times Q_{iA} \tag{8}$$

$$Max\ Z_B = (1-x) \times (\mathrm{Pr}_B^{1-\varepsilon}) - \sum_i P_i \times Q_{iB} \tag{9}$$

Equation (7) shows the wholesalers price following the mark-up pricing strategy. Both the equations (8) and (9) represent the retailers profit in the proposed market.

3.2.2. Scenario 2: Optimized wholesale price

In this scenario, the wholesaler involves a distinct optimization problem due to the offered price of retailers achieved by implementing behavior-based price discrimination strategy in the lower level problem. Hence, the retailers enter a behavior-based pricing model and the optimal decisions of this level will be considered in the bi-level programming approach to derive the leader optimal prices.

As stated before, there exists two periods of consumption in the lower level problem and also a bi-level programming approach should be applied to represent the Stackelberg competition among the wholesaler and retailers, more precisely.

Upper Level Problem (as Leader)

$$Max\ Z_i = \sum_j (P_i - C_i) \times Q_{ij} \tag{10}$$

$s.t.$

$$\sum_j Q_{ij} \le cap_i \qquad (\forall i \in I) \tag{11}$$

$$\sum_i Q_{ij} \le D_j \qquad (\forall j \in J) \tag{12}$$

$$Q_{ij}, P_i, D_j \in R^+ \qquad (\forall j \in J, \forall i \in I) \tag{13}$$

Lower Level Problem (as Followers)

$$\begin{aligned} &Max\ Z_A = x \times (\mathrm{Pr}_A^{1-\varepsilon}) - \sum_i P_i \times Q_{iA} \\ &Max\ Z_B = 1 - x \times (\mathrm{Pr}_B^{1-\varepsilon}) - \sum_i P_i \times Q_{iB} \end{aligned} \tag{14}$$

$s.t.$

$$P_i \le \mathrm{Pr}_j \qquad (\forall j \in J, \forall i \in I) \tag{15}$$

$$Q_{ij}, \mathrm{Pr}_j, P_i \in R^+ \qquad (\forall j \in J, \forall i \in I) \tag{16}$$

Equation **Error! Reference source not found.** shows the wholesaler profit in the bi-level programming approach. Constraints (11) describe the wholesaler distribution capacity. Constraints (12) ensure the market demand to be equal to the retailers ordering quantities. Constraints (13) ensure the non-negativity of decision variables. Equation (14) represent the retailers profit in the behavior-based price discrimination model. Constraints (15) demonstrate the retailers' optimal price due to the wholesale price range, and finally Constraints (16) keep the lower level decision variables non-negative. Now, the integrated model of the two defined scenarios can be solved in the next section.

4- Solution approach

To solve the presented bi-level models in both scenarios, first the lower-level optimal equilibrium should be derived. Then, the master problem can be integrated with the lower level optimal region to prepare a single-level equivalent form and find the ultimate optimal solutions of the proposed problem. Figure 2 shows the solution survey. First of all, the lower equilibriums must be derived in case of discrimination and no discrimination. As the paper presents two scenarios for the upper level problem, 4 distinct model will be created which should be dealt individually. (1-mark-up pricing model for the wholesalers using non-discriminated retail prices, 2-optimized wholesale model using non-discriminated retail prices, 3- mark-up pricing model for the wholesalers using discriminated retail prices and, 4-optimized wholesale model using discriminated retail prices). Therefore, first the BBPD equilibriums of the lower-level problem is presented in the following section. Then, the solution procedure of the integrated models in both scenarios will be described, consequently.

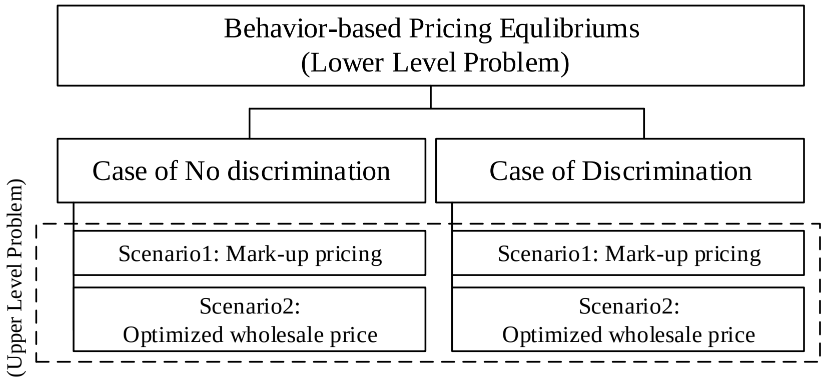

Fig 2. Solution structure of the defined scenarios

4-1- Bahevior-based pricing equlibriums

As stated before, the lower-level pricing model involves the optimal prices of the retailers in the competitive market. The retailers seek to find the appropriate prices due to customer' behaviors. Therefore, the concept of BBPD is used for deriving the model equilibriums considering customer elasticity to the offered retail prices and the customer geographical zone. Thus, two types of equilibriums are obtained in case of (i) no discrimination, and (ii) discrimination, respectively.

4-1-1- Case of no discrimination

The lower-level equilibriums for single-period behavior-based model which means no discrimination pricing can be derived as follows:

$$\mathrm{Pr}_j = [tr(1-\varepsilon)]^{1/1-\varepsilon} \tag{17}$$

$$D_j = [tr(1-\varepsilon)]^{-\varepsilon/1-\varepsilon} \tag{18}$$

$$\pi_j = [tr(1-\varepsilon)(1+\delta)](1/2) \tag{19}$$

Then the integrated model for the first aforementioned scenario can be written as follows:

- First scenario

$$\mathrm{P}_i = C_i \times (1+\alpha) \tag{20}$$

$$s.t.$$

$$\mathrm{Pr}_j = [tr(1-\varepsilon)]^{1/1-\varepsilon} \tag{21}$$

$$D_j = [tr(1-\varepsilon)]^{-\varepsilon/1-\varepsilon} \tag{22}$$

As the first scenario does not include any optimization on the wholesaler prices, the optimal values are $\mathrm{P}_i^* = C_i \times (1+\alpha)$, $\mathrm{Pr}_j^* = [tr(1-\varepsilon)]^{1/1-\varepsilon}$ and total fulfilled demand by the wholesalers and retailers is $D = \sum_j D_j^*$, $D_j^* = [tr(1-\varepsilon)]^{1/1-\varepsilon}$, respectively. But, for the second scenario the optimization model will be integrated as follows:

- Second scenario

$$Max\, Z_i = \sum_j (P_i - C_i) \times Q_{ij} \tag{23}$$

$s.t.$

$$\sum_j Q_{ij} \le cap_i \qquad (\forall i \in I) \tag{24}$$

$$\sum_i Q_{ij} \le D_j \qquad (\forall j \in J) \tag{25}$$

$$\mathrm{Pr}_j = Max\{P_i, [tr(1-\varepsilon)]^{1/1-\varepsilon}\} \qquad (\forall j \in J, \forall i \in I) \tag{26}$$

$$D_j = [tr(1-\varepsilon)]^{-\varepsilon/1-\varepsilon} \qquad (\forall j \in J) \tag{27}$$

$$Q_{ij}, P_i, D_j, \mathrm{Pr}_j \in R^+ \qquad (\forall j \in J, \forall i \in I) \tag{28}$$

Now, the model can be solved after applying linearization methods.

4-1-2- Case of discrimination

The case of discrimination pricing differs with the single-period pricing in delivering distinct prices in two periods. In two-period BBPD, there are two pricing process. In the first period a single uniform price will be offered to customers. Then, in the second period, the optimal behavior-based prices will be delivered to customers based on their purchase history in the previous period. Thus, each retailer sets a specific price for his own customers with Pr_o and another appropriate price for his rival customers with Pr_r. Each price seeking to maximize the associated retailers' profit and market share, simultaneously. Now, the lower-level equilibriums for behavior-based model concerning discrimination pricing can be derived as follows:

First period optimal values:

$$\mathrm{Pr}_j^1 = [tr(1-\varepsilon)(1+(\delta/3))]^{1/1-\varepsilon} \tag{29}$$

$$D_j^1 = [tr(1-\varepsilon)(1+(\delta/3))]^{-\varepsilon/1-\varepsilon} \tag{30}$$

Now, two different model can be concluded using BBDP optimal values for the first and second scenarios, respectively. For the first scenario, the model is made by adding the second period equilibriums as the master problem constraints which obtained by replacing the first period's optimal value.

- First scenario

$$\mathrm{P}_i = C_i \times (1+\alpha) \tag{31}$$

$s.t.$

$$\mathrm{Pr}_{oj} = [(2/3)tr(1-\varepsilon)]^{1/1-\varepsilon}$$
$$\mathrm{Pr}_{rj} = [(1/3)tr(1-\varepsilon)]^{1/1-\varepsilon} \tag{32}$$

$$D_{oj} = [(2/3)tr(1-\varepsilon)]^{-\varepsilon/1-\varepsilon}$$
$$D_{rj} = [(1/3)tr(1-\varepsilon)]^{-\varepsilon/1-\varepsilon} \tag{33}$$

As the first scenario does not include any optimization on the wholesaler prices, the optimal values are $P_i^* = C_i^* \times (1+\alpha), \Pr_j^* = E(\Pr_{oj}, \Pr_{rj}) = 1/2([(2/3)tr(1-\varepsilon)]^{1/1-\varepsilon} + [(1/3)tr(1-\varepsilon)]^{1/1-\varepsilon})$ and total fulfilled demands by the wholesalers and retailers are $D = \sum_j (D_j^*)$ and $D_j^* = D_{rj}^* + D_{oj}^* = ([(2/3)tr(1-\varepsilon)]^{-\varepsilon/1-\varepsilon} + [(1/3)tr(1-\varepsilon)]^{-\varepsilon/1-\varepsilon})$, respectively. But, for the second scenario the optimization model will be integrated as follows:

- Second scenario

$$Max\, Z_i = \sum_j (P_i - C_i) \times Q_{ij} \tag{34}$$

$s.t.$

$$\sum_j Q_{ij} \le cap_i \qquad (\forall i \in I) \tag{35}$$

$$\sum_i Q_j \ge D_j \qquad (\forall j \in J) \tag{36}$$

$$\Pr_j = Max\{P_i, \Pr_{rj}\} \qquad (\forall j \in J, \forall i \in I) \tag{37}$$

$$\Pr_j = [tr(1-\varepsilon)(1+(\delta/3)]^{1/1-\varepsilon} \qquad (\forall j \in J) \tag{38}$$

$$D_j = [tr(1-\varepsilon)(1+(\delta/3)]^{-\varepsilon/1-\varepsilon} \qquad (\forall j \in J) \tag{39}$$

$$Q_{ij}, P_i, \Pr_j \in R^+ \qquad (\forall j \in J, \forall i \in I) \tag{40}$$

Now, the model can be solved after applying linearization methods. The optimal solutions of the model then can be used in the follower problem to derive the second period optimal prices for the retailers.

4-2- Linearization of the model

As stated in sections 4.1.1 and 4.1.2, the second scenario models include non-linear terms in both the objective functions and constraints. The non-linear term is linearized using the following methods.

4-2-1- McCormick envelopes method

The bi-level models' objective functions in the second scenarios of behavior-based problems with different discrimination assumptions are non-linear. Nonlinearity of these terms is made by multiplying the continuous decision variables P_i and Q_{ij}. Hence, the McCormick Envelopes method is used for linearizing these terms McCormick (1976). Therefore, it is necessary to define two lower (L) and upper (U) bounds with distinct and suitable variation for the variable P_i. Setting the lower and upper bounds (L^P, U^P) by the leader is reasonable due to the Stackelberg structure and the leader authority in the competitive market. Moreover, Q_{ij} is assumed to be less than S^Q due to the total market demand. Thus, the following bounds can be defined for each continuous variable:

$$L^P \le P_i \le U^P \tag{41}$$

$$0 \le Q_{ij} \le S^Q \qquad (\forall j \in J) \tag{42}$$

Then, H_i can be replaced with the nonlinear term in the objective function as follows:

$$H_i = P_i \times Q_{ij} \qquad (\forall j \in J) \tag{43}$$

Afterwards, the following McCormick Envelopes constraints should be added to the model for completing the linearization procedure.

$$U^P \times Q_{ij} + S^Q \times P_i - U^P \times S^Q \leq H_{ij} \leq S^Q \times P_i + U^P \times Q_{ij} \qquad (\forall j \in J) \qquad (44)$$

$$L^P Q_{ij} \leq H_{ij} \leq U^P Q_{ij} \qquad (\forall j \in J) \qquad (45)$$

Now, the model non-linear constraints should be linearized with the following technique.

4-2-2- Classic form of linearization

Another non-linear term was defined in the set of constraints in maximization form. The classic reformulation of constraint can help linearize non-linear equations (26) and (37). The non-linear equations can be replaced by the following relations:

$$\Pr_j \geq P_i \qquad (\forall j \in J) \qquad (46)$$

$$\Pr_j \geq \Pr_{rj} \qquad (\forall j \in J) \qquad (47)$$

Now the integrated linear programming model can be solved easily to find the optimal solutions.

5- Computational experiments

In this part, a numerical case problem is used to examine the performance of proposed model. The proposed model is investigated on data used by Ali, Rahman et al. (2018) for sensitivity analysis. In addition, remaining parameters are also reported in table 1. Afterwards, the developed model is evaluated under some test problems and the results are described in details. This model is solved with the following scales, $|i| = 2$ and $|j| = 2$. It is necessary to mention that the presented model is solved using GAMS 24.3.3 in a Corei3 2.27 GHz system with CPLEX solver within 17.582 seconds.

Table 1. Required data

Parameter	Value	Parameter	Value
C_1	0.0035 millions	tr	0.0065 millions
C_2	0.0045 millions	I	Uniform [200,300]
cap_1	Uniform [5000, 15000]	$L^P{}_1, L^P{}_2$	0.12 millions
cap_2	Uniform [4000, 12000]	$U^P{}_1, U^P{}_2$	0.18 millions
α	0.2	$S^Q{}_1, S^Q{}_2$	14000

5-1- Sensitivity analyses on behavior-based price descrimination

The proposed model was solved using 12 test examples to derive better comparison among the case of no discrimination with the case of discrimination. As shown in figure 3, discriminative model is better than the other case in all the experiments. But, there exist a challenge. The case with no discrimination follow an increasing trend while the case of discrimination does not have the same.

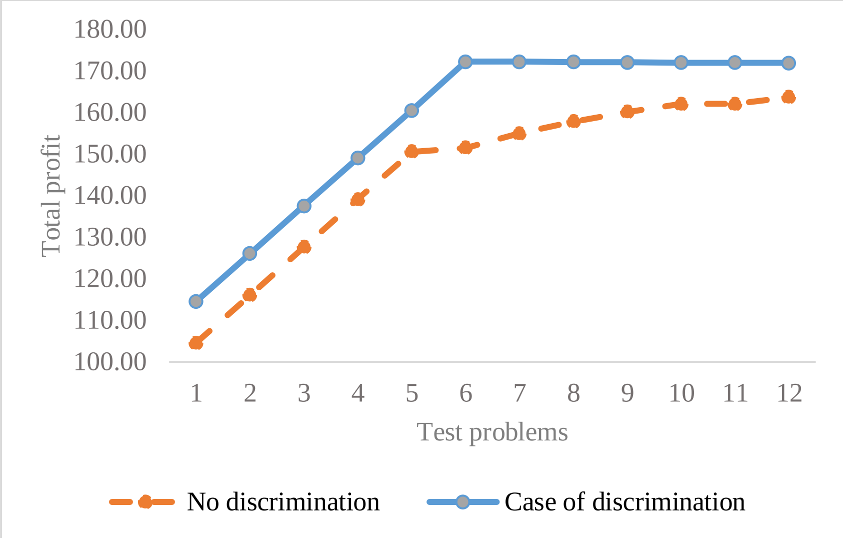

Fig 3. Comparison between defined models under different test problems

It proves this fact that the discriminative case is not profitable all the time, since in discriminative case lower prices will be offered to customers and may even have decreasing trend. But, in long-term planning it will bring more market share and profit for the individuals and is superior to the case of no discrimination. The main reason of this issue is the greater number of satisfied customers appealed by more reasonable prices.

In addition, table 2 and table 3 report different factors including total wholesale profit, total purchased quantity of products from wholesalers to retailers, total wholesale revenue and expected retail price by increasing the wholesale capacity which was described, previously.

Table 2. Analyses on the total profit and purchased quantity in the wholesalers' tier

Increasing Capacity (In percent)	Total profit (Millions)		Total purchased quantity	
	No discrimination	Discrimination	No discrimination	Discrimination
0	106.844	117.571	6890.12	8582.39
0.1	120.932	135.02	7971.25	9814.55
0.2	128.67	140.29	8671.41	11041.02
0.3	132.054	151.06	9436.73	11354.84
0.4	153.88	162.345	10167.77	11987.43
0.5	165.67	174.58	11023.59	12987.33

Table 3. Analyses on the total profit and purchased quantity in the wholesalers' tier

Increasing Capacity (In percent)	Total revenue (Millions)		Expected retail price	
	No discrimination	Discrimination	No discrimination	Discrimination
0	203.455	219.742	34581.62	30521.44
0.1	226.387	252.68	34581.62	30521.44
0.2	245.36	269.47	35482.7	31240.8
0.3	274.33	284.25	36107.68	31946.31
0.4	291.07	308.42	36107.68	31946.31
0.5	311.68	331.64	36107.68	31946.31

5-2- Sensitivity analysis on the wholesale marginal profit

Due to figure 4, increasing marginal profit percentage increases the value of the objective function and changing percentage will consequently have a descending form. This trend continues to a point. But after that, changing the percentage of the objective function is ascending sharply which shows severe declines in objective function value. This clearly shows the importance of setting a proper value to be acceptable by retailers. Therefore, a wholesaler can't offer the maximal marginal profit value for preventing retailers from following a switching cost strategy.

Finally, it can be concluded that in the system of pricing models, to find more profits managers should focus on some special factors which affect greatly on the supply chain performance.

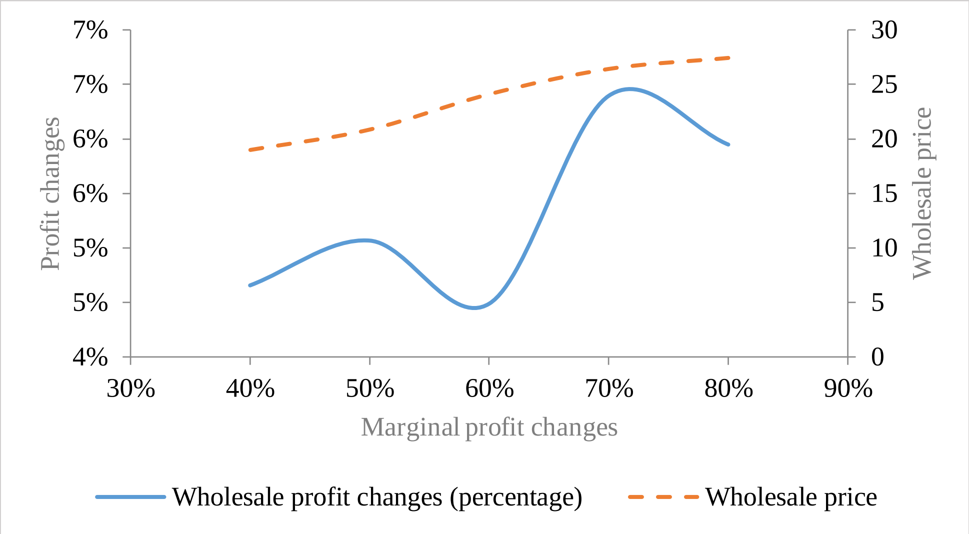

Fig 4. The objective function variations based on changing the marginal profit

6- Conclusions

In this study, the pricing concept is implemented with two important issues, competition and behavior of customers. Competition is assumed among wholesalers and retailers as the main members of supply chain. As a result of asymmetric competition, the Stackelberg game is used for modeling the competition.

In the developed bi-level model, the upper level includes the wholesalers' optimal decisions as the leader and the lower level involves the retailers' problem as follower. The wholesalers aims to maximize their own profit through offering best set of prices to retailers. And, the lower level problem attempts to maximize the retailer profit using behavior-based price discrimination. Hence, a two-stage programming approach is used in the lower level to get the optimal prices. Thus, two scenarios, (i) case of no discrimination and (ii) case of discrimination is defined to obtain more accurate price values. The case of behavior-based price includes two distinct steps including uniform pricing strategy and BBPD, respectively. Afterwards, both defined scenarios can be solved using the lower level equilibriums. Finally, the models is applied on an industrial case problem to be validated and derive sensitivity analyses. Moreover, some managerial insights is presented after carrying sensitivity analyses to conduct further researchers. In order to continue researches on competitive pricing with customer behavior, huff-like functions can be utilized. Moreover, adding inherent uncertainty of data or demand can make future researches more attractive. Disruption is the other concern may be suitable for extending the competitive behavior-based pricing models.

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