How Does Heterogeneous Consumer Behavior Affect Pricing Strategies of Retailers?

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ABSTRACT This paper presents the latest progress on pricing and revenue management. Consumer’s switching purchase behavior occurs frequently in perishable goods retail market, and we propose a two-period dynamic pricing model among online and offline retailers under heterogeneous purchase behavior of myopic consumers and strategic consumers. Through equilibrium solution and analysis, this study discusses the optimal pricing strategy under the influence of the service perception factor and the proportion of two kinds of consumers. Moreover, this paper analyzes the effect of three pricing strategies on profits to prove the effectiveness of price matching strategy implemented by offline retailers. The results show that the strategic behavior of heterogeneous consumers does not always have a negative impact on the profits of two retailers. The offline retailers can strategically choose to set higher prices to increase profits, and online retailers can also reduce the impact of heterogeneous consumer behavior by disclosing product attribute information. It is unwise for online retailers to take the initiative to match the price set by the offline retailers. In contrast, offline retailers can achieve a win-win situation for both retailers by matching the price of the online retailers actively.

INDEX TERMS Heterogeneous consumers, switching purchase behavior, dynamic pricing, price matching.

I. INTRODUCTION

The development of e-commerce technology has promoted the rapid rise of online stores, and the perishable retail industry has formed a dual market of offline and online stores. Consumers can directly experience and try the products in offline stores, while online purchases are more convenient and time-saving, thus forming heterogeneous purchase behavior. Heterogeneity is reflected in the fact that some consumers are myopic, while others are strategic. Strategic consumers will schedule their purchases strategically for anticipated future discounts, whereas myopic consumers will not. How to manage consumers with heterogeneous purchase behavior has obtained increasing attention of researchers in theory and practice. A study showed that among the surveyed consumers, 65 percent of them first search for product information on the Internet and then buy offline [1]. Another theoretical model was tested with a sample of 337 consumers. The results show near 50 percent tendency to switch from off-line to on-line across four product categories: books, airline tickets, wine, and stereo systems [2]. Consumers in the market are very different. Since consumers are either willing to pay for convenience or for service, there is a significant difference between a cost-oriented consumer and a convenience-oriented consumer. Besides, consumers have completely different preferences for online and offline retail stores, for brands, for quality, and for prices. As in [3], we also call this heterogeneous consumer behavior.

Obviously, heterogeneous consumer behavior poses an even greater challenge to retailers.Retailers want to know as much as possible about consumers’ preferences to satisfy their needs, but it is hard for retailers to know which consumers are likely to buy or not. Nor do retailers know how many consumers will go elsewhere. For offline retailers, the switching purchase behavior of heterogeneous consumers will lead to more service costs. For example, consumers come to experience for free and then buy from online retailers. For online retailers, offline retailers become their free exhibition halls. Online retailers have to lower prices to attract consumers, cause the cost advantage of online retailers is not obvious under heterogeneous purchase behavior. So how
should the offline and online retailers set prices to maximize profits?

We observed that the prices of online retailers are relatively low, since offline retailers have to pay the rent of the stores and the commission of the staff. We also clear that online retailers do not offer free experiences to consumers. While how do retailers set prices to maximize profits when faced with heterogeneous consumer behavior?

Some retailers through dynamic pricing to influence consumers’ purchase decision in response to heterogeneous consumer behaviors. A recent report from the Wall Street Journal shows the pricing strategies of e-retailers: according to price-research firm Decide Inc., the price of a general electric microwave moves nine times a day, and on Amazon, the price will fluctuate between $744.46 and $871.49. Ye et al. [4] considered a retailer using sponsored search marketing together with dynamic pricing. We have to admit that dynamic pricing promotes the rapid growth of sales volume, but retailers may have also fallen into the “price trap”, which is manifested in that more and more consumers strategically wait for product discounts before buying, forcing retailers into a vicious cycle of price reduction.

Empirical research also shows that consumers’ purchase decisions in such industries as consumer packaged goods, college textbooks, and apparel are forward-looking [5]–[7]. They choose to wait or compare prices and then switch to other retailers. Some scholars propose tactics to alleviate this kind of behavior of consumers for the retailers’ profits. One tactic, known as “price matching” by Jiang et al. [8] gave a theoretical explanation of the price matching guarantees (PMGs). Under the price matching strategy, if consumers find lower prices elsewhere within a period of time after purchase, the retailer will match the price and refund the difference. The study pointed out that PMGs increase retail demand while intensifying price competition. PMGs push retailers to offer deeper promotions because it increases the overall scope of consumer searches.

It should be noted that the online retailer is not a branch of the offline retailer in this research. Then how should a profit-maximizing retailer respond to such kind of switching purchase behavior underlying consumers’ purchase decision? Should the retailer apply dynamic pricing or price matching? What should be the optimal price under either strategy? Especially considering the existence of heterogeneous consumer behavior, which pricing strategy is better for retailers? Some business press refers to this browse-and-switch behavior as “showrooming”, and attributes it to the declining profits of offline retailers [9]. To study the effect of the switch behavior on retailers’ pricing strategies and profits, some researchers [9]–[11] analyzed stylized economic models that incorporates uncertainty in consumers’ valuation of the product, captures the heterogeneity among consumers in their inclination to purchase online. Finally, the equilibrium price results are given. Our paper builds on the above studies to perfect the consumer behavior model by incorporating important factor, that is, the proportion of heterogeneous consumer.

The results underscore the need to recognize heterogeneous consumer behavior, but also suggest that price matching is effective without precise knowledge of heterogeneous consumer behavior in many cases.

We study a stylized model in two retailers sell products over two periods. The retailers choose between two pricing strategies, dynamic pricing or price matching. Consumers then decide whether, when and where to buy product. We assume that some proportion of consumers purchase impulsively in the first period if the price is below their willingness to pay, while other consumers strategically wait or switch to other retailers for lower prices in the second period. The main purpose of this study is to discuss the two-period price decision and price matching under the heterogeneous consumer behavior. This paper attempts to answer the following three questions: when heterogeneous consumers have both myopic behavior and switching purchase behavior, (i) How does the presence of heterogeneous consumer behavior affect the retailers’ pricing strategy? In particular, do the retailers retain the benefits of applying dynamic pricing or price matching? (ii) Do the retailers benefit or suffer from heterogeneous consumer behavior? (iii) How much will the retailers potentially lose when they apply different pricing strategy?

Our study contributions to the literature on pricing strategies are twofold. First, we introduced heterogeneous consumer behavior into the study of two-period pricing. In the field of pricing and revenue management, some existing literature does not take into account the situation that consumers switch from online to offline. Considering the possibility of two kinds of conversions among consumers makes our study more comprehensive.

Second, we found that if consumers’ perception of products from online and offline retailers has little difference, it is more effective for offline retailers to match online retailers’ prices. It is a signal to online retailers that it is unwise to match offline retailer’s prices. Frankly speaking, bricks-and-mortar retailers have more control over prices, they are advised to take advantage of this superiority. Given the retailer’s pricing strategy, consumer then makes a purchase decision. By contrasting these two widely used pricing strategy, we characterize the conditions under which strategy is more profitable when consumers are affected by both strategies.

II. SURVEY OF EXISTING LITERATURE

The paper is related to three research streams: consumers’ choice between offline and online retailers, pricing equilibrium under duopoly competition, and the impact of dynamic pricing and price matching strategy on competition and heterogeneous consumer behavior.

A. LITERATURE ON CONSUMERS’ CHOICE BETWEEN OFFLINE AND ONLINE RETAILERS

From the past to the present, consumer behavior has always been the focus of theoretical research. Many factors, including but not limited to risk, convenience, and service
preferences [12], [13], affect consumers’ choice to shop offline or online. For example, Ilyas and Widayat [14] discussed the influencing factors of consumers’ online purchase. Their research was designed to test the role of gender in moderating the effects of online buying risks interacted with the shopping frequency on the buyers’ anxiety. Online purchase provides savings in efforts and time, and the option to search for and compare information [15], while offline purchase mitigates uncertainty about the product through the touch and feel experience [16]. Melis et al. [17] identify the underlying drivers of online retailer choice and explore how these drivers change when multi-channel retailers gain online shopping experience. As offline retailers may feature in-person expert advice. Undecided or uncertain consumers may want to consult with such experts for physical product evaluation and face-to-face advice before making a purchase decision have shown that without pre-purchase in-person experience, consumers purchasing from an online channel can be more likely to return the product. It is clear that existing studies have analyzed many factors that influence consumers’ choice between online and offline retailers. Our study also considers how consumers’ switching purchase willingness affects their choice between the two retailers. All consumers can buy products only from online retailer or offline retailer.

B. LITERATURE ON PRICING EQUILIBRIUM UNDER DUOPOLY COMPETITION

The first stage establishes the equilibrium pricing of manufacturers under the background of oligopoly [18]. Gradually, a group of researchers advance this field to the second stage by extending the dynamic pricing competition between two manufacturers offering vertically differentiated products. More recently, a large amount of studies promote the application of dynamic pricing in various industries including but not limited to hotels, airlines, and retail. For example, Hu et al. [19] applied dynamic pricing to airlines. They analyzed dynamic pricing problems by means of the dynamic programming method and obtain the optimal pricing strategies. The above literature considers the equilibrium pricing of products or services with differences, but does not discuss the impact of heterogeneous consumer behavior on pricing and profits.

The common sense in marketing is that consumers are heterogeneous. A growing literature on revenue management and pricing assumes that consumers are heterogeneous in their pursuit of utility. Yang et al. [20] developed a model of two-period pricing problem when the consumer pool consists of strategic types and myopic types and consumer valuations are stochastic. By solving a two-stage dynamic programming problem, they provided the optimal pricing strategy for the seller. Colombo and Matsushima [21] considered the spatial competition between two traditional physical (or offline) retailers and an Internet (or online) retailer. They assumed consumers are heterogeneous across two dimensions: (i) the costs of traveling to either of the offline retailers and (ii) the costs of purchasing from the online retailer. Sun and Stephen [22] also studied how the equilibrium pricing among competing retailers depend upon assortments when consumers must search for this sort of fit information and are heterogeneous in their shopping behaviors. A consensus in [20], [23]–[28] is that heterogeneous consumer behaviors are discussed in all the above cases. Cui et al. [29] explored the best pricing strategy of firm B to respond to firm A’s price promotion at different observations.

C. LITERATURE ON THE IMPACT OF DYNAMIC PRICING AND PRICE MATCHING STRATEGY ON COMPETITION AND HETEROGENEOUS CONSUMER BEHAVIOR

More recently, given the theoretical importance and empirical evidence of price matching guarantees (PMGs), a group of marketing researchers have paid close attention to the area. Besides [8], there are a growing stream of literature choose price matching. Yankelevich and Vaughan [30] found that announcements to price-match raise prices by altering heterogeneous consumer search behavior by using a model of sequential search. Price increases grow in the proportion of consumers who invoke price-matching guarantees and in the level of equilibrium asymmetry. Darrat [31] proved that price matching guarantee (PMG) is an effective promotion strategy that many retailers use to show consumers that their prices are competitive. While some interesting academic research has been done on the general topic, an advantage of his study is that it is one of the first to explore a comparison of online price matching guarantee (OPMG) – those which match Internet competitor on-line prices – with the PMG of traditional retail stores.

Another innovation of our study is the exploring a comparison of two price matching strategies. Moreover, many literatures, such as [32], regarding the transition of consumers from online retailers to offline retailers as a critical condition and do not discuss it. This paper also considers two cases of consumers switching from offline to online and from online to offline, which is also one of the innovations of our study. Chen et al. [33] show that price-matching guarantees can indeed facilitate competition: The expected prices and profits can be strictly lower when all stores adopt price-matching guarantees than when they are not allowed to. They think that the prices and profits of retailers are always lower after taking price matching, which is totally different from our results. In their study, 50% of the consumers search for prices and compare them, whereas our research defines the proportion of consumers who will transfer, and takes it as a parameter in example analysis, which also makes the paper more comprehensive. Our research is most relevant to [34] and [33]. Our paper considers the choice between several pricing strategies, and further discuss the effectiveness of the price matching strategy.

Motivated by the above research, this paper constructs a two-period dynamic game model, and discusses the proportion of two kinds of consumers, service perception factor and myopic consumer arrival proportion on retailer’s revenue. We find that when the service perception factor of consumers
is large and there is little difference between myopic and strategic consumer numbers, the strategic behavior of consumers is beneficial to the service providing retailers, that is, the offline retailers. This is contrary to the traditional idea that strategic behavior always damages retailers’ profits.

The remainder of this paper is organized as follows. Section 2 introduces the model in detail, including model framework, assumption, and method. In Section 3, we analyze the dynamic pricing equilibrium between the two retailers. In Section 4, two types of price matching strategies are proposed, we differentiate the two price matching strategies using the RO match and the OR match to present that in the second period, offline retailers actively match the prices of online retailers, and online retailers actively match the prices of offline retailers, respectively. We further verify their effectiveness. In Section 5, we conduct numerical analysis on the impact of the related factors according to the profit change. Section 6 presents conclusions and directions for future research. All relevant proofs appear in the Appendix.

III. MODEL
Consider an offline retailer (denoted with a subscript r) who competes with an online retailer (denoted with a subscript o) in a common market. They hold equal inventory and satisfies the whole demand of the market. The two retailers are risk-neutral and pursue maximum profits. We assume that there are no vertical differentiations between products that offered by the two retailers. The products involved in this paper are perishable products, that is, they will deteriorate and lose their value if they are not sold within a certain period of time. Some products may have some salvage value after they expire, but we ignore this and normalize the value to zero in the model.

With the intensification of market competition and the shortening of product life cycle, it has become normal for retailers to choose discount sales, and the frequent price reduction and promotion of retailers will cultivate the strategic awareness of consumers. That is to say, in the face of the general market price reduction phenomenon, more and more consumers will choose delay buying or inter-temporal buying in order to obtain greater net utility, including consumers in our study who have switched to other retailers, such consumers are called strategic consumers. Strategic consumers do not have the retailers’ periodic market pricing information. Because it takes time for consumers to reach the offline retailer, the consumer is limited to a single retailer visit per period. In the competition model, the retailers sell their products to the consumers who visits the retailers in this period. We divide the selling seasons into two period (t = 1, 2). In period t(t = 1, 2) the consumer enquires a price p_t at the retailer he visits. N consumers are drawn independently in the market and assumed to be independent and identically distributed random variables. In addition, to catch the major features of the offline retailer and the online retailer in this study, the consumers’ perceived value on the product as purchased from the online retailer is differentiated from the perceived value at an offline retailer by a discount factor. Each consumer’s price valuation for one unit product purchased from the offline retailer is V with a uniform distribution of [0, 1], and for the product sold by the online retailer is θV. As in Chiang et al. [35] and Chen and Chen [13], where θ ∈ (0, 1], θV is the aggregate perceived value of consumer on the product purchased from the online retailer. θ represents a discount of the consumer’s willingness-to-pay (WTP) on an online purchase, reflecting the disadvantage of purchasing online without being able to experience the product before purchase, as compared to buying from the offline retailer (considering, for example, a newly launched product, or a product with significant non-digital attributes). The perceived value of online purchases is typically discounted (θ < 1 is common in practice) because for example, the consumer cannot touch, feel, or see the products [36], or physically inspect it to determine fit. It is worth noting that after free-riding in an offline retailer, consumers purchase from an online retailer. The consumer’s price valuation is supposed to be θV, but it is still V since consumers enjoy the services of offline retailer for free. However, the strategic behavior discussed in our article is different from that. As long as consumers complete the purchase from online retailers, we all think the price valuation of the consumer is θV. Both of the retailers do not know V with certainty, but they have prior knowledge of the density of V, denoted f(V), with distribution function F(V).

The consumers in the market are heterogeneous, which is manifested in the difference of the highest price acceptable to consumers, the intuitive feeling brought to consumers by product attributes, and the urgency for consumers to obtain products. Among all consumers, the number of consumers who initially arrived at the offline retailer is mn(m ∈ [0, 1]). Some consumers are price-sensitive and strategic, and they may wait for the price to drop. An office lady who wants to own a Longchamp bag will buy it on The Black Friday when prices are reduced. Perhaps she can get a nice scarf with the money she saved. This can also be well reflected in the aviation industry. An American Airlines member is flying a business trip this day. Pressed for time, the airline has no tickets, so he bought tickets from another airline. In this paper, the strategic consumer will consider the future price reduction of the product, compare the utility size of the two periods according to the future availability probability of product, and then decide whether to buy or wait to buy. If the product is suitable and the price is acceptable, consumers will buy it. On the contrary, the consumer thinks he does not need the product temporarily or the price is unacceptable, he will leave. For those myopic consumers, if the net effect of the purchase is negative, they will leave. They do not consider the possibility of a future price cut, nor do they care if the product will be out of stock in the future. They are only concerned about whether the effect of purchasing the product in the current period is positive. Myopic consumers tend to leave if they buy a product with a negative net effect. Information asymmetry causes retailers not to know exactly how many
of their consumers are myopic. Therefore, we define the proportion of myopic consumers of offline retailers as $\alpha (\alpha \in [0, 1])$. Consequently, the number of consumers who initially arrived at the online retailer is $(1 - \alpha)N$. We also assume that the proportion of myopic consumers who arrived online retailer is $\beta (\beta \in [0, 1])$.

For offline retailers, some consumers experience products and services from offline and then buy from online retailers. Others choose not to buy and leave. The same goes for consumers of online retailers. Some consumers browse the product information on the Internet and then go to the offline retailer to buy it. Others not to complete the purchase and leave. In order to facilitate the analysis, we do not consider the purchase cost of consumers going to the two retailers. In the first period, the consumer enters the market first and the retailer sets the price. Each retailer has opportunities to make price changes during the rest selling seasons. The retailers decide to choose one of the following pricing strategies for selling more products to maximize profits.

1) All of the retailers can choose a dynamic pricing strategy to sell the products during the first period of sales season.

2) Offline retailer can implement price matching in the second sales period. The offline retailer gives strategic consumers a price that matches the price of the online retailer to attract more consumers to the offline retailer in the second period, and continues its usual price to those myopic consumers.

3) Online retailer can implement price matching in the second sales period. The online retailer gives strategic consumers a price that matches the price of the offline retailer to attract more consumers to the online retailer in the second period, and continues its usual price to those myopic consumers.

Regarding the fact that this paper does not implement price matching in the first period, it is believed that the information the retailers is asymmetric and they have difficulty in identifying whether the consumer is a strategic consumer or not. At the same time, there are some loyal consumers of offline retailers among the consumers who come to purchase in the first period.

Since the retailers sell products over two periods and possibly change prices, the consumers strategically choose when to purchase the product based on their valuation and the pricing strategies of retailers. For convenience, we differentiate the three pricing strategies using the superscripts $(D)$, $(RO)$, and $(OR)$ to present dynamic pricing, offline retailer match online retailer’ prices, and online retailer match offline retailer’ prices, respectively. In addition, let $p_{Q_q}^D(F(V)) = Q! (1 - F(V))^{Q - q} F(V)^q / q! (Q - q)!$ denote the probability that the retailer, who is visited by $Q$ consumers and sells $q$ units in the first period, where $W = \{D, RO, OR\}$. For the convenience of the following statement, $p_{Q_q}^W(F(V))$ is simplified to $p_{Q_q}^W$.

### IV. DYNAMIC PRICING STRATEGY

In this section, we analyze optimal price and equilibrium profits under the dynamic strategy. The subsequent are devoted to the analysis of two cases: one consumer and $N$ consumers. Two retailers post prices for two periods with $(p_{T1}^D, p_{T2}^D)$. The decision-making process is as follows.

#### A. ONE CONSUMERS

In this subsection, we simplify the process and analyze the basic model with one consumer in the market.

In each period the price of the retailer not visited by the consumer is not relevant, and no assumption is needed for a retailer’s knowledge about the other retailer’s price. The consumer needs to consider the intertemporal choice between two retailers over two periods, where each consumer decides which retailer to purchase from and when to purchase in order to maximize consumer utility. A consumer can also decide not to purchase, in which case he/she receives zero utility.

1) ARRIVE AT THE OFFLINE RETAILER

We assume that the offline retailer encounters the consumer in the first period, and the consumer will visit the competing online retailer in the second period, where $\alpha$ represents the probability that the consumer is myopic and $1 - \alpha$ represents the probability that he will switch to an online retailer.

We denote the expected profit of the offline retailer as $\pi_{T1}^D(1, 0)$ in one consumer case. When the offline retailer is visited by the consumer in the first period, we have the following:

$\pi_{T1}^D(1, 0) = \max_{p_{T1}^D} \left( (1 - \alpha) p_{T1}^D + (1 - \alpha)(1 - p_{T1}^D) \right)$

(1)

Similarly, the expected profit of the online retailer can be written as follows:

$\pi_{T2}^D(0, 1) = \max_{p_{T2}^D} \left( (1 - \alpha) p_{T1}^D - p_{T2}^D \right) \left( 1 - \frac{p_{T2}^D}{\theta} \right)$

(2)

According to the above analysis, the two retailers’ equilibrium price and profits can be directly calculated when there is one consumer in the market, as shown in Theorem 1.

For the sake of simplification, we define

$A(\alpha, \theta) = 4 \alpha\theta^2 - 2 \alpha^2\theta^2 + \alpha \theta - \theta - 2$

$B(\alpha, \theta) = 3 \alpha\theta - \alpha\theta^2 - 2$

$C(\alpha, \theta) = \sqrt{A^2 - 8 \theta (\theta - 1) B}$

(3)

These notations will be used throughout the paper.

**Theorem 1:** In the dynamic pricing strategy, when there is only one consumer in the market and he initially arrived at the offline retailer, the optimal price of two retailers is as follows:

$p_{T1}^D = \frac{\alpha - 1}{\alpha \theta - \theta} A(\alpha, \theta) + C(\alpha, \theta) + \frac{\theta - 1}{2(\alpha \theta - 1)}$

$p_{T2}^D = \frac{A(\alpha, \theta) + C(\alpha, \theta)}{4B(\alpha, \theta)}$

(4)

The expected profits of two retailers are as follows:

$\pi_{T1}^D(1, 0) = \frac{1}{64B(\alpha, \theta)^2 (\theta - 1)(\alpha \theta - 1)} \times (A(\alpha, \theta) + C(\alpha, \theta))(\alpha - 1)$
\[
(A(\alpha, \theta) + C(\alpha, \theta))\alpha \\
+ 8\theta B(\alpha, \theta) - A(\alpha, \theta) - C(\alpha, \theta) - 8B(\alpha, \theta))
\]
\[
\pi_o^D(0, 1) = \frac{1}{128\theta(\theta - 1)(\alpha\theta - 1)B(\alpha, \theta)}(\alpha - 1)(A(\alpha, \theta) \\
+ C(\alpha, \theta))^2(2\alpha - \alpha - 1) \\
\times (A(\alpha, \theta) + C(\alpha, \theta) - 4\theta B(\alpha, \theta))
\]

The proof of Theorem 1 is in the Appendix.

2) ARRIVE AT THE ONLINE RETAILER

We assume that the online retailer encounters the consumer in the first period, and the consumer will visit the competing offline retailer in the second period.

We denote the expected profit of the online retailer as \(\pi_o^D(1, 0)\) in one consumer case. When the online retailer is visited by the consumer in the first period, we have the following:

\[
\pi_o^D(1, 0) = \max_{p_o^D} \left( \beta \left( 1 - \frac{p_o^D}{\theta} \right) + (1 - \beta) \frac{p_o^D - p_o^D}{1 - \theta} \right)
\]

Similarly, the expected profit of the offline retailer can be written as follows:

\[
\pi_r^D(0, 1) = \max_{p_r^D} \left( 1 - \beta \right)(1 - \frac{p_r^D - p_r^D}{1 - \theta})(1 - p_r^D)
\]

According to the above analysis, the two retailers’ equilibrium price and profits can be directly calculated when there is one consumer in the market, as shown in Theorem 2. To simplify presentation, we define

\[
D(\beta, \theta) = 7\theta + 8\beta + 6\theta^2\beta - 4\theta^2 - 17\theta
\]
\[
E(\beta, \theta) = 2\theta + 3\beta - 56\beta
\]
\[
F(\beta, \theta) = \sqrt{D - 8E(2\theta^2 - \beta + 3\theta^2\beta)}
\]

These notations will be used throughout the paper. Theorem 2: In the dynamic pricing strategy, when there is only one consumer in the market and he initially arrived at the online retailer, the optimal price of two retailers is as follows:

\[
p_o^D = \frac{\theta(1 - \beta)}{\theta + \beta - 2\theta\beta} \frac{D(\beta, \theta) - F(\beta, \theta)}{E(\beta, \theta)} + \frac{\theta\beta(1 - \beta)}{2(\theta + \beta - 2\theta\beta)}
\]
\[
p_r^D = \frac{D(\beta, \theta) - F(\beta, \theta)}{4E(\beta, \theta)}
\]

The expected profits of two retailers are as follows:

\[
\pi_o^D(1, 0) = \frac{1}{64(\theta - 1)(2\theta\beta - \beta - \theta)E(\beta, \theta)} \left( 4\theta E(\beta, \theta) + D(\beta, \theta) - F(\beta, \theta) - 4E(\beta, \theta) \right) \\
- D(\beta, \theta) + F(\beta, \theta))^2
\]
\[
\pi_r^D(0, 1) = \frac{1}{128(\theta - 1)(2\theta\beta - \beta - \theta)E(\beta, \theta)} \left( 2\theta(\beta - 1)(D(\beta, \theta) - F(\beta, \theta) - 4E(\beta, \theta)) = 3\beta - 3F(\beta, \theta) \\
- 2\theta E(\beta, \theta) + F(\beta, \theta) = 2\theta E(\beta, \theta) - 2\beta(D(\beta, \theta) + 4E(\beta, \theta)) \right)
\]

The proof of Theorem 2 is in the Appendix.

According to Theorem 1 and Theorem 2, the simplified calculation of the retailers’ profit can be obtained directly when there are \(N(N > 1)\) consumers in the market, as shown below.

B. N CONSUMERS

In this subsection we extend the model to \(N\) consumers. We assume the consumers necessarily as two groups. That is, in the first period \(mN\) consumers visit the offline retailer, and \((1 - m)N\) consumers visit the online retailer. Where \(mN\) and \((1 - m)N\) represent the number of myopic consumers and strategic consumers who visited the offline retailer. Similarly, \(mN\) and \((1 - m)N\) represent the number of myopic consumers and strategic consumers who visited the online retailer, respectively. Due to the strategic behavior of consumers and the presence of myopic consumers, the consumers maintain the pattern over periods. Myopic consumer attributes ensure that they do not appear in the second period.

Because the consumers’ valuations may be different, it is possible that some consumers will purchase products in the first period while others will continue the search. Thus, in the first period the equation can be derived, as shown at the bottom of next page. In the same way,

\[
p_o^D(1 - m)N - n_1, n_2 = \frac{((1 - m)N - n_1)!}{n_2!(1 - m)N - n_1 - n_2)!} \times \left( \frac{1 - (1 - \beta)(1 - F(\beta, \theta))}{1 - \beta}(1 - \frac{p_r^D - p_o^D}{1 - \theta}) \right)^{(1 - m)N - n_1 - n_2}
\]

The total expected profits of the offline retailer are given by

\[
\pi_o^D(mN, (1 - m)N) = \sum_{n_1=0}^{mN} p_o^D(n_1) p_{mN}^{n_1} + \sum_{n_1=0}^{(1 - m)N} p_o^D((1 - m)N, n_1) p_{mN}^{n_1} \\
\sum_{n_2=0}^{(1 - m)N - n_1} n_2 p_r^D(n_1, n_2)
\]

We can see that since the number of products sold is a variable in the first period, thus the number of consumers reaching the competition retailer is difficult to be estimated in the second period. We simplify the calculation and discuss the equilibrium decision of the two retailers.
Theorem 3: In the dynamic pricing strategy, when they are $N(N > 1)$ consumers in the market, the expected profits of two retailers are as follows:

$$
\pi^D_r(mN, (1 - m)N) = mN\pi^D_1(1, 0) + (1 - m)N\pi^D_2(0, 1)
$$

where $\pi^D_1(1, 0)$, $\pi^D_2(0, 1)$, $\pi^D(1, 0) = (1 - m)N\pi^D_1(1, 0) + mN\pi^D_2(0, 1)$

1) ONE CONSUMER

The following analysis is consistent with dynamic pricing scenario. The offline/online retailer is visited by a consumer in the first period, and we have the following equation:

$$
\pi^{RO}_{11}(1, 0) = \max_{p^RO_{11}} \left( \alpha(1 - p^RO_{11})p^RO_{11} + (1 - \alpha) \times (1 - \frac{p^RO_{11} - p^RO_{21}}{1 - \theta}p^RO_{21}) \right)
$$

where $\pi^{RO}_{11}(1, 0)$ and $\pi^{RO}_{21}(0, 1)$ are the expected profits from selling one unit in the first period when a consumer first visits the offline/online retailer.

According to the above analysis, the retailers’ equilibrium price and profits can be calculated when there is a consumer in the market, as shown in Theorem 4.

To simplify presentation, we define

$$
G(\alpha, \theta) = \alpha\theta + \theta + 2
$$

$$
H(\alpha, \theta) = \sqrt{\alpha^2\theta^2 + 10\alpha\theta^2 - 4\alpha\theta + 17\theta^2 - 12\theta + 4}
$$

$$
I(\alpha, \beta) = 5\alpha\beta - \alpha + 9\beta - 1
$$

$$
J(\alpha, \beta, \theta) = 8(\alpha + 2)(2\theta\beta - \beta - \theta)
$$

Theorem 4: In the RO match strategy, when there is only one consumer in the market, the prices after the RO match are as follows:

$$
\begin{align*}
\hat{P}^{RO}_{11} &= \frac{1}{2} + \frac{(1 - \alpha)G(\alpha, \theta) + H(\alpha, \theta)}{8\alpha(\theta - 1)(\alpha + 2)} \\
\hat{P}^{RO}_{21} &= \frac{G(\alpha, \theta) + H(\alpha, \theta)}{4(\alpha + 2)} \\
\hat{P}^{RO}_{21} &= \frac{(\theta I(\alpha, \theta) + (\beta - 1)H(\alpha, \theta) - 4\alpha\beta - 6\beta + 2)\theta}{J(\alpha, \beta, \theta)}
\end{align*}
$$

V. PRICE MATCHING STRATEGY

While dynamic pricing allows a retailer to discriminate price among consumers, it also provides an incentive for strategic consumers to postpone purchases and wait for lower prices. Some consumers may purchase online after the offline retailer has enjoyed the service, while others browse the product information online for free, and then go to the offline retailer to purchase directly even without the introduction of the staff. Some of the remaining consumers left without buying. Therefore, in view of the presence of heterogeneous consumers, we begin to analyze the effectiveness of price matching.

Based on the heterogeneous consumer behavior, we will discuss two kinds of price matching in this subsection, namely the RO match strategy and the OR match strategy. Since the retailers in the first period do not know the market sales and consumer information, the RO match means the offline retailer actively matches the online retailer’s price in the second period, the OR match refers to the online retailer matching the price of the offline retailer in the second period. Similar to Section 3, we also do the analysis according to the path of one consumer promotion to $N$ consumers.

A. THE RO MATCH STRATEGY

When the offline retailer chooses the option of price matching, it gives strategic consumers a price that matches the price of the online retailer ($p_{o2}$), so that they will not switch to the online retailer in the second period, and continues the usual price ($p_{r1}$) to those myopic consumers.

$$
\begin{align*}
p^D_{mN, n_1} &= \frac{mN!(1 - ((1 - \alpha)(1 - F(p^D_{r1} - p^D_{o2}) + \alpha(1 - F(p^D_{r1})))^{mN-n_1})}{n_1!(mN - n_1)!} \times ((1 - \alpha)(1 - F(p^D_{r1} - p^D_{o2}) + \alpha(1 - F(p^D_{r1})))^{n_1}.
\end{align*}
$$
\[ p_{r2}^{\text{RO}} = \frac{G(\alpha, \theta) + H(\alpha, \theta)}{4(\alpha + 2)} \]  

(18)

The expected profits are as follows:

\[
\pi_{r1}^{\text{RO}}(1, 0) = \alpha \left( \frac{1}{4} - \frac{(1 - \alpha)(G(\alpha, \theta) + H(\alpha, \theta))}{8\alpha(\theta - 1)(\alpha + 2)} \right)^2 + \frac{1}{32\alpha(\theta - 1)^2(\alpha + 2)^2}((\alpha(4 - 8\theta) + 2(G(\alpha, \theta) + H(\alpha, \theta) - 8\theta + 4))(\theta - 1)\alpha + (\alpha - 1)(G(\alpha, \theta) + H(\alpha, \theta)))(\alpha - 1)(G(\alpha, \theta) + H(\alpha, \theta))
\]

(19)

\[
\pi_{o2}^{\text{RO}}(0, 1) = \frac{1}{64\alpha\theta(\theta - 1)^2(\alpha + 2)^2}((2 - 2\theta)\alpha^2 + \alpha(\alpha(4 - 8\theta) + 2(G(\alpha, \theta) + H(\alpha, \theta) - 8\theta + 4))(\theta - 1)\alpha + (\alpha - 1)(G(\alpha, \theta) + H(\alpha, \theta)))(\alpha - 1)(G(\alpha, \theta) + H(\alpha, \theta))
\]

(20)

\[
\pi_{r2}^{\text{RO}}(1, 0) = \frac{1}{128(\theta - 1)(\alpha + 2)^2}((\alpha(4 - 8\theta) + 2(G(\alpha, \theta) + H(\alpha, \theta) - 8\theta + 4))(\theta - 1)\alpha + (\alpha - 1)(G(\alpha, \theta) + H(\alpha, \theta)))(\alpha - 1)(G(\alpha, \theta) + H(\alpha, \theta))
\]

(21)

\[
\pi_{o1}^{\text{RO}}(1, 0) = \frac{1}{(\theta - 1)(\alpha + 2)^2}((-\frac{I(\alpha, \beta)}{36})(H(\alpha, \theta) - 4\alpha - 6)\beta + \theta J - H(\alpha, \theta) + 2)(\alpha(\alpha(4 - 8\theta) + 2(G(\alpha, \theta) + H(\alpha, \theta) - 8\theta + 4))(\theta - 1)\alpha + (\alpha - 1)(G(\alpha, \theta) + H(\alpha, \theta)))(\alpha - 1)(G(\alpha, \theta) + H(\alpha, \theta))
\]

(22)

The proof of Theorem 4 is in the Appendix. According to Theorem 4, the simplified calculation of the retailers’ profits can be obtained directly when there are \( N \) consumers in the market, as shown below.

2) \( N \) CONSUMERS

When there are \( N \) Consumers In The Market, The method similar to the previous analysis can get the maximum expected profits of retailers when the RO match strategy is adopted. The total expected profits of the offline retailer are given by

\[
\pi_r^{\text{RO}}(mN, (1 - m)N) = \sum_{n_1=0}^{mN} p_{r1}^{\text{RO}}(n_1) + \sum_{n_2=0}^{(1-m)N-n_1} p_{r2}^{\text{RO}}(1-m)N-n_1,n_2
\]

(23)

**Theorem 5**: In the RO match strategy, when they are \( N(N > 1) \) consumers in the market, the expected profits of two retailers are as follows:

\[
\pi_r^{\text{RO}}(mN, (1 - m)N) = mN\pi_{r1}^{\text{RO}}(1, 0) + (1 - m)N\pi_{r2}^{\text{RO}}(1, 0)
\]

\[
\pi_o^{\text{RO}}((1 - m)N, mN) = (1 - m)N\pi_{o1}^{\text{RO}}(1, 0) + mN\pi_{o2}^{\text{RO}}(0, 1)
\]

(24)

where \( \pi_{r1}^{\text{RO}}(1, 0), \pi_{o1}^{\text{RO}}(1, 0), \pi_{r2}^{\text{RO}}(0, 1), \) and \( \pi_{o2}^{\text{RO}}(0, 1) \) are shown in (15) and (16); they are the retailers’ expected profits under the RO match strategy, in the market with a single consumer. The linear relationship in Theorem 3 still exists.

The proof of Theorem 5 is in the Appendix.

**B. THE OR MATCH STRATEGY**

When the online retailer chooses the option of price matching, it gives strategic consumers a price that matches the price of the offline retailer \( (p_{r2}) \), so that they will not switch to the offline retailer in the second period, and continues the usual price \( (p_{o1}) \) to those myopic consumers.

1) ONE CONSUMER

When the offline/online retailer is visited by a consumer in the first period, we have the following equation:

\[
\pi_{r1}^{\text{OR}}(1, 0) = \max_{p_{r1}} \left(\alpha(1 - p_{r1})p_{r1}^{\text{OR}} + (1 - \alpha)(1 - \frac{p_{r1}^{\text{OR}} - p_{o1}^{\text{OR}}}{1 - \theta}p_{o1}^{\text{OR}})\right)
\]

\[
\pi_{o1}^{\text{OR}}(1, 0) = \max_{p_{o1}} \left(\beta \left(1 - \frac{p_{o1}^{\text{OR}}}{\theta}\right) + (1 - \beta)\frac{p_{o2}^{\text{OR}} - p_{o1}^{\text{OR}}}{1 - \theta}\right)
\]

(25)

where \( \pi_{r1}^{\text{OR}}(1, 0) \) and \( \pi_{o1}^{\text{OR}}(1, 0) \) are the expected profits from selling one unit in the first period when a consumer first visits the offline/online retailer.

Similarly, the expected profits of the online/offline retailer can be written as follows:

\[
\pi_{o2}^{\text{OR}}(0, 1) = \max_{p_{o2}} \left(1 - \alpha\right)\left(1 - \frac{p_{r1}^{\text{OR}} - p_{o2}^{\text{OR}}}{1 - \theta}\right)\left(1 - \frac{p_{o2}^{\text{OR}}}{\theta}\right)
\]

\[
\pi_{r2}^{\text{OR}}(0, 1) = \max_{p_{r2}} \left(1 - \beta\right)\left(1 - \frac{p_{r2}^{\text{OR}} - p_{o1}^{\text{OR}}}{1 - \theta}\right)\left(1 - \frac{p_{r2}^{\text{OR}}}{\theta}\right)
\]

(26)
According to the above analysis, the retailers’ equilibrium price and profits can be calculated when there is a consumer in the market, as shown in Theorem 6.

To simplify presentation, we define

\[ K(\alpha, \theta) = 4\alpha^2 \theta^2 + 3\alpha^2 \theta + 8\alpha \theta^2 - 12\alpha \theta - 10\alpha - 15\theta + 22 \]

\[ M(\alpha, \theta) = 3\alpha^2 \theta^2 + 5\alpha^2 \theta + 2\alpha^2 - 11\alpha \theta - 9\alpha + 10 \]

\[ S(\beta, \theta) = 2\beta - 2\theta - 4\theta \beta \]

\[ L(\alpha, \theta) = \sqrt{16\alpha^4 \theta^4 + 24\alpha^4 \theta^3 - 32\alpha^3 \theta^4 + 9\alpha^4 \theta^2 - 112\alpha^3 \theta^3 + 64\alpha^2 \theta^2 - 28\alpha^2 \theta - 168\alpha \theta^2 + 4\alpha^2 + 44\alpha \theta + 65\theta^2 - 8\alpha - 20\theta + 4} \]

\[ \text{(27)} \]

**Theorem 6:** In the OR match strategy, when there is only one consumer in the market, the prices after the OR match are as follows:

\[ p^\text{OR}_{r1} = \frac{K(\alpha, \theta) + L(\alpha, \theta)}{8M(\alpha, \theta)} \]

\[ p^\text{OR}_{r2} = \frac{4 - 2\alpha \theta + 2\alpha}{1 - \alpha} + \frac{K(\alpha, \theta) + L(\alpha, \theta)}{8M(\alpha, \theta)} + \theta - 1 \]

\[ p^\text{OR}_{o1} = \frac{4 - 2\alpha \theta + 2\alpha}{1 - \alpha} \cdot \frac{K(\alpha, \theta) + L(\alpha, \theta)}{8M(\alpha, \theta)} + \theta - 1 \]

\[ p^\text{OR}_{o2} = \frac{4 - 2\alpha \theta + 2\alpha}{1 - \alpha} \cdot \frac{K(\alpha, \theta) + L(\alpha, \theta)}{8M(\alpha, \theta)} + \theta - 1 \]

\[ \text{(28)} \]

The expected profits are as follows:

\[ \pi^\text{OR}_{r1}(1, 0) = \frac{(\alpha(2 + \theta) - 3)(K(\alpha, \theta) + L(\alpha, \theta))^2}{64(\theta - 1)M(\alpha, \theta)^2} \]

\[ \text{(29)} \]

\[ \pi^\text{OR}_{r2}(0, 1) = \frac{1}{64(\theta - 1)(\alpha - 1)^2M(\alpha, \theta)^2} \]

\[ \pi^\text{OR}_{o1}(0, 1) = \frac{1}{64\theta(\theta - 1)(\alpha - 1)^2M(\alpha, \theta)^2} - 2M(\alpha, \theta) + 4M(\alpha, \theta)(\theta + 1)K(\alpha, \theta) + 3L(\alpha, \theta)K(\alpha, \theta) + 3L(\alpha, \theta)K(\alpha, \theta) \]

\[ - 4\theta M(\alpha, \theta) + \frac{2}{2} + 4M(\alpha, \theta)(\theta + 1)K(\alpha, \theta) + L(\alpha, \theta) - 2M(\alpha, \theta)) \]

\[ \text{(30)} \]

\[ \pi^\text{OR}_{o2}(0, 1) = \frac{1}{64(\theta - 1)(\alpha - 1)^3SM^3} (((4\beta M + (\beta - 1)(K + L))\alpha + (4 - 8\beta)M)\theta^2) \]

\[ \text{+ ((4S - 4\beta)M) \theta} \]

\[ \text{+ (S + \beta - 1)(K + L))\alpha} \]

\[ \text{+ (8\beta - 8S - 4M - 2(1 - \beta)(K + L))\theta} \]

\[ \text{+ S(\alpha - 2)(K + L - 4M))} \]

\[ \text{+ ((K + L)\alpha - 4M)\theta + (\alpha - 2)(K + L - 4M)(\beta - 1)} \]

\[ \text{+ (K + L)\alpha - 2(K + L - 2M))} \]

\[ \text{(31)} \]

\[ \pi^\text{OR}_{o1}(1, 0) = \frac{1}{16(1 - \theta)(\alpha - 1)^2M(\alpha, \theta)^2N(\alpha, \theta)^2} \cdot \theta(((K(\alpha, \theta) + L(\alpha, \theta) + 4M(\alpha, \theta) + K(\alpha, \theta) + L(\alpha, \theta) - 4M(\alpha, \theta))\alpha} \]

\[ - 2(4\theta M(\alpha, \theta) + K(\alpha, \theta) + L(\alpha, \theta) + 4M(\alpha, \theta))\theta - 4M(\alpha, \theta))\beta - (\theta + 1) \]

\[ \times (K(\alpha, \theta) + L(\alpha, \theta))\alpha} \]

\[ + 2(2\theta M(\alpha, \theta) + K(\alpha, \theta) + L(\alpha, \theta) - 2M(\alpha, \theta))\beta - (\theta + 1) \]

\[ \times (2(\theta - 1)) + S(\beta, \theta) - \theta} \]

\[ \text{(32)} \]

The proof of Theorem 6 is in the Appendix. According to Theorem 6, the simplified calculation of the retailers’ profits can be obtained directly when there are \(N\) consumers in the market, as shown below.

2) \(N\) CONSUMERS

Similar to the previous analysis, this subsection discusses how to maximize the expected profit when the online retailer adopts the or match strategy when there are \(N\) consumers in the market. The total expected profits of the offline retailer are given by

\[ \pi^\text{OR}_{\pi}(mN, (1 - m)N) = \sum_{n_1=0}^{mN} p^\text{OR}_{r1}(n_1p^\text{OR}_{r1}) + \sum_{n_2=0}^{(1-m)N} p^\text{OR}_{r2}(p^\text{OR}_{r2}) \]

\[ \sum_{n_1=0}^{(1-m)N-n_1} \sum_{n_2=0}^{N-n_1-n_2} \]

\[ \text{(33)} \]

**Theorem 7:** In the OR match strategy, when they are \(N(N > 1)\) consumers in the market, the expected profits of two retailers are as follows:

\[ \pi^\text{OR}_{\pi}(mN, (1 - m)N) = mN\pi^\text{OR}_{r1}(1, 0) + (1 - m)N\pi^\text{OR}_{r2}(0, 1) \]

\[ \pi^\text{OR}_{\pi}(1 - m)N, (1 - m)N) = (1 - m)N\pi^\text{OR}_{o1}(1, 0) + mN\pi^\text{OR}_{o2}(0, 1) \]

\[ \text{(34)} \]

where \(\pi^\text{OR}_{r1}(1, 0), \pi^\text{OR}_{r2}(0, 1), \pi^\text{OR}_{o1}(1, 0), \text{and } \pi^\text{OR}_{o2}(0, 1)\) are shown in (25) and (26); they are the retailers’ expected profits under the OR match strategy, in the market with a single consumer.

The proof of Theorem 7 is in the Appendix.

In the following, we will analyze the effectiveness of three pricing strategies.
remains as high as 19%. That is because offline retailers can about 8%, while the potential profits loss of online retailer from 0.1 to 0.5, the profits of offline retailers increases by competitor. From Table 1, we found that when \( \alpha \) the more profits it generates and the lower the profits of its portion of myopic consumers that the offline retailer has, rules. In the dynamic pricing strategy, the higher the pro-

\[ \alpha \] 

the value of \( \theta \), from 0.3 to 0.9, and the value of \( m \), from 0.4 to 0.8. The profits two retailers, as they change with \( \alpha \), \( \beta \), \( \theta \), and \( m \), are summarized in Table 1, 2, 3, and 4, respectively.

The following conclusions can be drawn with Table 1 and 2.

As the proportion of myopic consumers \( (\alpha \text{ and } \beta) \) increases, the profits of two retailers show different changing rules. In the dynamic pricing strategy, the higher the proportion of myopic consumers that the offline retailer has, the more profits it generates and the lower the profits of its competitor. From Table 1, we found that when \( \alpha \) changes from 0.1 to 0.5, the profits of offline retailers increases by about 8%, while the potential profits loss of online retailer remains as high as 19%. That is because offline retailers can set higher prices for myopic consumers. Since most myopic consumers have made purchases, fewer consumers have gone to online retailers, so the online retailer’s profits have fallen.

VI. THE EFFECTIVENESS OF PRICE MATCHING AND THE SIGNIFICANCE OF MANAGEMENT

This section verifies the above analysis by numerical simulation. We discuss the sensitivity analysis of parameters, including the proportion of two kinds of consumers, service perception factor and other parameters, and verify the effectiveness of price matching strategy. Through the comparison of profits, we can decide which pricing strategy is superior.

A. ANALYSIS OF PARAMETER INFLUENCE

1) IMPACT OF MYOPIC CONSUMER PROPORTION ON THE EQUILIBRIUM PROFITS

As mentioned in [2], about 50% of consumers tend to switch from offline to online retailers, so \( \alpha \) and \( \beta \) are in the range of \([0.1, 0.5]\). Lin et al. [37] use a research model based on consumer value theory, they investigate the determinants of consumer post-purchase price comparison searches in the context of online price-matching guarantees (PMGs). The data they collected from about 300 eligible respondents will be tested according to the proposed research model. In the next numerical analysis, we set the market size (i.e. the number of consumers) to 300. As the fraction of consumers who are myopic \( (\alpha) \) increase, the offline retailer will reduce the selling price to occupy more market share. As a result, the demand of the offline retailer increases while that of the online retailer decreases slightly. The decrease in the price and the increase in the demand contribute to an increase or a decrease in the profits of the offline retailer. Therefore, it is necessary to study the effect of the proportion of myopic consumers on the profits of retailers. Similarly, the impact of \( \beta \) on the profits of online retailer is worth analyzing. We vary the value of \( \alpha \) from 0.1 to 0.5, the value of \( \beta \) from 0.1 to 0.5, the value of \( \theta \) from 0.3 to 0.9, and the value of \( m \) from 0.4 to 0.8. The profits two retailers, as they change with \( \alpha \), \( \beta \), \( \theta \), and \( m \), are summarized in Table 1, 2, 3, and 4, respectively.

The following conclusions can be drawn with Table 1 and 2.

As we can see from

set higher prices for myopic consumers. Since most myopic consumers have made purchases, fewer consumers have gone to online retailers, so the online retailer’s profits have fallen.

We get the conclusions as follows: under heterogeneous consumer behavior, the proportion of two kinds of consumers is an important factor affecting retailers’ expected profits. Under the dynamic pricing, the retailer’s expected profits will benefit from the increase in the number of consumers who are myopic, and suffer from the increase in the number of consumers transferred to competitors. The offline retailers should encourage consumers to experience as much as possible under dynamic pricing.

The offline retailers implement the RO match in order to reduce the loss of profits brought by strategic consumers. Therefore, as the proportion of myopic consumers of the offline retailer increases, its profits will decrease, and the effect of the RO match is less obvious. The rate of profit decrease of offline retailer (about 77%, Table 1) is higher than the rate of profit increase of online retailer (about 61%, Table 1). The same conclusion can be drawn from the data in Table 2. It is not feasible for online retailers to enforce the OR match. In reality, the prices of online retailers are also lower than offline retailers. Offline retailers can attract part of online retailers by lowering prices, but online retailers will only lose their original loyal consumers by raising prices.

It is essential to note that the table in which the profit is 0 means that the retailer’s implementation of price matching is invalid, because the online retailer does not provide the service and if the price is too high, no consumer will buy it. Even if some consumers are used to browsing information online first, once they find that the online price is higher, they will switch to offline retailers to purchase.

2) IMPACT OF SERVICE PERCEPTION FACTOR ON THE EQUILIBRIUM PROFITS

As discussed in [32], \( \theta \) is essential for profits of two retailers. When \( \theta \) is sufficiently high, the offline retailer will price the product considering the presence of the heterogeneous consumers, leading to changes in the retailer’s profits.

Table 3 shows that providing enough service is not always a good thing for offline retailers in the RO match strategy. On the premise of being able to reflect the differences with online retailers, offline retailers can reduce their services and maintain the service perception factor at a higher level to achieve the goal of reducing costs. As we can see from

### Table 1: The equilibrium profits with change of \( \alpha \).

| \( \alpha \) | \( \pi_D^o \) | \( \pi_D^r \) | \( \pi_{RO}^o \) | \( \pi_{RO}^r \) | \( \pi_{OR}^o \) | \( \pi_{OR}^r \) |
|-------|--------|--------|--------|--------|--------|--------|
| 0.10  | 36.98  | 32.51  | 246.47 | 12.28  | 98.13  |         |
| 0.20  | 37.80  | 31.31  | 124.00 | 15.08  | 103.50 |         |
| 0.30  | 38.58  | 29.87  | 84.55  | 17.32  | 107.68 |         |
| 0.40  | 39.29  | 28.09  | 65.81  | 18.80  | 105.93 |         |
| 0.50  | 39.98  | 26.28  | 55.97  | 19.82  |        | 0       |

### Table 2: The equilibrium profits with change of \( \beta \).

| \( \beta \) | \( \pi_D^o \) | \( \pi_D^r \) | \( \pi_{RO}^o \) | \( \pi_{RO}^r \) | \( \pi_{OR}^o \) | \( \pi_{OR}^r \) |
|-------|--------|--------|--------|--------|--------|--------|
| 0.10  | 49.55  | 19.34  | 66.16  | 17.41  | 0      |         |
| 0.20  | 47.46  | 20.97  | 63.72  | 17.99  | 0      |         |
| 0.30  | 45.14  | 22.66  | 60.81  | 18.57  | 0      |         |
| 0.40  | 42.60  | 24.41  | 58.40  | 19.15  | 0      |         |
| 0.50  | 39.98  | 26.31  | 55.64  | 19.78  | 0      |         |
TABLE 3. The equilibrium profits with change of $\theta$. 

| $\theta$ | $\pi^D_r$ | $\pi^D_o$ | $\pi^{RO}_r$ | $\pi^{RO}_o$ | $\pi^{OR}_r$ | $\pi^{OR}_o$ |
|----------|-----------|-----------|-------------|-------------|-------------|-------------|
| 0.30     | 41.05     | 16.04     | 48.08       | 13.58       | 0           |             |
| 0.40     | 40.77     | 20.07     | 50.75       | 16.69       | 0           |             |
| 0.50     | 39.77     | 26.29     | 55.46       | 19.77       | 0           |             |
| 0.60     | 37.69     | 21.20     | 65.03       | 22.02       | 0           |             |
| 0.70     | 34.02     | 17.46     | 85.89       | 20.69       | 5.84        |             |
| 0.71     | 33.48     | 17.30     | 89.50       | 19.97       | 7.46        |             |
| 0.72     | 32.96     | 17.13     | 93.43       | 19.13       | 8.98        |             |
| 0.73     | 32.39     | 16.94     | 97.89       | 18.13       | 10.32       |             |
| 0.74     | 31.81     | 16.72     | 102.92      | 16.85       | 11.51       |             |
| 0.75     | 31.17     | 16.48     | 108.10      | 15.34       | 12.57       |             |
| 0.80     | 27.69     | 14.93     | 153.24      | 0.65        | 14.73       |             |
| 0.85     | 22.93     | 12.67     | 255.73      | 0           | 9.98        |             |
| 0.90     | 16.99     | 9.63      | 557.48      | 0           | 0           |             |

Table 3, where $\theta \in (0.6, 0.74)$, the profits of both retailers is always higher than that under dynamic pricing, which can achieve a win-win situation.

Our conclusions can also provide a better explanation for the pricing strategies of retailers under heterogeneous consumer behavior. This confirms the conclusion that offline retailers take the initiative to implement the price matching strategy, supplemented by price reduction, to achieve the goal of increasing the profits of two retailers.

When the service perception factor is large enough, the RO match is more effective for offline retailers, while online retailers are reluctant to embrace it, because it means offline retailers are taking over most of the market. This suggests that facing the impact of the online e-commerce, offline retailers should still as far as possible to retain consumers by service or free experience. In reality, it can also be seen that many offline retailers take a variety of activities to attract consumers to their stores.

3) IMPACT OF CONSUMER ARRIVAL RATE OF OFFLINE RETAILERS ON THE EQUILIBRIUM PROFITS

In this subsection, we will analyze the impact of the initial number of people arriving at the offline retailer on profits. The more consumers initially arrive at the offline retailer, the more consumers will wait to buy at a lower price or switch to online retailer, so the profits of offline retailer declines while that of online retailer increases. However, under different pricing strategies, the trend of profit changes is different, as shown in Table 4.

Table 4 shows that under the dynamic pricing strategy, the more consumers arrive at the offline retailer in the first period, the more service the offline retailer will provide. Meanwhile, many consumers will go to the online retailer to buy after the offline experience, so the profits of the offline retailer will decline. When $m$ changes from 0.4 to 0.8, the potential profits loss of offline retailer remains as high as about 44%, while the potential profits of online retailer increases by about 19%. Under the RO match, the initial arrival rate of consumers begins to show a positive correlation with the earnings of offline retailers. The value of $m$ increased from 0.4 to 0.8, and the profits of offline retailer increased by about 65%. This could also explain the fact that in reality, many offline retailers lower their prices to match online retailers, increasing profits by attracting more initial consumers.

4) EFFECTIVENESS OF PRICE MATCHING STRATEGY

In order to clearly reflect the effectiveness of the two price matching strategy, we define

\[
\Delta \pi^{RO}_r = \pi^{RO}_r(mN, (1-m)N) - \pi^{D}_r(mN, (1-m)N),
\]

\[
\Delta \pi^{RO}_o = \pi^{RO}_o(mN, (1-m)N) - \pi^{D}_o(mN, (1-m)N),
\]

\[
\Delta \pi^{OR}_r = \pi^{OR}_r(mN, (1-m)N) - \pi^{D}_r(mN, (1-m)N),
\]

\[
\Delta \pi^{OR}_o = \pi^{OR}_o(mN, (1-m)N) - \pi^{D}_o(mN, (1-m)N).
\]

In order to analyze the impact of $\theta$ on incremental profits, we now use two intuitive and clear figures to illustrate the effects of two matching methods. Among them, Figure 1 shows that the RO match strategy is effective, and Figure 2 indicates that the OR match strategy is not enough effective.
In reality, many offline retailers choose to implement price matching strategy. Target, the US discount retail giant, made a high-profile foray into Canada in 2012 and unveiled a new “price matching” strategy in 2014. One of the highlights is the range of matching was extended to their online stores, including Bestbuy.ca, Futureshop.ca, ToysRUs.ca, CanadianTire.ca and Amazon.ca. As long as consumers use their phones to find deals on these stores and show them to shop assistants, Target promised to return the price difference. Price matching strategies help retailers retain loyal consumers. The strategy of Target comes on the eve of a holiday season. Analysts expect a solid holiday season – consulting Firm AlixPartners is predicting holiday retail sales will rise 2.8% to 3.4%. Price matching strategy is adopted by many retailers in reality. According to a poll by BDO USA (2015), price matching was the second most successful promotional strategy for US retailers (free shipping was number one). And PMGs are increasingly being used. For instance, in 2014, an estimated 10% of retailers adopted PMGs, growing to 18% just one year later [38].

The drawback is that we do not take into account the cost to shopping. Specifically, when the consumer’s shopping cost with the online retailer is moderate, as shown in Figure 1, the offline retailer is likely to implement the RO match, since losing a large pool of strategic consumers will be very costly for the offline retailer. When the shopping cost at the online retailer is high, the offline retailer does not worry about heterogeneous consumers, as they have no incentive to experience the products and services of offline retailers for free. The RO match helps to mitigate the switching behavior of the strategic consumers when the cost of shopping on line is moderate.

VII. CONCLUSION

Heterogeneous consumer behavior often occurs in the actual sales activities of the products. Retailers must also consider all possible behaviors——buy immediately, leave, or move to a competitor until the second period comes. In such circumstances, this paper have studies the optimal equilibrium of retailers, and further analyzes the effectiveness of dynamic pricing and two price matching strategies. Some earlier study suggests that the retailer suffers from the price matching.

In stark contrast, our analysis indicates that price matching can reinstate the superiority of the offline retailers over the online retailers. This is one of the salient management significance of our study.

Moreover, our research provides new insights for management facing heterogeneous consumer behavior. Intuitively, if consumers switch to online retailers, it will harm the profits of offline retailers. However, we come to the opposite conclusion. Retailers can take advantage of consumers’ desire to be free-riders and strategically choose to set higher prices to increase their profits. Strategic behavior has a positive impact on retailers’ profits, which is not true in all cases. If the proportion of myopic consumers is very high, the service provider, that is to say, the offline retailer must find a way to reduce consumer strategic behavior. Retailers can reduce the number of consumers who just look and do not purchase by restricting certain goods to bricks-and-mortar stores. Then, products that are only available in offline retailers will have a radiation effect, boosting consumers’ propensity to buy other goods. Of course, retailers can also create a more engaged shopping experience for some of their offline retailers, typically in upmarket areas such as downtown and high-traffic locations. Retailers enhance the interaction and connection between consumers and brands by holding promotional events, product displays and new product launches. When we go shopping in large shopping malls, we often find offline retailers that attract consumers through such activities.

The information advantages of online retailers make them become the first choice of consumers, but they could not display or try products like offline retailers. If it provides consumers with free experience services, it will produce a large logistics cost. Therefore, it is better for offline retailers to attract more consumers with the advantage of low price, rather than actively match the price of offline retailers. The present results also shows that when consumer’s shopping cost is high, the online retailer should not implement the OR match strategy. When online retailer implement price matching, it is difficult to reflect the advantages of information and low price.

Besides, retailers are advised to rethink pricing, thus we discussed the effectiveness of price matching. Under the assumption that consumers in the market has heterogeneous behaviors, when the service perception factor of consumers is large or the proportion of myopic consumers of offline retailers is small, the implementation of the RO match by the offline retailer can increase the profits of both retailers. First, price-matching diminishes firms’ incentives to lower prices to attract consumers who have no search costs. Second, for consumers with positive search costs, price-matching lowers the marginal benefit of search, inducing them to accept higher prices. In 2017, offline retailers specifically introduced the concept of “online and offline price comparison” in response to the online price war. On the day of Double Eleven in China, 33 offline retailers in Rainbow’s south region placed price comparison boards next to more than 600 counter products, writing down the offline prices and the prices of the official.
flagship retailers online at the same time, ensuring that the offline prices are the same or better than online prices.

In general, the offline retailer can set higher prices or choose whether to match the online retailer’s prices. For the online retailer, when the offline retailer implements dynamic pricing, it is not recommended that online retailers actively implement the OR match, otherwise the profits will go down. For example, online travel booking website Expedia.com promises to refund the price difference between the price of the same product, as well as an additional $50 travel coupon, if the consumer finds the price of the same product is lower within 24 hours after booking hotels, air tickets, car rental, etc. Nevertheless, online retailers offering PMGs face lots of challenges as the popularity of mobile technologies (e.g., everyone owns a tablet and smartphone). Consumers can compare prices online in real time. BestBuy’s strategy is to provide low price guarantee both online and offline: when consumers find lower prices in other offline stores or e-commerce websites, they can reflect to BestBuy’s customer service. Once verified, BestBuy will adjust its price. At the same time, within two weeks after the purchase of BestBuy, if the price of this product drops, consumers can directly come to the offline store to make up the difference. Through these two “low price strategies”, consumers do not have to turn to other competitors because of the price, and even effectively hit e-commerce enterprises like Amazon. Briefly speaking, for retailers, some consumers are allowed to switch to other retailers or competitors. But the best bet is to build a stable consumer base so that loyal consumers will not switch.

The present research findings show that when providing service is expensive and consumer’s shopping cost is also high, the offline retailer should not implement price matching. Even for products with high digital attributes, for which online shopping can reduce search time and transportation costs, consumers may have a high or low online shopping cost, depending on such variables as delivery time or trust in online transactions and shipping procedures, and the offline retailer should not implement a price matching strategy [39]–[40]. The conclusion of this paper is different. When the service perception factor of consumers is large or the proportion of myopic consumers of offline retailers is small, the offline retailer needs to implement a price matching strategy. Therefore, the offline retailer should carefully evaluate the consumers’ switching purchase willingness before deciding whether or not to implement a price matching strategy.

It should be pointed out that, first of all, how online and offline retailers identify heterogeneous consumers’ purchase behavior is still a big problem. Second, many offline retailers have begun to implement “online and offline” sales pattern (e.g., BestBuy). In our paper, when studying the pricing decisions of the two retailers, they are separated and analyzed independently. Researchers can study the online+offline situation of the same brand retailer, which can provide some reference for BestBuy’s pricing practices. Third, the case of two retailers offering heterogeneous products might be more striking. In the future, the research content of this paper can be expanded and investigated, such as constructing a game model of multi-period pricing decision under the competition of multiple retailers.

**APPENDIX**

**A. THE PROOF OF THEOREM 1**

The profit of the two retailers can be obtained from (1) and (2). The two retailers’ first-order condition for profits maximization are \( \partial \pi^o_1(1,0)/\partial p^o_1 = 0 \) and \( \partial \pi^o_2(0,1)/\partial p^o_2 = 0 \), we can solve \( p^o_1 \) and \( p^o_2 \) jointly. Moreover, the second derivative of profit with respect to price is less than zero. As a result, the profit of the offline retailer is maximized at \( p^o_1 = \frac{\theta-1}{\theta} \cdot \frac{A(\alpha,\theta)+C(\alpha,\theta)}{8B(\alpha,\theta)} + \frac{\theta-1}{\theta} \cdot \frac{1}{\Sigma(\alpha,\theta)} \), and the maximized profit is given by

\[
\pi^o_1(1,0) = \frac{1}{64B(\alpha,\theta)^2(\theta-1)(\alpha\theta-1)} \times ((A + C(\alpha,\theta))\alpha + 8B(\alpha,\theta) - A(\alpha,\theta)) - C(\alpha,\theta) - 8B(\alpha,\theta)
\]

The profit of the online retailer is maximized at \( p^o_2 = \frac{A(\alpha,\theta)+C(\alpha,\theta)}{4B(\alpha,\theta)} \), and the maximized profit is given by

\[
\pi^o_2(0,1) = \frac{1}{128\theta(\theta-1)(\alpha\theta-1)B(\alpha,\theta)^2} \times (\alpha(\alpha(\alpha,\theta))\alpha + 8B(\alpha,\theta) - A(\alpha,\theta)) - C(\alpha,\theta) - 4B(\alpha,\theta)
\]

**B. THE PROOF OF THEOREM 2**

The profit of the two retailers can be obtained from (7) and (8). The two retailers’ first-order condition for profits maximization are \( \partial \pi^o_1(0,1)/\partial p^o_1 = 0 \) and \( \partial \pi^o_1(1,0)/\partial p^o_1 = 0 \), we can solve \( p^o_1 \) and \( p^o_2 \) jointly. Moreover, the second derivative of profit with respect to price is less than zero. As a result, the profit of the offline retailer is maximized at \( p^o_1 = \frac{\theta(1-\theta)}{\theta+\theta-2\beta} \cdot \frac{C(\beta,\theta)}{8E(\beta,\theta)} + \frac{\theta(1-\theta)}{\theta+\theta-2\beta} \cdot C(\beta,\theta) \), and the maximized profit is given by

\[
\pi^o_1(1,0) = \frac{1}{64(\theta-1)(2\theta^2 - \beta - \theta)E(\beta,\theta)^2} \times \phi((4E(\beta,\theta) + D(\beta,\theta)) - F(\beta,\theta)) - F(\beta,\theta) - 4E(\beta,\theta)D(\beta,\theta) + F(\beta,\theta))^2
\]

The profit of the online retailer is maximized at \( p^o_2 = \frac{D(\beta,\theta)}{4E(\beta,\theta)} \), and the maximized profit is given by

\[
\pi^o_2(0,1) = \frac{1}{128(\theta-1)(2\theta^2 - \beta - \theta)E(\beta,\theta)^2} \times (\beta-1)(D(\beta,\theta) - F(\beta,\theta) - 3F(\beta,\theta) - 20E(\beta,\theta))\beta + 8E(\beta,\theta) + F(\beta,\theta) - 2(\beta(\beta,\theta) - F(\beta,\theta) - 4e(\beta,\theta))\)).
\]
C. THE PROOF OF THEOREM 3

\[ \pi^D_r(mN, (1 - m)N) = \max_{p^D_{r1}} \sum_{n_{r1}=0}^{mN} P_{mN,n_{r1}} n_{r1} p^D_{r1} + \max_{p^D_{r2}} \sum_{n_{r2}=0}^{(1-m)N} P_{(1-m)N,n_{r2}} \]

\[ \times ((1 - m)N - n_{r2}) p^D_{r2} \left( 1 - F\left(\frac{p^D_{r1} - P_{r2}}{\theta}\right) \right) \]

\[ = \max_{p^D_{r1}} \sum_{n_{r1}=0}^{mN} n_{r1} \cdot \frac{mN!}{n_{r1}!(mN - n_{r1})!} \]

\[ \times \left[ 1 - \left( (1 - \alpha) \left( 1 - F\left(\frac{p^D_{r1} - P_{r2}}{\theta}\right) \right) \right) \right]^{mN-n_{r1}} \]

\[ + \alpha \left( 1 - F\left(\frac{p^D_{r1}}{\theta}\right) \right) \right]^{(1-m)N-n_{r2}} \]

\[ \cdot \left[ 1 - \left( (1 - \beta) \left( 1 - F\left(\frac{p^D_{r2} - P_{r2}}{\theta}\right) \right) \right) \right]^{n_{r1}} \]

\[ + \max_{p^D_{r2}} \left( 1 - F\left(\frac{p^D_{r2}}{\theta}\right) \right) \sum_{n_{r2}=0}^{(1-m)N - n_{r2}} \]

\[ \cdot \left[ \frac{mN\pi^D_{r1}(1, 0) + (1 - m)N\pi^D_{r2}(0, 1)}{\theta} \right] \]

where the above equality follows by the induction step; the last one follows (5) and (6).

D. THE PROOF OF THEOREM 4

The profit of the two retailers can be obtained from (15). The two retailers’ first-order condition for profits maximization are \( \partial \pi^D_{r1}(1, 0)/\partial p^D_{r1} = 0 \) and \( \partial \pi^D_{r2}(0, 1)/\partial p^D_{r2} = 0 \), we can solve \( p^D_{r1} \) and \( p^D_{r2} \) jointly. As a result, the profit of the offline retailer is maximized at \( p^D_{r1} = \frac{1}{2} \) + \( (1-\alpha)G(a, \theta)+H(a, \theta)) \), and the profit of the online retailer is maximized at \( p^D_{r2} = \frac{G(a, \theta)+H(a, \theta)}{4a+2} \). Since offline retailers match online retailers, therefore \( p^D_{r2} = \frac{G(a, \theta)+H(a, \theta)}{4a+2} \).

E. THE PROOF OF THEOREM 5

\[ \pi^D_{ro}(mN, (1 - m)N) = \max_{p^D_{r1}} \sum_{n_{r1}=0}^{mN} P_{mN,n_{r1}} n_{r1} p^D_{r1} + \max_{p^D_{r2}} \sum_{n_{r2}=0}^{(1-m)N} P_{(1-m)N,n_{r2}} \]

\[ \times ((1 - m)N - n_{r2}) p^D_{r2} \left( 1 - F\left(\frac{p^D_{r1} - P_{r2}}{\theta}\right) \right) \]

\[ = \max_{p^D_{r1}} \sum_{n_{r1}=0}^{mN} n_{r1} \cdot \frac{mN!}{n_{r1}!(mN - n_{r1})!} \]

\[ \times \left[ 1 - \left( (1 - \alpha) \left( 1 - F\left(\frac{p^D_{r1} - P_{r2}}{\theta}\right) \right) \right) \right]^{mN-n_{r1}} \]

\[ + \alpha \left( 1 - F\left(\frac{p^D_{r1}}{\theta}\right) \right) \right]^{(1-m)N-n_{r2}} \]

\[ \cdot \left[ 1 - \left( (1 - \beta) \left( 1 - F\left(\frac{p^D_{r2} - P_{r2}}{\theta}\right) \right) \right) \right]^{n_{r1}} \]

\[ + \max_{p^D_{r2}} \left( 1 - F\left(\frac{p^D_{r2}}{\theta}\right) \right) \sum_{n_{r2}=0}^{(1-m)N - n_{r2}} \]

\[ \cdot \left[ \frac{mN\pi^D_{r1}(1, 0) + (1 - m)N\pi^D_{r2}(0, 1)}{\theta} \right] \]

\[ = mN\pi^D_{r1}(1, 0) + (1 - m)N\pi^D_{r2}(0, 1) \]
where the above equality follows by the induction step; the last one follows (19) and (21).

F. THE PROOF OF THEOREM 6
The profit of the two retailers can be obtained from (25) and (26). The two retailers’ first-order condition for profits maximization are \( \partial \pi_{r1}^{OR}/(1, 0)/\partial p_{r1}^{OR} = 0 \) and \( \partial \pi_{r2}^{OR}/(0, 1)/\partial p_{r2}^{OR} = 0 \), we can solve \( p_{r1}^{OR} \) and \( p_{r2}^{OR} \) jointly.

As a result, the profit of the offline retailer is maximized at \( p_{r1}^{OR} = \frac{K(\alpha(\theta) + 1)}{SM(\alpha, \theta)} \), and the profit of the online retailer is maximized at \( p_{r2}^{OR} = \frac{4 - 2\alpha\theta - 2\alpha}{1 - \alpha} \cdot \frac{K(\alpha(\theta) + 1)}{SM(\alpha, \theta)} + \frac{\theta - 1}{1 - \alpha} \). The profit of the online retailer can be obtained from (25). The profit of the online retailer is maximized at \( \partial \pi_{r1}^{OR}/(1, 0)/\partial p_{r1}^{OR} = 0 \). The profit of the online retailer is maximized at \( p_{r1}^{OR} = \frac{4 - 2\alpha\theta - 2\alpha}{1 - \alpha} \cdot \frac{K(\alpha(\theta) + 1)}{SM(\alpha, \theta)} + \frac{\theta - 1}{1 - \alpha} \cdot \frac{(1 - \beta)}{1 - \theta} \). As for retailers’ profits, Equation (28) is substituted into (25) and (26) to get (29)-(32).

G. THE PROOF OF THEOREM 7
\[
\pi_r^{OR}(mN,(1-m)N) = \max_{p_{r1}^{OR}} \sum_{n_{r1}=0}^{mN} p_{r1}^{OR} m_{N,n_{r1}} p_{r1}^{OR} + \max_{p_{r2}^{OR}} \sum_{n_{r2}=0}^{(1-m)N} p_{r2}^{OR} (1-m)N,n_{r2} \times ((1-m)N - n_{r1}) p_{r2}^{OR}(1 - F(p_{r2}^{OR}/\theta)) \times \left[ 1 - \left(1 - \alpha\right) \left(1 - F(p_{r1}^{OR} - p_{r2}^{OR})/1 - \theta\right) \right]^{mN - n_{r1}} + \alpha \left(1 - F(p_{r1}^{OR}/\theta)\right)^{n_{r1}} + \max_{p_{r2}^{OR}} p_{r2}^{OR} \left(1 - F(p_{r2}^{OR}/\theta)\right) \sum_{n_{r2}=0}^{(1-m)N} ((1-m)N - n_{r2}) \times \frac{1 - \left(1 - \alpha\right) \left(1 - F(p_{r1}^{OR} - p_{r2}^{OR})/1 - \theta\right)}{1 - \beta} \left(1 - F(p_{r2}^{OR} - p_{r1}^{OR})/1 - \theta\right) \right]^{n_{r1}} \times \left[ 1 - \left(1 - (1 - \beta) \left(1 - F(p_{r2}^{OR} - p_{r1}^{OR})/1 - \theta\right) \right]^{n_{r1}} \times \max_{p_{r1}^{OR}} mN p_{r1}^{OR} \times \left[ 1 - \alpha\right] \left(1 - F(p_{r1}^{OR} - p_{r2}^{OR})/1 - \theta\right) \right]
\]

where the above equality follows by the induction step; the last one follows (25) and (26).

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