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Effects of BOPS implementation under market competition and decision timing in omnichannel retailing

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ABSTRACT

One of the most significant fulfillment paradigms is the buy online and pick-up-in-store (BOPS) in omnichannel retailing. However, BOPS incurs many new operational challenges in the presence of competition, like competitive intensity and decision-making timing. To mitigate these problems, a multi-stage, non-cooperative duopoly game is constructed to investigate the competitive implications of introducing a BOPS strategy. First, we consider the situation when competing retailers simultaneously make BOPS decisions. Our results examine how heterogeneous customers choose optimal purchase decisions to maximize their utility and identify the mechanisms of three major effects (i.e., channel migration effect, price self-compensation effect, and limited market share effect). Meanwhile, we analyze when the intensity of competition is strong, intermediate, and weak respectively, the equilibrium strategy of different-type retailers is determined by which configuration. After that, with consideration of total consumer surplus, we shed light on how competing retailers obtain win–win configurations, i.e., both competing retailers and customers are better off, after deploying the BOPS. Subsequently, the investigation extends to broader cases with sequential decisions. Contrary to the common view that second-mover superiority, there exists first-mover superiority in deploying the BOPS. Finally, numerical examples are provided to analyze the impact of cross-selling benefits, fixed cost of BOPS, heterogeneous customer behavior, BOPS convenience, operation cost and competitive intensity on the optimal profit. Our finding was compared with previous studies to provide a novel way to design the BOPS for responding to competitors to maximize customer-oriented profits.

1. Introduction

With the growing popularity of the online-merge-offline model, many retailers blindly add new online or offline channels, resulting in difficult-to-achieve complementarity of online and offline benefits (Ryu et al., 2019). In today's industry and academia, how to carry out in-depth integration of channels to boost sales and customer satisfaction is a popular issue (Cai & Lo, 2020; Caro et al., 2020). The prevalence of omnichannel strategy has transformed the customer interactions model and provided a seamless shopping experience across all accessible channels (Bayram & Cesaret, 2021; Harsha et al., 2019; Jin et al., 2018; Mou, 2022; Nageswaran et al., 2020). In such an omnichannel retailing context, many retailers (e.g., Zara, Walmart, Suning, H&M, etc) have quickly melted into the new retail paradigm of omnichannel to optimize the customer's shopping experience and maximize order fulfillment flexibility (Gao et al., 2022; Hu et al., 2022).

One of the most significant fulfillment paradigms is the BOPS strategy which allows customers to purchase online but visit a nearby physical store to pick them up within hours (Kim et al., 2022). The benefit of this fulfillment paradigm for retailers includes faster delivery, higher store traffic, and generated additional cross-selling profits (Gallino & Moreno, 2014; Jin et al., 2018). And its benefit for customers includes instant gratification, additional shopping assurance, and the convenience of hassle-free shopping (Lin et al., 2021). In 2019, in order to attract customers during the " Double-11" Shopping Festival in China, UNIQLO deployed the BOPS and achieved the fastest sales volume of 1 billion in history. Hence, BOPS has become a powerful competitive "weapon" in the retail market.

Meanwhile, 80% of omnichannel retailers have implemented BOPS (Total Retail & Orckestra, 2020)[1]. Additionally, BOPS is also a way for retailers to touch new customers, which can generate additional transactions. According to UPS research, 45% of the customers who choose to

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[1] Total Retail, & Orckestra (2020). 2020 Top 100 omnichannel retailers. https://mytotalretail.tradepub.com/free/w_defa618/?p=w_defa618.

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pick up at the store will add new orders when they pick up at the store (UPS, 2015).

The sheer explosion of BOPS strategy has attracted widespread attention from the industry and academia. However, most literatures focus on the BOPS operation decision of retailers from the perspective of oligopoly or single entity, ignoring the competitive factors prevalent in retail practice (Akturk & Ketzenberg, 2022). In practice companies seldom sell in a monopoly market, they often face competition from rivals (Feng & Zhang, 2017). And competing retailers may adopt consistent or inconsistent channel strategies and decision-making sequence changes. For instance, Kohl's and Walmart, competitors in the same category, significantly increased their sales by implementing BOPS (Li et al., 2022). Additionally, competition between an established retailer and a new entrant is quite common. KFC took the lead in adopting BOPS channel, McDonald's also provided the BOPS channel (Wang et al., 2020). Based on this retail practice, retailers are faced with the issue of whether to deploy BOPS in the context of competition, and the optimal strategy of old retailers and new entrants to deal with the competition is a key issue that needs to be solved urgently in the BOPS model.

Furthermore, the deployment of BOPS in a competitive environment is affected by heterogeneous customer behavior, BOPS convenience, and operating costs. Specifically, the BOPS has triggered consumers to interact with all available channels, prompting consumers to show heterogeneous preferences for channels. These results also coincide with practice. Gao et al. (2022) proposed that some consumers may consider the physical store too far away and choose online purchase, while some may be more impatient to wait for online delivery and choose offline purchase. However, it ignores that the degree of market competition affects customers' preference for brands. Therefore, it is necessary to consider these characteristics of heterogeneous consumers in the operation decisions of BOPS. On the other hand, factors such as market competition often force retailers to improve the convenience of BOPS, but they also need consider the actual operating costs of BOPS. Thus, convenience and operating costs of BOPS are important factors that competing retailers must consider, both for the retailer's decision and the consumer's purchasing decision. Motivated by these observations, the emergence of several questions is worthy of exploration.

(i) Whether BOPS channel should be deployed in a duopoly setting? Could competing retailers deploy consistent or inconsistent BOPS strategy?
(ii) How do BOPS operating costs, consumer heterogeneity, and market competition intensity affect retailers' price decisions? Whether there exists a win–win configuration that benefits both consumers and competing retailers?
(iii) How the decision timing of retailers affects the equilibrium results?

To mitigate the above problems, we construct a multi-stage, non-cooperative game framework to investigate the competitive implications of introducing a BOPS strategy in an omnichannel retailing context. The competing retailers are likely to offer a BOPS strategy to sell differentiated but substitutable products. First, we consider the situation that competing retailers (Retailer A and Retailer B) simultaneously decide on whether to adopt the BOPS strategy. Then, four possible scenarios are given rise to discuss and derive the Nash equilibrium results in the duopoly market (i.e., No-No strategy, BOPS-No BOPS strategy, No BOPS-BOPS strategy, BOPS-BOPS strategy). After that, we explore the existence of a win–win situation between two competing retailers and consumers under all possible scenarios. Subsequently, the analysis also covers the scenario in which the competing retailers sequentially make BOPS decisions. Finally, numerical examples are provided to analyze the impact of various parameters on optimal profit, aiming to provide some managerial insights.

To the best of our knowledge, this research is the first to study simultaneous vs. sequential omnichannel retail operations with BOPS under duopoly competition, which broadens the research perspective of omnichannel retail operations than previous studies. We explore competition intensity and decision-making timing on equilibrium decisions regarding the implementation of the BOPS. The equilibrium results presented in this research make us shed light on what conditions and when omnichannel retailers should adopt the BOPS strategy across a competitive setting, and help retailers implement the best response policy to their opponents achieving maximum profits and customer satisfaction. We obtain some managerial insights by examining the impacts of various parameters on optimal profit across different decision-making timings. Thus, our study will be worthy of the development of the fulfillment paradigm in the era of omnichannel retailing.

The rest of this study is structured as follows. Section 2 reviews the literature and identifies the research gap. Section 3 details the main model, assumptions, and the sequence of events in the duopoly game. Section 4 discusses a duopoly model with simultaneous decisions, and derives the equilibrium and profitability results. Section 5 presents extension models with the sequential decision. Section 6 describes numerical examples and managerial insights. Section 7 concludes this study and discuss future research prospects.

2. Literature review

2.1. Omnichannel retailing with BOPS

The development of omnichannel strategy in retail practice has attracted extensive academic attention, mainly focusing on showrooming (Bell et al. 2018, 2020; Gao & Su, 2017b; Li et al., 2020), buy online and return in the physical store (He et al., 2020; Jin et al., 2020; Mandal et al., 2021; Nageswaran et al., 2020), ship-from-store (Bayram & Cesaret, 2021; He et al., 2021; Jiu, 2022) and BOPS (Gallino & Moreno, 2014; Gao & Su, 2017a; Gao et al., 2022; Hu et al., 2022; Jin et al., 2018; Kong et al., 2020; Lin et al., 2021; MacCarthy et al., 2019; Shi et al., 2018). Notably, as the most popular used omnichannel fulfillment paradigm in practice, a great deal of scholars has focused on the issues of BOPS in omnichannel operation management. Gallino and Moreno (2014) empirically investigated the consumers' shopping decisions under the deployment of BOPS. The results show that BOPS has the functions of cross-selling and channel-shift, and can stimulate consumers' impulse shopping behavior. Gao and Su (2017a) constructed the rational expectation equilibrium model to explore the choice of purchasing channels for heterogeneous consumers, which identifies the information effect and convenience effect. Hu et al. (2022) further utilize rational expectation equilibrium to analyze the impact of BOPS on inventory decisions and customers' purchasing behavior. The result shows that the performance of BOPS depends on the online waiting cost and store visiting cost. Jin et al. (2018) demonstrated that the ROPS strategy has the advantages of unconditional cancellation of orders and price premium over the BOPS strategy. Shi et al. (2018) examined the ordering decision of retailers using BOPS strategy with pre-orders under the return situation, which suggests the BOPS with pre-orders is not necessarily beneficial to retailers. Kong et al. (2020) further find that the retailers may not always benefit from BOPS strategies under different pricing strategies, which depends on BOPS operation cost, customer hassle cost, and cross-selling benefit. MacCarthy et al. (2019) explored the best performance frontiers of BOPS strategy to solve the problem of uncertain inventory, and achieved the minimum picking rate under a target service level. Lin et al. (2021) find that the BOPS strategy can achieve a win–win outcome between manufacturers and retailers in terms of quality and price under certain conditions. Gao et al. (2022) examined how the BOPS strategy affects the number and size of retailers' stores from a new perspective. The above-mentioned studies focus on analyzing the impact of BOPS on price, inventory decision, and channel preference in a monopoly context. Different from this angle, in our study, we investigate the multi-factor competitive implications of

Table 1
Review of related literature.

Study	Omnichannel	decision-making timing	BOPS operating cost	Consumer heterogeneity	Cross-selling effect	competition
Gallino and Moreno (2014)	BOPS				√	
Gao and Su (2017a)	BOPS			√	√	
Shi et al. (2018)	BOPS			√		
Jin et al. (2018)	BOPS			√		
MacCarthy et al. (2019)	BOPS					
Li et al. (2020)	showrooming			√		
Jin et al. (2020)	BORP			√		
Nageswaran et al. (2020)	BORP			√		
He et al. (2020)	BORP			√		
Kong et al. (2020)	BOPS		√	√	√	
Wang et al. (2020)	BOPS		√	√	√	√
Mandal et al. (2021)	BORP/showrooming			√		
Lin et al. (2021)	BOPS			√		
Hu et al. (2022)	BOPS			√		
Gao et al. (2022)	BOPS/BORP showrooming			√		
Our research	BOPS	√	√	√	√	√

Table 2
The definition of notations.

Notation	Definition and comments
A, B	Subscript index of retailer A and retailer B, respectively. $g = A, B$
s, o, b	Subscript index of the offline channel, the online channel, and the BOPS channel, respectively
nn, bb, bn, nb	Superscript index of NN, BB, BN, and NB scenarios, respectively
$U_{g,s}$	The utility of consumers purchasing from the retailer's offline channel, $g = A, B$
$U_{g,o}$	The utility of consumers purchasing from the retailer's online channel, $g = A, B$
$U_{g,b}$	The utility of consumers purchasing from the retailer's BOPS channel, $g = A, B$
v	Each customer perceived value of the product
x	Customer brand preference, random variable, $x \in U[0, 1]$
m	Consumers' sensitivity of product differentiation, $m > 0$
h_s	The customer hassle cost in offline channel (covers the inconvenience of traveling to the store)
h_o	The customer hassle cost in online channel (covers inconvenience of online searching, the wait for deliveries)
h_b	The customer hassle cost in BOPS channel (covers both the online and offline hassle costs, $h_b = \lambda_s h_s + \lambda_o h_o$)
λ_s	The proportions of the offline hassle cost incurred in the BOPS channel, $\lambda_s \in (0, 1)$
λ_o	The proportions of the online hassle cost incurred in the BOPS channel, $\lambda_o \in (0, 1)$
α	The fraction of customers with low store hassle cost, $\alpha \in [0, 1]$
θ	The fraction of customers with low online hassle cost, $\theta \in [0, 1]$
c	Unit production cost in the offline channel
r	Unit cross-selling benefit from every customer who comes to the store
k	Unit operating cost in the BOPS channel
H	The online and offline hassle costs are sufficiently Large
p_g^j	The selling price of retailer g under j scenarios ($g = A, B, j = nn, bb, bn, nb$)
$D_{g,s}^j$	The demands of retailer g's offline channel under j scenarios ($g = A, B, j = nn, bb, bn, nb$)
$D_{g,b}^j$	The demands of retailer g's online channel under j scenarios ($g = A, B$, $j = nn, bb, bn, nb$)
$D_{g,b}^j$	The demands of retailer g's BOPS channel under j scenarios ($g = A, B, j = nn, bb, bn, nb$)
$\prod_g^j$	Profit of the retailer g under j scenarios ($g = A, B, j = nn, bb, bn, nb$)
F	The fixed cost of BOPS channel

introducing a BOPS strategy in a duopoly setting. Moreover, we explore the impact of decision-making timing on the deployment of BOPS to seek the best decision point. This is the first paper studying simultaneous vs. sequential omnichannel retail operations with BOPS under competition, and aims to address common phenomenon in retail practice nowadays.

2.2. Retail strategy in a duopoly

Another research stream of retail strategy in the duopoly market is closely related to our study. Boyaci and Gallego (2004) explored the equilibrium service strategies in uncoordinated, coordinated and hybrid competition scenarios. Sinha and Sarmah (2010) investigated the coordination and competition in the supply chain distribution system in which two suppliers compete to sell differentiated products through a common retailer. Kireyev et al. (2017) studied the implementation of a self-matching pricing strategy in different competitive scenarios, including monopoly, the duopoly of two competitive multi-channel retailers, and the mixed duopoly of multi-channel retailers and e-retailers. Feng and Zhang (2017) constructed a competitive newsvendor model to study the impact of strategic behavior on inventory decisions. Chen et al. (2020) developed a two-stage game model to explore how enterprises and e-retailers strategically adopt the two business models of reselling and agency selling business models in the competitive setting. Zhou et al. (2020) developed a multi-stage game model to characterize the bundling decision in a duopoly environment. Chen and Chen (2021) examined a market network model in which two firms compete for a market network customer through the sale of substitutable goods. The abovementioned studies have paid little attention to competition between omnichannel strategies, which is inconsistent with real practice. Harvard Business Review shows that the share of retailers offering BOPS jumped to 44% when the Covid-19 pandemic hit. Moreover, nearly 75% of people still want to using BOPS channel to purchase after the pandemic ends[22]. With increasing consumers demanding a seamless shopping experience, retailers aggressively adopted the BOPS strategy include Walmart, Suning, Uniqlo, Gap, Zara, McDonald's, and KFC, and many more. Consequently, competition among omnichannel retailers is common to observe. Nonetheless, there are two papers closely related to our research. Wang et al. (2020) developed the Stackelberg model to explored whether and when retailers should adopt the BOPS in a duopoly. This duopoly model setting ignores the timing of retailers' decisions. Decision timing is the choice of retailers between simultaneous decision and sequential decision (Wu et al., 2018). The simultaneous decision under which each retailer implement BOPS separately without knowing the decision of rivals, or the sequential decision under which established retailers make a decision first and the decision is revealed to the new entrants. The distinction between these two decision-making sequences reflects whether to being the first-mover retailers in a competitive market. We consider this feature to be more

[2] Ketzenberg, M., & Akturk, M. S. (2021). How "buy online, pick up in-store" Gives Retailers an Edge. Harvard Business Review (May 25). https://hbr.org/2021/05/how-buy-online-pick-up-in-store-gives-retailers-an-edge.

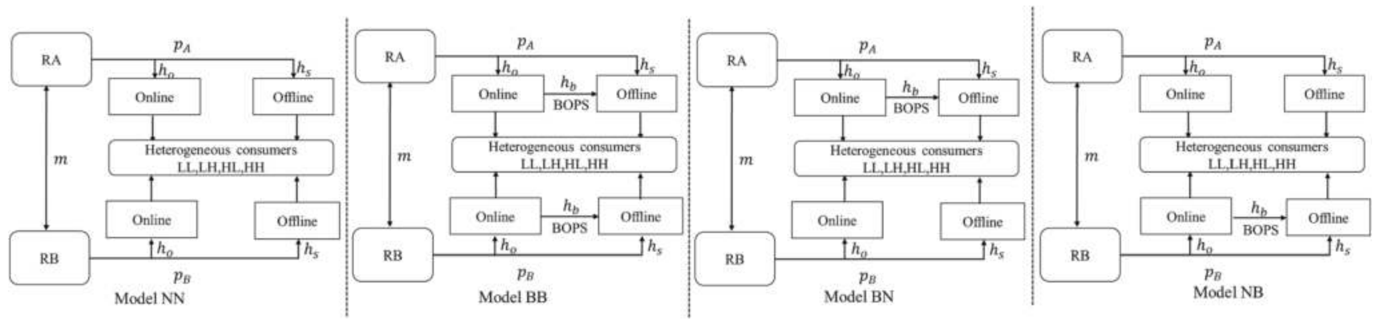


Fig. 1. Omnichannel strategy combination model under duopoly competition.

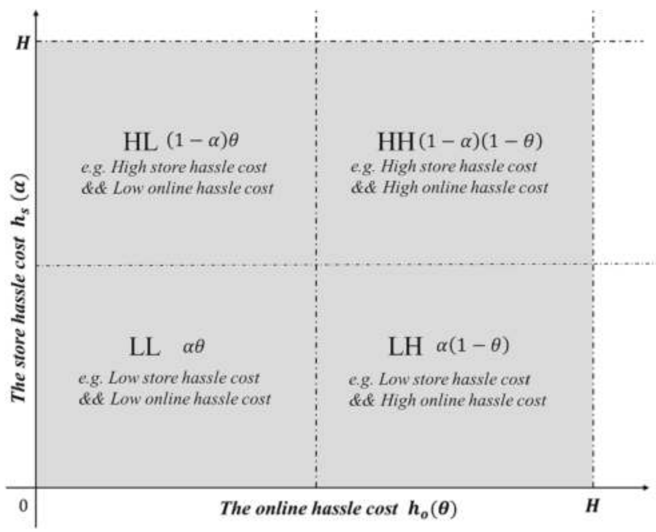


Fig. 2. Market segments for heterogenous customers.

in line with the retail practice. Gao and Su (2017a) examined the impact of the BOPS on store operations in monopoly setting. Our paper differs from these two studies in three folds. (i) In their model, the timing of decisions among competitors was not considered. We propose the duopoly model to explore the decision differences from simultaneous decision and sequential decision, which summarize some novel insights for operation management in practice. (ii) The operating cost incurred by BOPS is not considered, which is inconsistent with real practice. As retailers with BOPS have integrated information and transactions from all available channels and package products, resulting in additional costs. We integrate the BOPS operating cost to characterize equilibrium results, and shed light on what conditions can benefit retailers. (iii) They overlooked analyzing the win–win outcome after deploying the BOPS. Considering this angle in an omnichannel retailing is significant as the core goal of omnichannel is to provide customers with a seamless customer experience (Kim et al., 2022). Instead, we explore equilibrium configuration and identify the win–win and lose-lose intervals.

To highlight the differences between our study and the above-mentioned literature, we summarize the related literature and compare them in Table 1.

3. Model

The following notations are summarized to develop the mathematical models in Table 2.

3.1. Problem description

We construct the duopoly model in which competing omnichannel retailers (Retailer A and Retailer B) are likely to offer a BOPS option to purchase differentiated but substitutable products. For example, H&M and ZARA sell the same categories, but each has a dedicated design and brand, thereby highlighting channel competition. As a result, four strategies combination models can be derived, namely NN, BB, NB, and BN. The model NN represents neither retailer deploys the BOPS option, the model BB indicates that both retailers offer the BOPS strategy, and the model NB (BN) represents only one retailer offers the BOPS. Fig. 1 illustrates the omnichannel strategy combination model under duopoly competition. In line with Shao (2021), retailers set the same price for online and offline channel, which is consistent with industrial practice. However, different retailers have different selling prices, i.e., retailers A and B have selling prices of p_A and p_B, respectively.

When shopping in physical store, each customer will incur an offline hassle cost h_s. Similarly, when shopping online, each customer will incur store hassle cost h_o. When customers buy online and pickup in store, they incur the BOPS hassle cost h_b, which includes both online and offline hassle costs. Based on the difference between h_s and h_o, we assume that the market contains four consumer segments: LL-type (i.e., Low store hassle cost, Low offline hassle cost), LH-type (i.e., Low store hassle cost, High offline hassle cost), HL-type (i.e., High store hassle cost, Low offline hassle cost), and HH-type (i.e., High store hassle cost, High offline hassle cost). Besides, the parameter m indicates the degree of market competition. The specific assumptions are as follows.

3.2. Consumer heterogeneity

To make the model more consistent with retail practice, we characterize customer heterogeneity in terms of brand preference and consumer shopping behavior.

Brand preference: we use the Hotelling model to portray customers' brand preferences for retailers. It is assumed that competing retailers are located at both ends of a linear market, and customers are uniformly distributed between the linear markets. The misfit cost mx is incurred when purchasing from the retailer A. While purchasing from retailer B, they incur the misfit cost $m(1-x)$. Note that the parameter m measures consumers' sensitivity of product differentiation. While a higher value of m suggests that consumers have strong brand preferences and that there is less fierce competition, the lower of m shows a low degree of product differentiation and fierce market competition. This assumption is widely used in the operations management (e.g., Kireyev et al., 2017; Jin et al., 2020).

Consumer shopping behavior: In practice, some consumers may consider the physical store too far away and choose online purchase, while some may be more impatient to wait for online delivery and choose offline purchase (Gao & Su, 2017a). This phenomenon indicates that consumer shopping behaviors are varied in the store hassle cost h_s (i.e., the distance between physical store and customers) and the online hassle cost h_o (i.e., online searching and wait for shipment). Therefore, in line with Jin et al. (2020), we assume there are two types of consumers: low store hassle cost and high store hassle cost. The fraction of

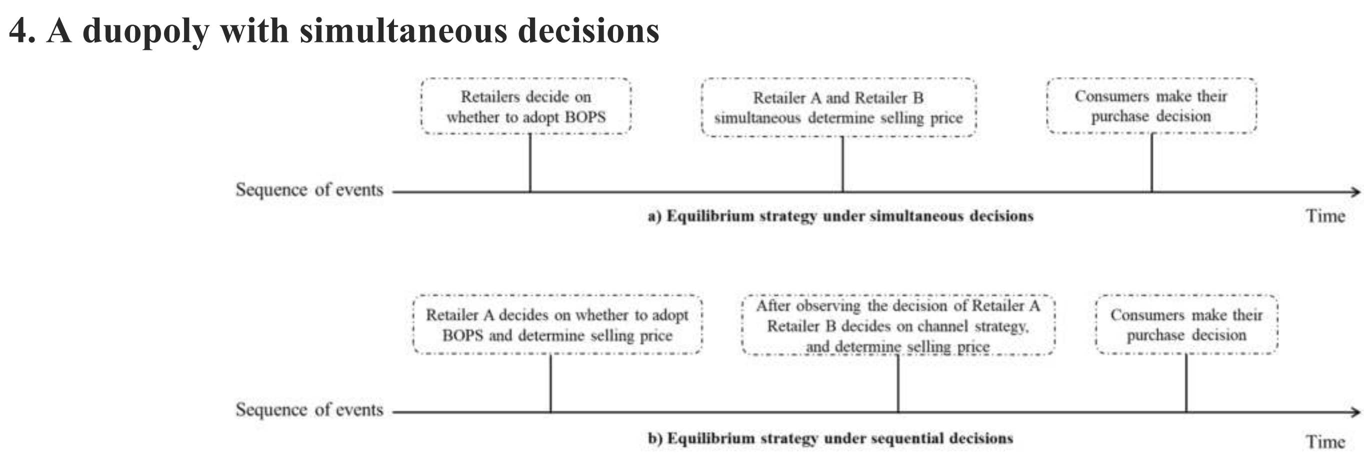


Fig. 3. Sequence of events in omnichannel retailing.

the former is α and that of the latter is $1-\alpha$ where $\alpha \in [0,1]$. Moreover, in line with Wang et al. (2020), we additionally assume there are two types of consumers: low online hassle cost and high online hassle cost. The fraction of the former is θ and that of the latter is $1-\theta$ where $\theta \in [0,1]$. For simplicity, the low store hassle cost and low online hassle cost are normalized to zero. Whereas the high store hassle cost and high online hassle cost are assumed to be sufficiently Large (denoted by H), such that nonnegative demand exists in both channels (Gao & Su, 2017a; Jin et al., 2020). Therefore, consumers are divided into four segments (shown in Fig. 2), depending on their differences in store and online hassle cost. And customers are unfirmly distributed within the following "square"$\{(h_o, h_s) \,|h_o \in [0, H], h_s \in [0, H]\}$.

3.3. Customer utility

In our model, consumers may purchase by three options, namely, buy online (denoted BO), buy from a physical store (denoted BP), and buy from BOPS. Customers strategically choose one of three alternative channels from competing retailers to maximize their utilities. Each consumer has valuation value v of the product.

If customers choose purchase product from online channel of retailers, they will incur a hassle cost $h_o > 0$ associated with online shopping, which covers the wait for deliveries and the annoyance of online searching (Gao & Su, 2017a; Gao et al., 2022; Kong et al., 2020; Mandal et al., 2021). When purchasing from retailer A, a consumer at preference location x incurs the misfit cost mx, while purchasing from retailer B, which incurs the misfit cost $m(1-x)$. Then, we derive the customers' expected utility from purchasing online of retailer A. Each customer obtains a utility of $v-p_A-h_o-mx$.On the contrary, if customers choose purchase product from online channel of retailer B, each customer obtains a utility of $v-p_B-h_o-m(1-x)$.

Accordingly, if customers visit the store to purchase product, they will incur an offline hassle cost $h_s > 0$, which includes the inconvenience of traveling to the store (Gao et al., 2022; Kong et al., 2020). Then, we derive the customers' expected utility from purchasing a physical store of retailer A. Each customer obtains a utility of $v-p_A-h_s-mx$. On the contrary, each customer obtains a utility of $v-p_B-h_s-m(1-x)$ from retailer B.

When customers purchase from the BOPS channel, they will incur a portion of both the online and offline hassle costs. Following Gao et al. (2022), we denote the hassle cost of BOPS as $h_b = \lambda_s h_s + \lambda_o h_o$, where λ_s and λ_o represents the proportions of the offline and online hassle cost incurred in the BOPS channel, respectively. Then, we derive the customers' expected utility from BOPS channel of retailer A. Each customer obtains a utility of $v-p_A-h_b-mx$. On the contrary, each customer obtains a utility of $v-p_B-h_b-m(1-x)$ from retailer B.

Based on the above model descriptions, we summarize the consumer utility functions of two retailers as follows:

$$U_{g,s} = \begin{cases} U_{A,s} = v - p_A - h_s - mx \\ U_{B,s} = v - p_B - h_s - m(1-x) \end{cases} \tag{1}$$

$$U_{g,o} = \begin{cases} U_{A,o} = v - p_A - h_o - mx \\ U_{B,o} = v - p_B - h_o - m(1-x) \end{cases} \tag{2}$$

$$U_{g,b} = \begin{cases} U_{A,b} = v - p_A - (\delta_s h_s + \delta_o h_o) - mx \\ U_{B,b} = v - p_A - (\delta_s h_s + \delta_o h_o) - m(1-x) \end{cases} \tag{3}$$

We use U to denote consumers' utility. The subscript g denotes retailer A and retailer B, $g = A, B$, respectively.

And the subscript s, o, b denote offline, online, and the BOPS channel, respectively. Next, we discuss the utility functions of all channels under the customer market segments. For LL-type customers, the utility of retailer A's BP/BO/BOPS channel are $v-p_A-mx$. And the utility of retailer B's BP/BO/BOPS channel are $v-p_B-m(1-x)$; For LH-type customers, the utility functions of retailer A's BO, BP and BOPS channels are $v-p_A-mx-H$, $v-p_A-mx$ and $v-p_A-mx-\lambda_o H$ respectively; And the utility functions of retailer B's BO, BP and BOPS channels are $v-p_B-m(1-x)-H$, $v-p_B-m(1-x)$ and $v-p_B-m(1-x)-\lambda_o H$ respectively; For HL-type customers, the utility functions of retailer A's BO, BP and BOPS channels are $v-p_A-mx$, $v-p_A-mx-H$ and $v-p_A-mx-\lambda_s H$ respectively; And the utility functions of retailer B's BO, BP and BOPS channels are $v-p_B-m(1-x)$, $v-p_B-m(1-x)-H$ and $v-p_B-m(1-x)-\lambda_s H$ respectively; For HH-type customers, the utility functions of retailer A's BO, BP and BOPS channels are $v-p_A-mx-H$, $v-p_A-mx-H$ and $v-p_A-mx-(\lambda_s+\lambda_o)H$ respectively; And the utility functions of retailer B's online, offline and BOPS channels are $v-p_B-m(1-x)-H$, $v-p_B-m(1-x)-H$ and $v-p_B-m(1-x)-(\lambda_s+\lambda_o)H$ respectively.

4. A duopoly with simultaneous decisions

This section discusses the situation in which competing retailers make BOPS decisions simultaneously. Considering a three-stage game in which retailer A and retailer B decide on whether to adopt the BOPS simultaneously in stage 1, determine their selling price in stage 2, and customers make their purchase decision (i.e., from which retailer and which channel to purchase) in stage 3. We then examine retailer profitability under all possible scenarios and analyze the Nash equilibrium results. Moreover, we extend the discussion to the scenario when retailers sequentially choose the BOPS strategy. The decision sequence is shown in Fig. 3.

4.1. Equilibrium prices and payoffs

There are four possible scenarios discussed in the duopoly market: (1) neither retailer deploy the BOPS (i.e., No-No strategy), (2) only one retailer deploys the BOPS (i.e., BOPS-No BOPS strategy or No BOPS-BOPS strategy), (3) both retailers deploy the BOPS (i.e., BOPS-BOPS strategy). Because the equilibrium results of BOPS-No BOPS and No BOPS-BOPS strategy are similar in the presence of simultaneous decisions, this section only discusses the BOPS-No BOPS strategy.

4.1.1. No–No strategy

When neither retailer deploys the BOPS, each customer purchases from the offline and online channel. This situation is equivalent to traditional retail channel. The corresponding utilities are given in Appendix A. Customers will strategically choose purchasing channels from competing retailers to maximize their utilities. For example, if $U_{A,s} > \max(U_{A,o}, 0)$ and $U_{B,s} > \max(U_{B,o}, 0)$, customers prefer offline channel to purchase. In finalizing the purchase decision, the consumer also considers brand preference between the two retailers. Then a comparison between $U_{A,s}$ and $U_{B,s}$ determines the purchase decision. We can determine the preferred location x_{AB} by solving $U_{A,s} = U_{B,s}$. Customers with $0 \le x \le x_{AB}$ prefer offline channel of retailer A, consumers with $x_{AB} < x \le 1$ prefer offline channel of retailer B. We repeat the above analysis, the optimal purchase decisions of heterogeneous consumers are illustrated in Lemma 1.

Lemma 1. For the case of No-No strategy, there exists the threshold x_{AB} such that:

(a) For LL- and HH-type customers, regardless of any channels, retailer A is optimal choice when $0 \le x \le x_{AB}$; if $x_{AB} < x \le 1$, retailer B is the optimal choice;

(b) For LH-type customers, offline channel of retailer A is optimal choice when $0 \le x \le x_{AB}$; if $x_{AB} < x \le 1$, offline channel of retailer B is the optimal choice;

(c) For HL-type customers, online channel of retailer A is optimal choice when $0 \le x \le x_{AB}$; if $x_{AB} < x \le 1$, online channel of retailer B is the optimal choice.

Lemma 1 shows how segmented customers choose optimal purchase decisions to maximize their utility in the traditional channel. We observe that consumers with LL and HH segments have no preference for purchasing channels, but have a significant brand preference for retailers. In contrast, consumers with LH and HL segments have an apparent preference for channels and retailers' brands. Then, we discuss the total demand of retailers through all possible channels by considering the customer market segments.

4.1.1.1. Demand functions. Consumers are heterogeneous in brand preference and consumer shopping behavior. On the consumer shopping behavior side. We assume there are four types of consumers: LL-type customers (i.e., low store hassle cost and low online hassle cost), LH-type customers (i.e., low store hassle cost and high online hassle cost), HL-type customers (i.e., high store hassle cost and low online hassle cost), and HH-type customers (i.e., high store hassle cost and high online hassle cost). The fractions of specific consumers are shown in Fig. 2. On the brand preference side, consumers are uniformly distributed on a line segment of length $[0, 1]$,which reflects consumers' sensitivity of product differentiation. By comparing the utility functions of different channels of two retailers, customers will strategically choose one of three alternative channels from competing retailers to maximize their utilities. To characterize the total demand of retailers, we analyze customers' utilities for all possible channels by considering the customer market segments (shown in Appendix A). We can derive that half LL-, half HH– and LH-type customers prefer purchasing retailer $i's$ offline channels. half LL-, half HH– and HL-type customers prefer purchasing retailer $i's$ online channels. Thus, the demands of offline and online channel for retailer i are as follows:

$$\begin{cases} D^{nn}_{A,s} = \dfrac{(1-\theta+\alpha)}{2}x_{AB}, D^{nn}_{A,o} = \dfrac{(1-\alpha+\theta)}{2}x_{AB} \\ D^{nn}_{B,s} = \dfrac{(1-\theta+\alpha)}{2}(1-x_{AB}), D^{nn}_{B,o} = \dfrac{(1-\alpha+\theta)}{2}(1-x_{AB}) \end{cases} \tag{4}$$

In this situation, the expected profit functions of the No-No strategy are:

$$\prod_A^{nn} = \underbrace{\frac{1}{2}(1-\theta+\alpha)x_{AB}(p_A-c+r)}_{\text{offline store:half LL,LH, half HH}} + \underbrace{\frac{1}{2}(1+\theta-\alpha)x_{AB}p_A}_{\text{online store:half LL,HL, half HH}} \tag{5}$$

$$\prod_B^{nn} = \underbrace{\frac{1}{2}(1-\theta+\alpha)(1-x_{AB})(p_B-c+r)}_{\text{offline store:half LL,LH, half HH}} + \underbrace{\frac{1}{2}(1+\theta-\alpha)(1-x_{AB})p_B}_{\text{online store:half LL,LH, half HH}} \tag{6}$$

As shown in Eqs. (5) and (6), these terms correspond to the profits from the offline and online channels, respectively. Since customers who visit a store are more likely to buy additional products, resulting in cross-selling benefits. According to UPS, 45% of customers who visited the store made an additional purchase (UPS, 2015). Therefore, we define r as unit cross-selling benefit from every customer who comes to the store. Given that the operational cost c of offline channel means that a retailer incurs the cost of investing in physical store space and extra product storage, which is higher than the online product cost (Wang et al., 2020). Without loss of generality, let the unit online product cost be zero (Kong et al., 2020). Consequently, $P_g - c + r$ represents the marginal profit of offline channel, and P_g represents the profit margin of online channel. Implementation of BOPS incurs the operation cost k in the BOPS channel (Kong et al., 2020). $P_g - k + r$ represents the marginal profit of BOPS channel. The optimal pricing decision and optimal profit are given by the following Proposition 1.

Proposition 1. If neither retailer adopts the BOPS under duopoly setting, the optimal prices and profits are:

$$p_A^{nn*} = p_B^{nn*} = m + \frac{(c-r)(1-\theta+\alpha)}{2} \tag{7}$$

$$\prod_A^{nn*} = \prod_B^{nn*} = \frac{m}{2} \tag{8}$$

Proposition 1 characterizes the optimal price and profits for the No-No strategy. It can be easily shown that p_g^{nn*} is increasing in product differentiation and fixed cost of production but is decreasing with cross-selling benefit. This phenomenon reflects two facts. On the hand, when the intensity of competition is strong (i.e., m is lower), retailers will lower their selling prices to obtain the market share. And faced with higher offline production costs, retailers raise the selling price to maintain their margin profit. On the other hand, if cross-selling increases additional profits to guarantee the profitability of retailers, retailers have an incentive to reduce prices to attract more consumers. The proposition 1 shows that competition is inevitable, but retailers can utilize the cross-buying behavior of customers to adjust prices. Also, it is worth highlighting that the outcomes of the symmetric game have identical prices and profits in this situation.

4.1.2. BOPS-No BOPS strategy

To better understand the impact of the BOPS strategy on retailers' operational decisions, we next analyze the BOPS-No BOPS strategy. When retailer A deploys the BOPS, but retailer B does not. Hence, there are three options (i.e., offline channel, online channel, and BOPS channel) offered for each customer in retailer A, while only two options (i.e., offline channel and online channel) are offered in retailer B. For characterizing the impact of BOPS performance on consumer behavior, we consider three distinct cases: (i) Case S_i: where $\lambda_s + \lambda_o < 1$, the strong

Table 3
The demands of BOPS-No BOPS strategy.

Case	S_i	S_{ii}	S_{iii}
$D^{bn}_{A,s}$	$\left(\alpha-\frac{2}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\theta+2\alpha-\alpha\theta)x_{AB}$	$\frac{1}{2}\left(1-\theta+\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}$
$D^{bn}_{B,s}$	$\left(\alpha-\frac{1}{2}\alpha\theta\right)(1-x_{AB})+\frac{1}{2}(1-\alpha)(1-\theta)(1-x'_{AB})$	$\frac{1}{2}(1-\theta+\alpha)(1-x_{AB})$	$\frac{1}{2}(1-\theta+\alpha)(1-x_{AB})$
$D^{bn}_{A,o}$	$\left(\theta-\frac{2}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\alpha+2\theta-\alpha\theta)x_{AB}$	$\frac{1}{2}\left(1+\theta-\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}$
$D^{bn}_{B,o}$	$\left(\theta-\frac{1}{2}\alpha\theta\right)(1-x_{AB})+\frac{1}{2}(1-\alpha)(1-\theta)(1-x'_{AB})$	$\frac{1}{2}(1-\alpha+\theta)(1-x_{AB})$	$\frac{1}{2}(1-\alpha+\theta)(1-x_{AB})$
$D^{bn}_{A,b}$	$\frac{1}{3}\alpha\theta x_{AB}+(1-\alpha)(1-\theta)x'_{AB}$	$\frac{1}{3}(1-\theta-\alpha+2\alpha\theta)x_{AB}$	$\frac{1}{3}\alpha\theta x_{AB}$
$D^{bn}_{B,b}$	0	0	0

degree of convenience for BOPS, (ii) Case S_{ii}: where $\lambda_s+\lambda_o=1$, the intermediate degree of convenience for BOPS, (iii) Case S_{iii}: where $\lambda_s+\lambda_o>1$, the weak degree of convenience for BOPS. The strategic decisions of heterogeneous consumers are illustrated in Lemma 2.

Lemma 2. For the case of BOPS-No BOPS strategy, there exists the threshold x_{AB} and x'_{AB} such that, where $x'_{AB}=(p_B-p_A)/2m+1/2+(1-\lambda_s-\lambda_o)H/2m$.

(a) For LL-, HL- and LH-type customers in all cases: if $0\le x\le x_{AB}$, purchasing from retailer A is optimal choice. if $x_{AB}<x\le 1$, purchasing from retailer B is optimal choice; LL-type customers with all available channels are optimal choice, LH-type (HL-type) customers with offline (online) channel are optimal choice.
(b) For HH-type customers in Case S_i: if $0<x\le x'_{AB}$, BOPS option of retailer A is optimal choice. if $x'_{AB}<x\le 1$, BOPS option of retailer B is optimal choice.
(c) For HH-type customers in Case S_{ii}: if $0\le x\le x_{AB}$, all three channels of retailer A are optimal choice. if $x_{AB}<x\le 1$, traditional channel of retailer B is optimal choice.
(d) For HH-type customers in Case S_{iii}: if $0\le x\le x_{AB}$, traditional channel of retailer A is optimal choice; if $x_{AB}<x\le 1$, traditional channel of retailer B is optimal choice.

Lemma 2 indicates that BOPS have transformed consumer shopping behavior, especially affecting worst-case (i.e., HH-type) consumers. When the value of $\lambda_s+\lambda_o$ decreases, HH-type consumers gradually switch traditional channel to BOPS channel. It shows that deployment of the BOPS is not always an optimal strategy to attract store traffic, unless the convenience of BOPS channel is better than traditional channels. Moreover, it is noticeable that the threshold of preference points for HH-type consumers is larger than other customers segments ($x'_{AB}>x_{AB}$) when the value of $\lambda_s+\lambda_o$ is smaller. This suggests that the more significant the BOPS advantage, the more demand the retailer will obtain. Thus, retailers could explore some new methods or technologies to improve shopping convenience and enhance channels' interaction for omnichannel retailing (Cai & Lo, 2020). For instance, Farfetch, a global luxury brand seller, utilize VR to provide personalized virtual fitting experience for consumers (Yang & Ji, 2022).

4.1.2.1. Demand functions. We analyze consumers' purchase decisions in different cases. (1) For the *Case* S_i, one-third LL- and LH-type customers prefer retailer A's offline channels, and LH-, half LL-, and half HH-type customers prefer retailer B's offline channels; One-third LL- and HL-type customers prefer retailer A's online channels, and HL-, half LL- and half HH-type customers prefer retailer B's online channels; HH– and one-third LL-type customers prefer retailer B's BOPS channels. (2) For the *Case* S_{ii}, one-third LL-,LH-, and one-third HH– type customers prefer retailer A's offline channels, and LH-, half LL-, and half HH-type customers prefer purchasing retailer B's offline channels; One-third LL-, HL-, and one-third HH-type customers prefer retailer A's online channels, and HL-, half LL-and half HH-type customers prefer retailer B's online channels; One-third LL- and One-third HH-customers prefer retailer B's BOPS channels. (3) For the *Case* S_{iii}, one-third LL-, LH-, and half HH-type customers prefer retailer A's offline channels, and LH-, half LL-, and half HH-type customers prefer retailer B's offline channels; One-third LL-, HL-, and half HH-type customers prefer retailer A's online channels, and HL-, half LL-and half HH-type customers prefer retailer B's online channels; One-third LL-type customers prefer retailer B's BOPS channels. Consequently, the demands of offline, online and BOPS channel for retailer A and B are shown in Table 3.

Next, we can derive the expected profit functions of the BOPS-No BOPS strategy.

Case S_i: BOPS with strong level of convenience

$$\prod_A^{bn}=\underbrace{\left(\alpha-\frac{2}{3}\alpha\theta\right)x_{AB}(p_A-c+r)}_{\text{offline store: LH, 1/3LL}}+\underbrace{\left(\theta-\frac{2}{3}\alpha\theta\right)x_{AB}p_A}_{\text{online store: HL, 1/3LL}}+\underbrace{\left[\frac{1}{3}\alpha\theta x_{AB}+(1-\alpha)(1-\theta)x'_{AB}\right](p_A-k+r)}_{\text{BOPS: HH, 1/3LL}} \tag{9}$$

$$\prod_B^{bn}=\underbrace{\left[\left(\alpha-\frac{1}{2}\alpha\theta\right)(1-x_{AB})+\frac{1}{2}(1-\alpha)(1-\theta)(1-x'_{AB})\right](p_B-c+r)}_{\text{offline store: LH, half LL and half HH}}+\underbrace{\left[\left(\theta-\frac{1}{2}\alpha\theta\right)(1-x_{AB})+\frac{1}{2}(1-\alpha)(1-\theta)(1-x'_{AB})\right]p_B}_{\text{online store: HL, half LL and half HH}} \tag{10}$$

Case S_{ii}: BOPS with intermediate level of convenience

$$\prod_A^{bn}=\underbrace{\frac{1}{3}(1-\theta+2\alpha-\alpha\theta)x_{AB}(p_A-c+r)}_{\text{offline store: LH, 1/3LL,1/3HH}}+\underbrace{\frac{1}{3}(1-\alpha+2\theta-\alpha\theta)x_{AB}p_A}_{\text{online store: HL, 1/3LL,1/3HH}}+\underbrace{\frac{1}{3}(1-\theta-\alpha+2\alpha\theta)x_{AB}(p_A-k+r)}_{\text{BOPS: 1/3HH, 1/3LL}} \tag{11}$$

$$\prod_B^{bn}=\underbrace{\frac{1}{2}(1-\theta+\alpha)(1-x_{AB})(p_B-c+r)}_{\text{offline store: LH, half LL and half HH}}+\underbrace{\frac{1}{2}(1-\alpha+\theta)(1-x_{AB})p_B}_{\text{online store: HL, half LL and half HH}} \tag{12}$$

Case S_{iii}:BOPS with weak level of convenience

$$\prod_A^{bn} = \underbrace{\frac{1}{2}\left(1-\theta+\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}(p_A-c+r)}_{\text{offline store: LH, 1/3LL,half HH}} + \underbrace{\frac{1}{2}\left(1+\theta-\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}p_A}_{\text{online store: HL, 1/3LL,half HH}} + \underbrace{\frac{1}{3}\alpha\theta x_{AB}(p_A-k+r)}_{\text{BOPS: 1/3LL}} \tag{13}$$

$$\prod_B^{bn} = \underbrace{\frac{1}{2}(1-\theta+\alpha)(1-x_{AB})(p_B-c+r)}_{\text{offline store: LH, half LL and half HH}} + \underbrace{\frac{1}{2}(1-\alpha+\theta)(1-x_{AB})p_B}_{\text{online store: HL, half LL and half HH}} \tag{14}$$

Proposition 2. If only one retailer adopts the BOPS under duopoly setting, the optimal prices and profits are:

Case S_i: BOPS with strong level of convenience

$$p_A^{bn*} = m+\varepsilon\frac{\rho}{3}+\frac{4k\beta-r(3\alpha+15-15\theta+8\alpha\theta)+c(3+15\alpha-8\alpha\theta-3\theta)}{18} \tag{15}$$

$$p_B^{bn*} = m-\varepsilon\frac{\rho}{3}+\frac{k\beta-r(6+3\alpha-6\theta+2\alpha\theta)+c(3+6\alpha-2\alpha\theta-3\theta)}{9} \tag{16}$$

$$\prod_A^{bn*} = \frac{[18m+\beta(c-2k+r)]^2-12\varepsilon\rho\begin{bmatrix}-3(c-2k+r+6m+8c\alpha-7k\alpha-r\alpha)\\+\theta[3(c+7k-8r)+14\alpha(c+r-2k)]\end{bmatrix}+36\varepsilon^2\rho^2}{648m} \tag{17}$$

$$\prod_B^{bn*} = \frac{[18m-(r+c-2k)\beta]^2+6\varepsilon\rho\begin{bmatrix}6(c-2k+r-6m)+3\alpha(-11c+4k+7r)\\+\theta[21c+12k-33r+8\alpha(r+c-2k)]\end{bmatrix}+36\varepsilon^2\rho^2}{648m} \tag{18}$$

Case S_{ii}:BOPS with intermediate level of convenience

$$p_A^{bn*} = m+\frac{c(7+11\alpha-4\alpha\theta-7\theta)-r(11+7\alpha-11\theta+4\alpha\theta)+k(4-4\alpha-4\theta+8\alpha\theta)}{18} \tag{19}$$

$$p_B^{bn*} = m+\frac{c(4+5\alpha-4\theta-\alpha\theta)-r(5+4\alpha+\alpha\theta-5\theta)+k(1-\alpha-\theta+2\alpha\theta)}{9} \tag{20}$$

$$\prod_A^{bn*} = \frac{[18m+(c-2k+r)(1-\alpha-\theta+2\alpha\theta)]^2}{648m} \tag{21}$$

$$\prod_B^{bn*} = \frac{[18m-(c-2k+r)(1-\alpha-\theta+2\alpha\theta)]^2}{648m} \tag{22}$$

Case S_{iii}: BOPS with weak level of convenience

$$p_A^{bn*} = m+\frac{(9+9\alpha-9\theta)(c-r)-2\alpha\theta(c+r-2k)}{18} \tag{23}$$

$$p_B^{bn*} = m+\frac{9c(\alpha+1)+2\alpha\theta k-c\theta(9+\alpha)-r(9-9\theta+9\alpha+\alpha\theta)}{18} \tag{24}$$

$$\prod_A^{bn*} = \frac{[18m+(c-2k+r)\alpha\theta]^2}{648m} \tag{25}$$

$$\prod_B^{bn*} = \frac{[18m-(c-2k+r)\alpha\theta]^2}{648m} \tag{26}$$

For notational convenience, we define the following parameters: $\varepsilon = (1-\alpha)(1-\theta)$. $\beta = 3-3\alpha-3\theta+4\alpha\theta$, $\rho = (1-\lambda_s-\lambda_o)H$. Proposition 2 characterizes the optimal prices and profits for the BOPS-No BOPS strategy under different cases. The retailers' optimal prices p_i^{bn*} increase with BOPS operating cost k in all scenarios. This is consistent with real practice. The higher operating costs of BOPS may incur a significant decline in operating profit, thus setting higher prices to compensate for the loss. Different from the symmetric game, the outcomes of asymmetric game have different prices and profits.

Proposition 3. Compared to the retailer B without deploying the BOPS, the retailer A benefits from establishing a BOPS channel when.

$$k \le \begin{cases} \dfrac{4m(r+c)\beta+3\varepsilon\rho[8m+9c\alpha-3r\alpha-(3c-9r+4c\alpha+4r\alpha)\theta]}{8m\beta+6\varepsilon\rho(3\alpha+3\theta-4\alpha\theta)}, & \textit{case } S_i \\ \eta\ , \textit{case } S_{ii} \textit{ and case } S_{iii} \end{cases} \tag{27}$$

For the convenience of analysis, we define parameter $\eta = (r+c)/2$, that is, the threshold of BOPS operating cost, which reflects the maximum operating cost in the BOPS channel under moderate competition. Proposition 3 comes from comparing the profits of retailers adopting and not adopting the BOPS channel. When the convenience of BOPS is high, the threshold of operating cost to benefit from the deployment of the BOPS channel is influenced by the intensity of competition. But the result exists counterintuitive. Contrary to the common view that the operating costs of deploying the BOPS should increase to attract foot traffic in intensity competition. The findings suggest that retailers deploying BOPS can achieve benefits without investing much BOPS operating costs when competition is fierce. Additionally, we observe the threshold of BOPS operating cost is independent of competition when the convenience of BOPS is low. This is because the inconvenience of BOPS makes it difficult to attract consumers in the competitive setting.

Fig. 4 shows the BOPS operating cost k of retailer A as a function of m. First and intuitively, the maximum threshold of BOPS operating cost k in case S_i is large than case S_{ii} and S_{iii}, which suggests that the more convenient the BOPS, the larger the profit area of retailer A.

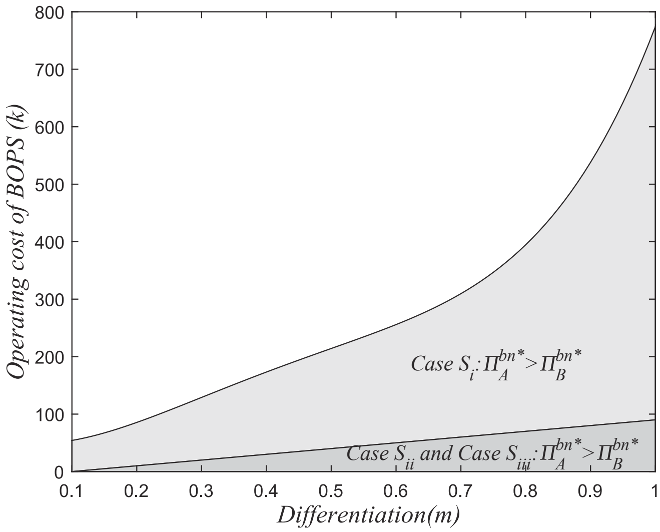


Fig. 4. The BOPS operating cost of retailer A as a function of m.

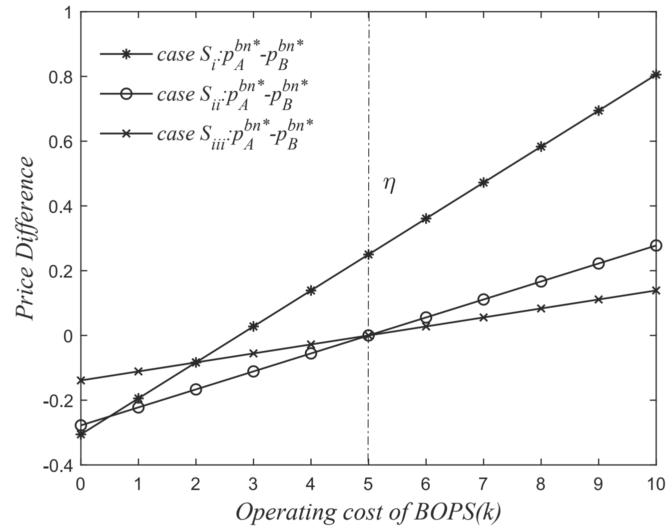


Fig. 5. The price difference of retailers as a function of k.

Furthermore, when competition is weak and BOPS convenience is high, retailers deploying BOPS obtain more benefits. This shows that consumers prefer the convenience of channel even though product substitutability is low. Therefore, when competitive retailers sell products with low differentiation, they can gain competitive advantages by improving channel convenience.

Proposition 4. When the BOPS operating cost is high, the retailer A with deploying the BOPS can effectively achieve a price premium.

Proposition 4 follows by comparing retailers' optimal prices with and without deploying the BOPS channel (see Fig. 5). When the BOPS operating cost is high, the selling price of retailer A is constantly higher than retailer B. This is because that retailer A's price increases in it to compensate for the negative impact of high BOPS operating costs on profits. We refer to this as the price self-compensation effect of the BOPS strategy. In practice, customers are willing to pay for extra instant gratification avoiding long waits. As a result, retailers deploying BOPS channels charges the premium price generating price discrimination for achieving excess profit under a duopoly context. Furthermore, retailers deploying BOPS channels with a strong level of BOPS convenience will gain more premium advantages. Therefore, in the case of asymmetric equilibrium, retailers can utilize BOPS to regulate prices and gain price competitive advantages.

4.1.3. *BOPS–BOPS strategy*

In this scenario, both retailers deploy the BOPS channel. Similarly, we discuss the total demand of retailers through all possible channels by considering the customer market segments. The strategic decisions of heterogeneous consumers are illustrated in Lemma 3.

Lemma 3. For the case of BOPS-BOPS strategy, there exists the threshold x_{AB} such that:

(a) For LL-, HL- and LH-type customers in all cases: if $0 \le x \le x_{AB}$, purchasing from retailer A is optimal choice. if $x_{AB} < x \le 1$, purchasing from retailer B is optimal choice; LL-type customers with all available channels are optimal choice, LH-type (HL-type) customers with offline (online) channel are optimal choice.
(b) For HH-type customers in Case S_i: if $0 \le x \le x_{AB}$, BOPS option of retailer A is optimal choice. if $0 \le x \le x_{AB}$, BOPS option of retailer B is optimal choice.
(c) For HH-type customers in Case S_{ii}: if $0 \le x \le x_{AB}$, all three channels of retailer A are optimal choice. if $x_{AB} < x \le 1$, all three channels of retailer A are optimal choice.
(d) For HH-type customers in Case S_{iii}: if $0 \le x \le x_{AB}$, traditional channel of retailer A is optimal choice; if $x_{AB} < x \le 1$, traditional channel of retailer B is optimal choice.

Lemma 3 suggests that customers with HH-type customers prefer the BOPS channel, while consumers with LH and HL segments have a significant preference for traditional channels. And customers with LL segments hold the same preference for No-No and BOPS-No BOPS strategies. After the implementation of the BOPS channel, HH-type customers shift from the traditional channels to the BOPS channel (i.e., channel migration effect). Furthermore, once BOPS is available and provides more consumer experience value and convenience, customers may prefer to buy online and pick up in-store. This shopping mode may benefit omnichannel retailers to increase customer flow and alleviate the risk of stockouts. Then, we discuss the total demands of retailers in different cases.

4.1.3.1. *Demand functions.*

We analyze consumers' purchase decisions in different cases. (1) For the *Case S_i*, one-third LL- and LH-type customers prefer retailer i's offline channels; One-third LL- and HL-type customers prefer retailer i's online channels; HH- and one-third LL-type customers prefer retailer i's BOPS channels. (2) For the *Case S_{ii}*, one-third LL-, one-third HH- and LH-type customers prefer retailer i's offline channels; One-third LL-,one-third HH–, and HL-type customers prefer retailer i's online channels; one-third HH– and one-third LL-type customers prefer retailer i's BOPS channels. (3) For the *Case S_{iii}*, one-third LL-, half HH– and LH-type customers prefer retailer i's offline channels; One-third LL-,half HH–, and HL-type customers prefer retailer i's online channels; one-third LL-customers prefer retailer i's BOPS channels. Consequently, the demands of offline, online and BOPS channel for retailer A and B are shown in Table 4.

Next, we can derive the expected profit functions of the BOPS-No BOPS strategy.

Case S_i: BOPS with strong level of convenience

Table 4
The demands of BOPS-BOPS strategy.

Case	S_i	S_{ii}	S_{iii}
$D^{bb}_{A,s}$	$\left(\alpha-\frac{2}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\theta+2\alpha-\alpha\theta)x_{AB}$	$\frac{1}{2}\left(1-\theta+\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}$
$D^{bb}_{B,s}$	$\left(\alpha-\frac{2}{3}\alpha\theta\right)(1-x_{AB})$	$\frac{1}{3}(1-\theta+2\alpha-\alpha\theta)(1-x_{AB})$	$\frac{1}{2}\left(1-\theta+\alpha-\frac{1}{3}\alpha\theta\right)(1-x_{AB})$
$D^{bb}_{A,o}$	$\left(\theta-\frac{2}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\alpha+2\theta-\alpha\theta)x_{AB}$	$\frac{1}{2}\left(1+\theta-\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}$
$D^{bb}_{B,o}$	$\left(\theta-\frac{2}{3}\alpha\theta\right)(1-x_{AB})$	$\frac{1}{3}(1-\alpha+2\theta-\alpha\theta)(1-x_{AB})$	$\frac{1}{2}\left(1+\theta-\alpha-\frac{1}{3}\alpha\theta\right)(1-x_{AB})$
$D^{bb}_{A,b}$	$\left(1-\theta-\alpha+\frac{4}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\theta-\alpha+2\alpha\theta)x_{AB}$	$\frac{1}{3}\alpha\theta x_{AB}$
$D^{bb}_{B,b}$	$\left(1-\theta-\alpha+\frac{4}{3}\alpha\theta\right)(1-x_{AB})$	$\frac{1}{3}(1-\theta-\alpha+2\alpha\theta)(1-x_{AB})$	$\frac{1}{3}\alpha\theta(1-x_{AB})$

$$\prod_A^{bb} = \underbrace{\left(\alpha-\frac{2}{3}\alpha\theta\right)x_{AB}(p_A-c+r)}_{\text{offline store: LH, 1/3LL}} + \underbrace{\left(\theta-\frac{2}{3}\alpha\theta\right)x_{AB}p_A}_{\text{online store: HL, 1/3LL}} + \underbrace{\left(1-\alpha-\theta+\frac{4}{3}\alpha\theta\right)x_{AB}(p_A-k+r)}_{\text{BOPS: HH, 1/3LL}} \tag{28}$$

$$\prod_B^{bb} = \underbrace{\left(\alpha-\frac{2}{3}\alpha\theta\right)(1-x_{AB})(p_B-c+r)}_{\text{offline store: LH, 1/3LL}} + \underbrace{\left(\theta-\frac{2}{3}\alpha\theta\right)(1-x_{AB})p_B}_{\text{online store: HL, 1/3LL}} + \underbrace{\left(1-\alpha-\theta+\frac{4}{3}\alpha\theta\right)(1-x_{AB})(p_B-k+r)}_{\text{BOPS: HH, 1/3LL}} \tag{29}$$

Case S_{ii}: BOPS with intermediate level of convenience

$$\prod_A^{bb} = \underbrace{\frac{1}{3}(1-\theta+2\alpha-\alpha\theta)x_{AB}(p_A-c+r)}_{\text{offline store: LH, 1/3LL,1/3HH}} + \underbrace{\frac{1}{3}(1-\alpha+2\theta-\alpha\theta)x_{AB}p_A}_{\text{online store: HL, 1/3LL,1/3HH}} + \underbrace{\frac{1}{3}(1-\theta-\alpha+2\alpha\theta)x_{AB}(p_A-k+r)}_{\text{BOPS: 1/3HH, 1/3LL}} \tag{30}$$

$$\prod_B^{bb} = \underbrace{\frac{1}{3}(1-\theta+2\alpha-\alpha\theta)(1-x_{AB})(p_B-c+r)}_{\text{offline store: LH, 1/3LL,1/3HH}} + \underbrace{\frac{1}{3}(1-\alpha+2\theta-\alpha\theta)(1-x_{AB})p_B}_{\text{online store: HL, 1/3LL,1/3HH}} + \underbrace{\frac{1}{3}(1-\theta-\alpha+2\alpha\theta)(1-x_{AB})(p_B-k+r)}_{\text{BOPS: 1/3HH, 1/3LL}} \tag{31}$$

Case S_{iii}: BOPS with weak level of convenience

$$\prod_A^{bb} = \underbrace{\frac{1}{2}\left(1-\theta+\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}(p_A-c+r)}_{\text{offline store: LH, 1/3LL,half HH}} + \underbrace{\frac{1}{2}\left(1-\alpha+\theta-\frac{1}{3}\alpha\theta\right)x_{AB}p_A}_{\text{online store: HL, 1/3LL,half HH}} + \underbrace{\frac{1}{3}\alpha\theta x_{AB}(p_A-k+r)}_{\text{BOPS: 1/3LL}} \tag{32}$$

$$\prod_B^{bb} = \underbrace{\frac{1}{2}\left(1-\theta+\alpha-\frac{1}{3}\alpha\theta\right)(1-x_{AB})(p_B-c+r)}_{\text{offline store: LH, 1/3LL,half HH}} + \underbrace{\frac{1}{2}\left(1-\alpha+\theta-\frac{1}{3}\alpha\theta\right)(1-x_{AB})p_B}_{\text{online store: HL, 1/3LL,half HH}} + \underbrace{\frac{1}{3}\alpha\theta(1-x_{AB})(p_B-k+r)}_{\text{BOPS: 1/3LL}} \tag{33}$$

Proposition 5. If both retailers adopt the BOPS under duopoly setting, the optimal prices and profits are:

$$Case\ S_i : p_A^{bb*} = p_B^{bb*} = m + \frac{c(3\alpha-2\alpha\theta) - r(3-3\theta+2\alpha\theta) + k\beta}{3} \tag{34}$$

$$Case\ S_{ii} : p_A^{bb*} = p_B^{bb*} = m + \frac{c(1+2\alpha-\theta-\alpha\theta) - r(2+\alpha-2\theta+\alpha\theta) + k(1-\alpha-\theta+2\alpha\theta)}{3} \tag{35}$$

$$Case\ S_{iii} : p_A^{bb*} = p_B^{bb*} = m + \frac{c(3+3\alpha-3\theta-\alpha\theta) - r(3+3\alpha-3\theta+\alpha\theta) + 2k\alpha\theta}{6} \tag{36}$$

$$\prod_A^{bb*} = \prod_B^{bb*} = \frac{m}{2} \tag{37}$$

Proposition 5 characterizes the optimal prices and profits for the BOPS-BOPS strategy. Under the BOPS-BOPS strategy, the optimal prices p_i^{bb*} are determined by the parameters m, r, c, k, and the proportion of

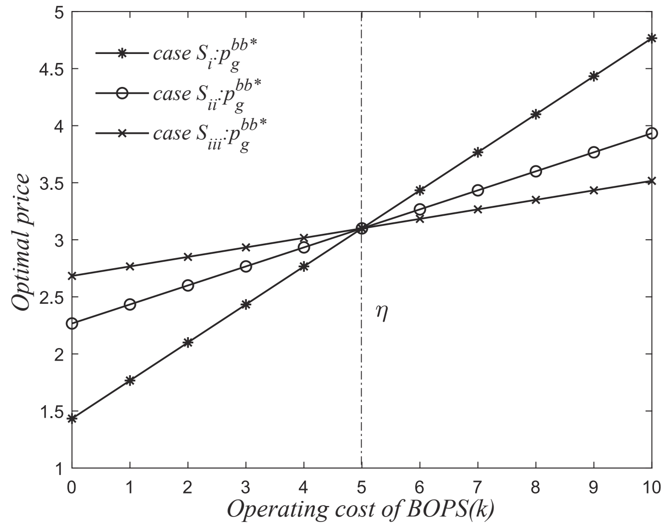


Fig. 6. The optimal price of retailers as a function of k.

heterogeneous customers. Fig. 6 shows how the optimal prices are affected by BOPS operating costs for three scenarios with different levels of BOPS performance. When the BOPS operating cost $k \leq \eta$, the optimal prices of *Case* S_i is the largest. However, when $k > \eta$, the optimal prices of *Case* S_i is the largest. This difference can be explained as follows. BOPS with low operating costs–a strong level of convenience can generate more cross-channel benefits, resulting in a price self-compensation effect and lower selling prices. Notably, when the intensity of convenience for BOPS is strong, competing retailers will charge the premium price to compensate for the loss of high operating costs. Additionally, even if the level of BOPS performance is weak, there are still consumers willing to purchase from the BOPS channel. We define this phenomenon as a limited market share effect.

Proposition 6. The optimal prices under three strategies have the following orders:

(a) For the *Case* S_i, it holds that

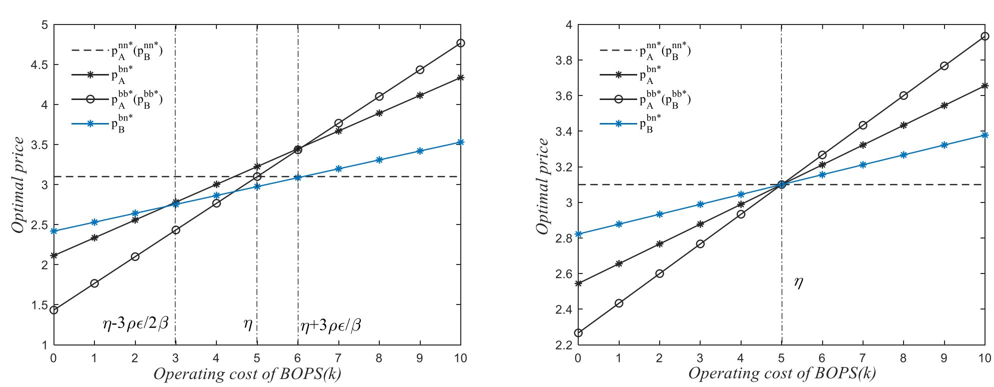
$$\text{Case } S_i \begin{cases} p_A^{nn*} > p_A^{bn*} > p_A^{bb*}, p_B^{nn*} > p_B^{bn*} > p_B^{bb*} \text{ if } k \leq \eta - 3\rho\varepsilon/2\beta \\ p_A^{bn*} > p_A^{nn*} > p_A^{bb*}, p_B^{nn*} > p_B^{bb*} > p_B^{bn*} \text{ if } \eta - 3\rho\varepsilon/2\beta < k \leq \eta \\ p_A^{bn*} > p_A^{bb*} > p_A^{nn*}, p_B^{bb*} > p_B^{nn*} > p_B^{bn*} \text{ if } \eta < k \leq \eta + 3\rho\varepsilon/\beta \\ p_A^{bb*} > p_A^{bn*} > p_A^{nn*}, p_B^{bb*} > p_B^{bn*} > p_B^{nn*} \text{ if } k > \eta + 3\rho\varepsilon/\beta \end{cases} \tag{38}$$

(b) For the *Case* S_{ii} or *Case* S_{iii}, it holds that

$$\text{Case } S_{ii}(\text{Case } S_{iii}) \begin{cases} p_A^{bb*} > p_A^{bn*} > p_A^{nn*}, p_B^{bb*} > p_B^{bn*} > p_B^{nn*} \text{ if } k \leq \eta \\ p_A^{nn*} > p_A^{bn*} > p_A^{bb*}, p_B^{nn*} > p_B^{bn*} > p_B^{bb*} \text{ if } k > \eta \end{cases} \tag{39}$$

Proposition 6 (a) indicates that the selling price difference of three strategies (i.e., No-No, BOPS-BOPS, BOPS-No BOPS) rely largely on BOPS operating cost when BOPS with a strong level of convenience. If the BOPS operating cost is low ($k \leq \eta - 3\rho\varepsilon/2\beta$), No-No strategy achieve higher selling prices than other strategies. When BOPS operating cost is relatively high ($\eta - 3\rho\varepsilon/2\beta < k \leq \eta + 3\rho\varepsilon/\beta$), BOPS-No BOPS (or No-No) strategy achieves higher selling prices than other strategies. Note that $k > \eta + 3\rho\varepsilon/\beta$, BOPS-BOPS strategy achieves higher selling prices than other strategies. Proposition 6 (b) compares optimal selling prices of three strategies in the case S_{ii} and S_{iii}.Notably, when the BOPS operating cost is low ($k \leq \eta$), BOPS-BOPS strategy obtains higher selling prices. Otherwise, when BOPS operating cost is relatively high ($k > \eta$), No-No strategy achieve higher prices. It is worth highlighting that higher the performance of BOPS will bring about higher premium capacity. To better compare the retail prices across different cases, Fig. 7 shows the optimal price of retailers as a function of k.

In summary, we consider three strategies by a duopoly with two competing retailers and identified three main effects of BOPS, i.e., channel migration effect, price self-compensation effect, and limited market share effect. First, once BOPS is available with low pickup hassle cost, The channels of customers in LL-type customers and HH-type customers are migrated to retailers deploying BOPS channels. We refer to this as the channel migration effect of BOPS. The channel migration effect shows that if the hassle cost associated with BOPS decreases, more and more customers prefer its channel. This finding indicates that if retailers want to stand out in the fierce market competition, they need to improve the convenience of BOPS channels to attract more consumers. Second, facing more cross-selling benefits, a retailer who adopts the BOPS strategy charges a lower selling price than a rival who does not. We identify the price self-compensation effect, which optimizes retail price to compensate for higher BOPS operating costs. Competing retailers should regard cross-selling benefit as an important feature to regulate pricing strategies when deploying the BOPS. Third, Particularly, even if the level of BOPS performance is weak, there are still consumers willing to purchase from the BOPS channel. We define this phenomenon as a limited market share effect. The limited market share effect highlights the fact that the adoption of BOPS is not always optimal but still obtains some limited market share. Such an effect is dominated by consumer heterogeneity and the BOPS functionality of information. As a result, the equilibrium outcome depends on the interaction of the three effects in the presence of competition. And higher the performance of BOPS will bring about higher premium capacity.



(a) *Case* S_i (b) *Case* S_{ii}

Fig. 7. The optimal price of retailers as a function of k.

4.2. Equilibrium analysis

This section analyzes the equilibrium decisions of competing retailers under three scenarios with varying BOPS performance levels:(i) BOPS with a strong level of convenience, (ii) BOPS with an intermediate level of convenience, (iii) BOPS with a weak level of convenience.

When BOPS with a strong level of convenience, it reflects retailers with a higher density of physical stores and delivery efficiency. Thus, this situation is often targeted retailers with the fulfillment capabilities or the scale–the retail giant (i.e., Amazon, JD, H&M, ZARA, UNIQLO, etc). For example, Amazon invested heavily in logistics and distribution, which offers fulfillment within one or two hours. Most retailers are now struggling to match Amazon's logistics without the ability and scale.

When BOPS with an intermediate level of convenience, it reflects the retailers with an intermediate density of physical stores and delivery efficiency. BOPS channel has the same performance level as a traditional channel. Thus, this situation is often targeted retailers with intermediate fulfillment capabilities or medium-sized retailers.

When BOPS with a weak level of convenience, it reflects a lower density of physical stores and delivery efficiency. Thus, this situation is often targeted retailers with small-sized or developing startups, which have a fewer number and/or smaller size of the physical stores.

To address the challenges of omnichannel deployment for retail giants, medium-sized and startups in a competitive environment, we discuss the retailer's equilibrium decisions regarding the implementation of the BOPS in the duopoly setting. The equilibrium result of this case is presented in Proposition 7.

Proposition 7. In a simultaneous duopoly game, when the level of convenience of BOPS is strong, intermediate, and weak respectively, the equilibrium strategy is determined by the following regions.

(i) Case S_i: for $(0,\eta_1)$, $[\eta,\eta_2)$ and $[\eta_3,+\infty)$, the optimal equilibrium is the BOPS-No BOPS (or No BOPS-BOPS) strategy; for $[\eta_1,\eta)$, the optimal equilibrium choice is the BOPS-BOPS strategy; for $[\eta_2,\eta_3)$, the optimal equilibrium choice is the No-No strategy;
(ii) Case S_{ii}: for $(0,\eta_4)$ or $[\eta_4,+\infty)$, the optimal equilibrium is the BOPS-No BOPS (or No BOPS-BOPS) strategy; for $[\eta_4,\eta)$, the optimal equilibrium choice is the BOPS-BOPS strategy; for $[\eta,\eta_5)$, the optimal equilibrium choice is the No-No strategy;
(iii) Case S_{iii}:for $(0,\eta_6)$ or $[\eta_7,+\infty)$,the optimal equilibrium strategy is the BOPS-No BOPS (or No BOPS-BOPS); for $[\eta_6,\eta)$,the optimal equilibrium choice is the BOPS-BOPS; for $[\eta,\eta_7)$, the No-No strategy is the optimal equilibrium choice. For notational convenience, we define the following parameters:

$$\eta_1 = \left[-18m + (r+c)\beta - 6\sqrt{9m^2+6m\rho-\rho^2}\right]\Big/2\beta\eta_2 = \left[18m\beta + (r+c)\beta^2 + 18\rho - 6\sqrt{9m^2\beta^2 - 6m\beta\rho(3+\beta) - (\beta^2-9)\rho^2}\right]\Big/2\beta$$

$$\eta_3 = \left[18m\beta + (r+c)\beta^2 + 18\rho + 6\sqrt{9m^2\beta^2 - 6m\beta\rho(3+\beta) - (\beta^2-9)\rho^2}\right]\Big/2\beta\eta_4 = \eta - 18m/(1-\alpha-\theta+2\alpha\theta)$$

$$\eta_5 = \eta + 18m/(1-\alpha-\theta+2\alpha\theta)\eta_6 = \eta - 18m/\alpha\theta\eta_7 = \eta + 18m/\alpha\theta$$

Proposition 7 presents the equilibrium results of retailers of different sizes in a competitive environment. For providing an intuitive understanding of equilibrium, we regard retailer B as an opponent and analyze the equilibrium results. The equilibrium results and profit comparison of BOPS strategy implementation are shown in Table 5.

Table 5
The equilibrium outcomes in simultaneous decision.

Case	k	Relationship	Equilibrium
S_i	$(0,\eta_1)$, $[\eta,\eta_2)$, $[\eta_3,+\infty)$	$\Delta\prod_A^{bn*}>0$, $\Delta\prod_B^{bn*}>0$	BN or NB
	$[\eta_1,\eta)$	$\Delta\prod_A^{bn*}>0$, $\Delta\prod_B^{bn*}<0$	BB
	$[\eta_2,\eta_3)$	$\Delta\prod_A^{bn*}<0$, $\Delta\prod_B^{bn*}>0$	NN
S_{ii}	$(0,\eta_4)$ or $[\eta_4,+\infty)$	$\Delta\prod_A^{bn*}>0$, $\Delta\prod_B^{bn*}>0$	BN or NB
	$[\eta_4,\eta)$	$\Delta\prod_A^{bn*}>0$, $\Delta\prod_B^{bn*}<0$	BB
	$[\eta,\eta_5)$	$\Delta\prod_A^{bn*}<0$, $\Delta\prod_B^{bn*}>0$	NN
S_{iii}	$(0,\eta_6)$ or $[\eta_7,+\infty)$	$\Delta\prod_A^{bn*}>0$, $\Delta\prod_B^{bn*}>0$	BN or NB
	$[\eta_6,\eta)$	$\Delta\prod_A^{bn*}>0$, $\Delta\prod_B^{bn*}<0$	BB
	$[\eta,\eta_7)$	$\Delta\prod_A^{bn*}<0$, $\Delta\prod_B^{bn*}>0$	NN

Note: $\Delta\prod_A^{bn*} = \prod_A^{bn*} - \prod_A^{nn*}(\prod_A^{bb*})$, $\Delta\prod_B^{bn*} = \prod_B^{bn*} - \prod_B^{nn*}(\prod_B^{bb*})$.

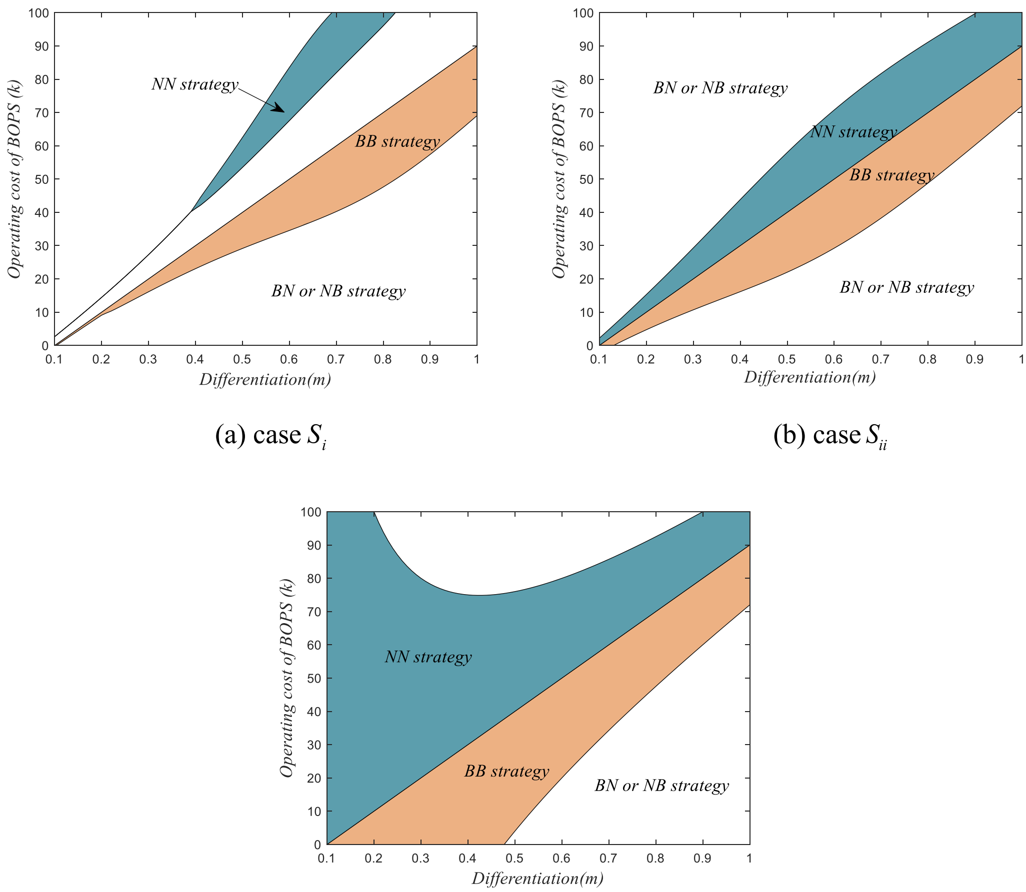
When the BOPS operation cost is lower than the certain threshold or overtops a certain threshold (i.e., Case S_i:$0<k\le\eta_1$ or $k>\eta_3$, Case S_{ii}: $0<k\le\eta_4$ or $k>\eta_5$,case(iii) $k<\eta_6$ or $k>\eta_7$), profits of competing retailers under BOPS-No BOPS (or No BOPS-BOPS) strategy are greater than other strategies($\Delta\prod_A^{bn*}>0$, $\Delta\prod_B^{bn*}>0$). This finding reveals a fact that given retailer B's decision of offering the BOPS option, the cross-selling profit generated is not sufficient to compensate the operating costs offering the BOPS. Meanwhile, if retailer A does not offer the BOPS and provides lower retail prices, which will dominate price competition and increase market share. In this case with the various types of retailers, adopting the asymmetric equilibrium can be profitable.

When the BOPS operation cost $k\le\eta$, there exists a threshold interval (i.e., Case S_i:$\eta_1<k<\eta$, Case S_{ii}: $\eta_4\le k<\eta$,case(iii) $\eta_6\le k<\eta$), profits of retailer A under BOPS-No BOPS strategy are greater than other strategies ($\Delta\prod_A^{bn*}>0$), while profits of retailer B under BOPS-No BOPS strategy are lower than other strategies ($\Delta\prod_B^{bn*}<0$). This finding reveals that given retailer B's decision of offering the BOPS option, its cross-selling profit could neutralize the BOPS operating costs. Thus, retailer A increases the attraction to customers and promotes an increase in total demand and profits by offering the BOPS. If retailer A chooses not to offer the BOPS, retailer B may set a lower price than retailer A, and is to the detriment of retailer A loses market share. Consequently, adopting the symmetric equilibrium can be profitable for competing retailers.

When the BOPS operation cost $k>\eta$, there exists a threshold interval (i.e., Case S_i:$\eta_2<k\le\eta_3$, Case S_{ii}: $\eta\le k<\eta_5$,case(iii) $\eta\le k<\eta_7$), profits of retailer A under BOPS-No BOPS strategy are lower than other strategies ($\Delta\prod_A^{bn*}<0$), while profits of retailer B under BOPS-No BOPS strategy are larger than other strategies ($\Delta\prod_B^{bn*}>0$). This finding reveals that the advantages of the BOPS are not conspicuous and the cross-selling profit just compensates for the BOPS operating cost. Not offering the BOPS synchronously could enable the retailers to maintain their market share and margin profit in response to the rival's decisions. Therefore, the equilibrium result is that neither retailer adopts the BOPS strategy.

In addition, if $\eta<k\le\eta_2$ in Case S_i, the Nash equilibrium is an asymmetric equilibrium. This phenomenon occurs because large-sized retailer A deploys omnichannel to improve customer service experience, which greatly increases fulfillment costs, leads to higher operating costs, and is difficult to make profits in the short term. The best choice for competitors is to forego omnichannel deployments to avoid channel losses. This also reveals that when large enterprises deploy omnichannel, they need to coordinate the shortest lead time, the lowest transportation cost, and the inventory point to fulfill the order, which is consistent with the practice.

Comparing competing retailers' Nash equilibrium in different cases



(a) case S_i (b) case S_{ii}

(c) case S_{iii}

Fig. 8. The Nash equilibrium region of competing retailers with *m*.

is illustrated in Fig. 8. The insights revealed the difference are presented as follows.

Corollary 1. When the intensity of competition is fierce, as the increasing BOPS operating cost, the large and medium-sized competing retailers can reach the asymmetrical equilibrium, while small-sized competing retailers can achieve the No-No equilibrium.

From the left regions of Fig. 8 show that when the product differentiation m is small, different retailers achieve different equilibrium strategies. Specifically, as the increasing BOPS operating cost, the large or medium-sized retailers reach an asymmetrical equilibrium. In contrast, startups achieve the No-No equilibrium. The main reason is that large and medium-sized retailers have more financial strength than startups to gain the competitive advantage from BOPS strategy. For start-ups, it is difficult to make omnichannel deployment due to financial constraints. This phenomenon is in line with reality, as we know of large companies such as Walmart, Best Buy, Apple, Suning, and Home Depot provide consumers with omnichannel shopping. But small-sized retailers rarely deploy an omnichannel strategy. Therefore, the omnichannel strategy is a lucrative opportunity for medium and large enterprises. Moreover, when the intensity of competition is moderate, retailers favor symmetric strategies as their size gets smaller. The first issue is that BOPS can only be profitable in a market with intense competition. Second, the greater operating costs of BOPS are unaffordable for small-scale enterprises to bear.

Corollary 2. When the intensity of competition is weak, all-sized competing retailers can reach the asymmetrical Nash equilibrium.

From the right regions of Fig. 8 shows that when the product differentiation m is large, competing retailers achieve the BOPS-No BOPS or No BOPS-BOPS strategy. That's because in the market with weak intensity of competition, the BOPS operating cost is relatively high, BOPS strategy may good fits with for luxury products with conspicuous consumers. Such consumers pay more attention to the personalized service of omnichannel strategy rather than price. If neither retailer offers the BOPS strategy, which hardly expands the market share and reaches new customers. If both retailers offer the BOPS strategy, which easily incurs vicious service competition. If a retailer adopts this strategy, it will increase the retail price because of the self-compensation effect. For this reason, the competitor who does not provide BOPS can still benefit from the increase in market share. Consequently, customers can benefit from the asymmetrical Nash equilibrium in this case.

4.3. Profitability analysis

Omnichannel retailing is a consumer-focused retail model. As a result, consumer surplus is a key area to explore when we examine BOPS strategy. Specifically, this section first analyzes equilibrium configuration from the perspective of consumers to ensure the highest total consumer surplus (TCS), and then explore the existence of a win–win situation between competing retailers and consumers. Specifically, the consumer surplus consists of LL, LH, HL and HH segments. The function of TCS is shown as follows:

$$TCS^{nn}=\underbrace{(\alpha+\theta-\alpha\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx-h_H\right)dx}_{purchase\ from\ retailer\ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)-h_H\right]dx}_{purchase\ from\ retailer\ B}\end{array}\right\}}_{LL,LH,HL}+\underbrace{(1-\alpha)(1-\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx-H\right)dx}_{purchase\ from\ retailer\ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)-H\right]dx}_{purchase\ from\ retailer\ B}\end{array}\right\}}_{HH} \tag{40}$$

$$TCS^{bn}=\underbrace{(\alpha+\theta-\alpha\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{bn}-mx-h_H\right)dx}_{purchase\ from\ retailer\ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{bn}-m(1-x)\right]dx}_{purchase\ from\ retailer\ B}\end{array}\right\}}_{LL,LH,HL}+\underbrace{(1-\alpha)(1-\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x'_{AB}}\left(v-p_A^{bn}-mx-(\lambda_s+\lambda_o)H\right)dx}_{purchase\ from\ retailer\ A}\\+\underbrace{\int_{x'_{AB}}^1\left[v-p_B^{bn}-m(1-x)-(\lambda_s+\lambda_o)H\right]dx}_{purchase\ from\ retailer\ B}\end{array}\right\}}_{HH} \tag{41}$$

$$TCS^{bb}=\underbrace{(\alpha+\theta-\alpha\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{bb}-mx-h_H\right)dx}_{purchase\ from\ retailer\ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{bb}-m(1-x)-h_H\right]dx}_{purchase\ from\ retailer\ B}\end{array}\right\}}_{LL,LH,HL}+\underbrace{(1-\alpha)(1-\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{bb}-mx-H\right)dx}_{purchase\ from\ retailer\ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{bb}-m(1-x)-H\right]dx}_{purchase\ from\ retailer\ B}\end{array}\right\}}_{HH} \tag{42}$$

Lemma 4. The total customers surplus in different scenarios are as follows:

(i) The total customers surplus of No-No strategy is:

$$TCS^{nn}=v-\frac{5m}{4}+\frac{(r-c)(1+\alpha-\theta)}{2}-\varepsilon H \tag{43}$$

(ii) The total customers surplus of BOPS-No BOPS strategy is:

$$Case\ S_i:TCS^{bn}=v-\frac{5}{4}m+\frac{\begin{array}{c}c^2\beta^2+(r-2k)^2\beta^2+24\beta\varepsilon\rho(r+2k)+36\varepsilon\rho^2(-5-4\alpha-4\theta+4\alpha\theta)\\+2c[54m(-3-9\alpha+3\theta+4\alpha\theta)+\beta(-2k\beta+r\beta-12\varepsilon\rho)]\\+108m[r(9+3\alpha-9\theta+4\alpha\theta)-2(k\beta-6\varepsilon\rho)]\end{array}}{1296m}-\varepsilon H \tag{44}$$

$$Case\ S_{ii}:TCS^{bn}=v-\frac{5}{4}m+\frac{\begin{array}{c}r^2(1-2\alpha)^2\theta^2+\left(4k^2+c^2\right)(1-\alpha-\theta+2\alpha\theta)^2+108mr(7-7\theta+5\alpha+2\alpha\theta)\\-4k(1-\alpha-\theta+2\alpha\theta)\left[54m+r(1-\alpha-\theta+2\alpha\theta)-r^2(\alpha-1)(1-2\theta-\alpha+4\alpha\theta)+2c(-2k+r)(1-\alpha-\theta+2\alpha\theta)^2\right]\\-r^2(\alpha-1)(1-2\theta-\alpha+4\alpha\theta)+2c\left[(-2k+r)(1-\alpha-\theta+2\alpha\theta)^2+54m(-5-7\alpha+5\theta+2\alpha\theta)\right]\end{array}}{1296m}-\varepsilon H \tag{45}$$

$$Case\ S_{iii}:TCS^{bn}=v-\frac{5}{4}m+\frac{-628m(c-r)(\alpha+1)+108m\theta[6(c-r)+(c-2k+r)\alpha]+(r+c-2k)^2\alpha^2\theta^2}{1296m}-\varepsilon H \tag{46}$$

(iii) The total customers surplus of BOPS- BOPS strategy is:

$$Case\ S_i:TCS^{bb}=v-\frac{5m}{4}+k\left(-1+\alpha+\theta-\frac{4\alpha\theta}{3}\right)+\frac{c\alpha(2\theta-3)+r(3-3\theta+2\alpha\theta)}{3}-\varepsilon H+\varepsilon\rho \tag{47}$$

$$Case\,S_{ii}:TCS^{bb}=v-\frac{5m}{4}+\frac{\alpha\theta(r+c-2k)+(\theta-1)(k+c-2r)+\alpha(r+k-2c)}{3}-\varepsilon H \tag{48}$$

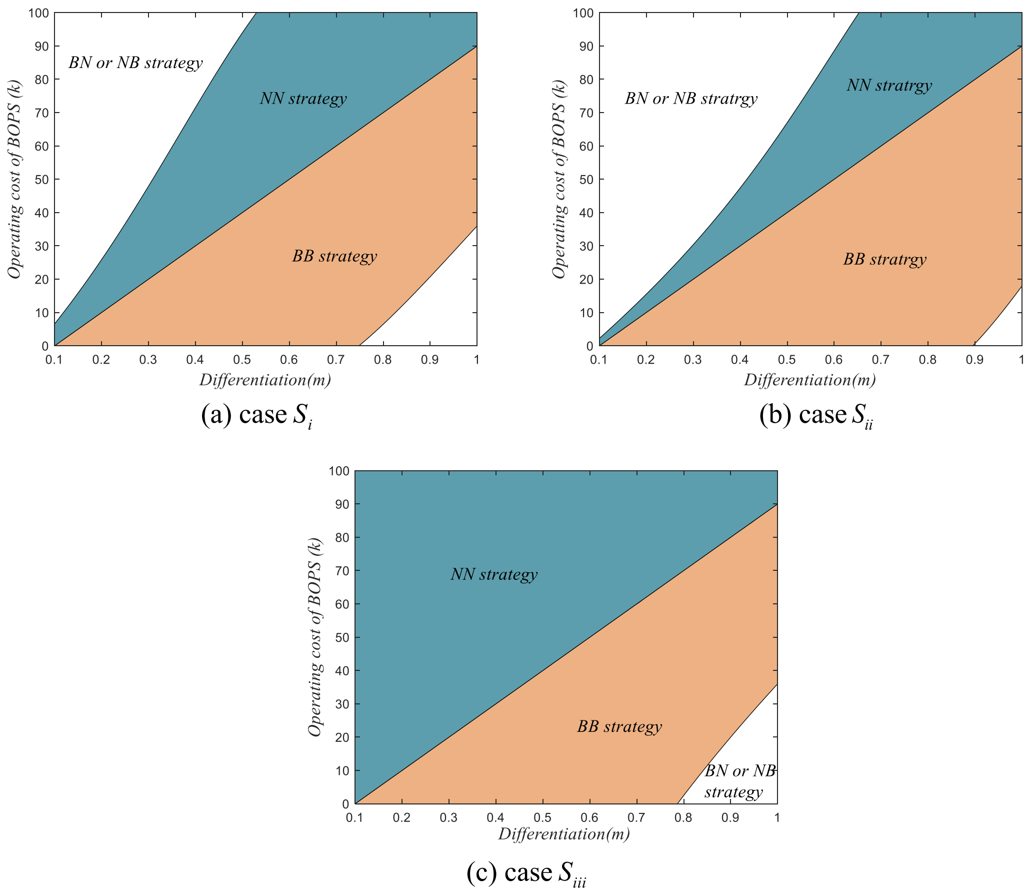


Fig. 9. The equilibrium strategy of customers preference with m.

$$\text{Case } S_{iii}: TCS^{bb} = v - \frac{5m}{4} + \frac{3(r-c)(1+\alpha-\theta)+\alpha\theta(c+r-2k)}{6} - \varepsilon H \tag{49}$$

Lemma 4 indicates that customers surplus decrease with the product differentiation and the upper limit of hassle cost. Since a fierce market environment will inevitably bring about service and price competition, customers could enjoy low prices and first-rate service from this situation. However, if time-sensitive consumers are far away from the nearest physical store, no matter whether they choose online or offline purchasing, they will incur excessive high hassle costs. Therefore, the expected utility of the product will decrease for customers. For improving the total customers surplus, omnichannel retailers should rationally allocate the number of the physical store and design the optimal service areas about the BOPS adoption. Then, the equilibrium results from the perspective of consumers are presented in Proposition 8.

Proposition 8. When the level of convenience of BOPS is strong, intermediate, and weak respectively, the consumer preference is determined by the following regions.

(i) Case S_i: for $0 < k \le \eta - \frac{24\rho+108m}{2\beta}$ and $k > \eta + \frac{54m}{\beta}$, customers prefer BOPS-No BOPS (or No BOPS-BOPS) strategy; for $\eta - \frac{24\rho+108m}{2\beta} < k \le \eta$, customers prefer BOPS- BOPS strategy;

for $\eta < k \le \eta + \frac{54m}{\beta}$, customers prefer No-No strategy;

(ii) Case S_{ii}: for $0 < k \le \eta - \frac{54m}{1-\alpha-\theta+2\alpha\theta}$ and $k > \eta + \frac{54m}{1-\alpha-\theta+2\alpha\theta}$, customers prefer BOPS-No BOPS (or No BOPS-BOPS) strategy; for $\eta - \frac{54m}{1-\alpha-\theta+2\alpha\theta} < k \le \eta$, customers prefer BOPS-BOPS strategy; for $\eta < k \le \eta + \frac{54m}{1-\alpha-\theta+2\alpha\theta}$, customers prefer No-No strategy;

(iii) Case S_{iii}: for $0 < k \le \eta - \frac{54m}{\alpha\theta}$ and $k > \eta + \frac{54m}{\alpha\theta}$, customers prefer BOPS-No BOPS (or No BOPS-BOPS) strategy; for $\eta - \frac{54m}{\alpha\theta} < k \le \eta$, customers prefer BOPS-BOPS strategy; for $\eta < k \le \eta + \frac{54m}{\alpha\theta}$, customers prefer No-No strategy;

Proposition 8 presents the strategy of customers preference in a competitive environment. When the BOPS operating cost k is low (or high) enough, the asymmetric strategy yields the highest surplus for consumers. This situation can be explained in the following aspects. First, retailer A with low BOPS operating costs provides information convenience, and the competitor could set a lower price to derive market share. Hence, in practice, consumers can obtain free-riding services from this situation, that is, they get inventory and price-related information at retailer A, and enjoy lower price from retailer B. Second, retailer A with higher BOPS operating costs provides shopping convenience (i.e., expand the service area of the store, smart shopping mode, items can be obtained in the shortest time). As a result, customers can enjoy more convenience or lower prices from the asymmetric equilibrium. When the BOPS operating cost k is intermediate, the symmetric strategy yields the highest surplus for consumers. This situation caused by the fact that the superiority of the BOPS is not conspicuous. Adopting the asymmetric strategy may not incur better omnichannel service, but may cause competitors to raise prices. Hence, customers are more willing to prefer the symmetric strategy in this situation.

In deriving insights regarding the impacts of competitiveness on equilibrium strategy from the perspective of consumers, we perform numerical studies to describe the equilibrium strategy of customers' preferences in different cases in Fig. 9. The difference reveals to us the

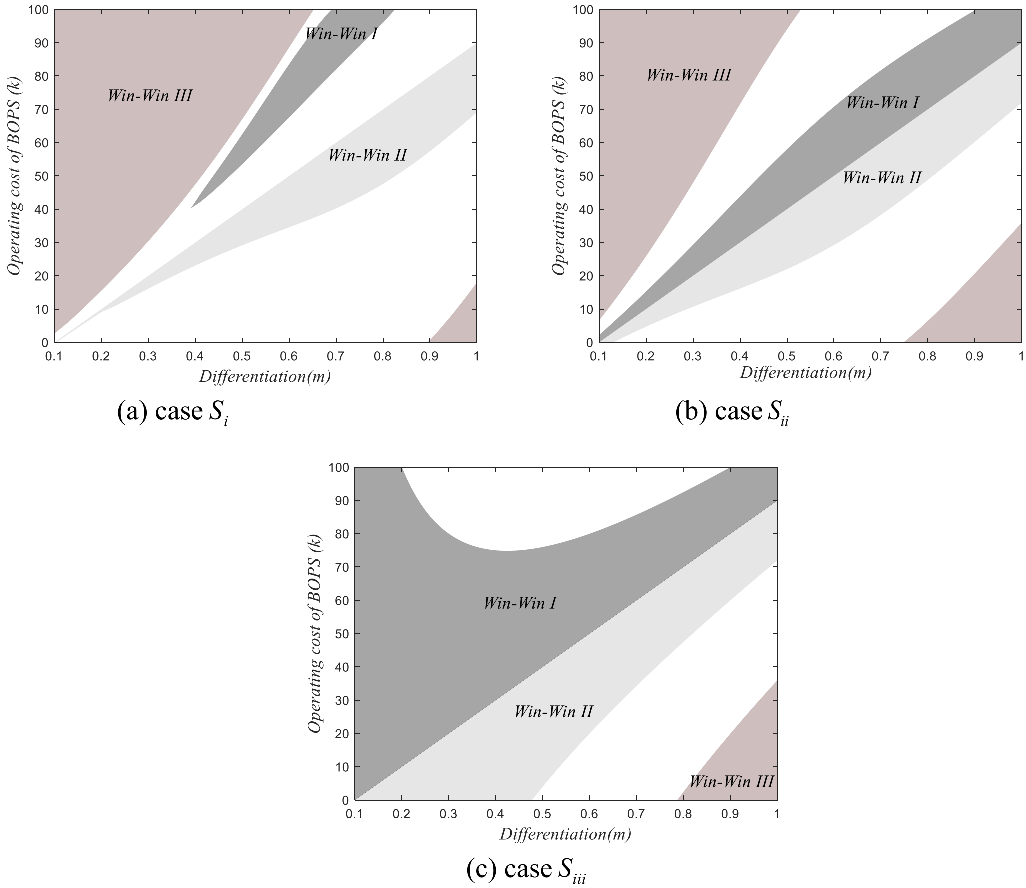


Fig. 10. The optimal equilibrium selection for win–win situation with m.

following insight:

Corollary 3. In a highly competitive market, some customers prefer the asymmetrical strategy of the large and medium-sized competing retailers. And some customers prefer the No-No strategy from the small-sized competing retailers; Otherwise, customers prefer the symmetrical strategy from all-sized competing retailers.

If the competition intensity is strong, customers benefit from the asymmetrical strategy of large and medium-sized competing retailers in Fig. 9(a) and (b). The phenomenon is caused by freeriding behavior. In practice, large and medium-sized retailers (i.e., Apple Inc.) will provide the price and customer service to compete in an intensely competitive market. After learning all the key information of products from the omnichannel services, they may purchase at a lower price from JD.com. We identify this phenomenon as freeriding. For the lack of competitiveness of small-sized retailers, blindly adopting an omnichannel strategy will increase the operational burden of retailers and need to increase sales prices to offset the losses. Hence, some consumers can't obtain benefits from this situation. In contrast, when the intensity of competition is intermediate and weak, the omnichannel strategy is difficult to exert its channel and service advantages. Therefore, the symmetric strategy can benefit more for consumers. Additionally, it is worth highlighting that the weaker the market competition, the larger the (N, N) region.

For the purpose of exploring win–win decision configurations that benefit both competing retailers and customers, we make a comparative analysis of the equilibrium conditions.

The light-grey region (Region I) represents the win–win situation where both competing retailers and customers are beneficial of No-No strategy.

The dark-grey region (Regions II) represents the win–win situation where both competing retailers and customers are beneficial of BOPS-BOPS strategy.

The dark-pink region (Regions III) represents the win–win situation where both competing retailers and customers are beneficial of asymmetrical strategy.

As illustrated in Fig. 10, three types of win–win regions are used in response to equilibrium strategy. It is noticeable that an appropriate equilibrium strategy based on a certain threshold of BOPS operating cost can be a win–win situation. This threshold is concluded as follows.

Corollary 4. In a simultaneous decision, the win–win situation is determined by the following regions.

(i) the deployment of No-No strategy enables the win–win situation, if and only if *Case* $S_i : \eta_2 < k \le \eta_3$, *Case* $S_{ii} : \eta \le k < \eta_5$, *Case* $S_{iii} : \eta \le k < \eta_5$;
(ii) the deployment of BOPS-BOPS strategy enables the win–win situation, if and only if *Case* $S_i : \eta_1 < k < \eta$, *Case* $S_{ii} : \eta_4 \le k < \eta$, *Case* $S_{iii} : \eta_6 \le k < \eta$;
(iii) the deployment of asymmetrical strategy enables the win–win situation, if and only if *Case* $S_i : 0 < k \le \eta - (24\rho + 108m)/2\beta$, $k > \eta + 54m/\beta$, *Case* $S_{ii} : 0 < k \le \eta - 54m/(1 - \alpha - \theta + 2\alpha\theta)$, $k > \eta + 54m/(1 - \alpha - \theta + 2\alpha\theta)$, *Case* $S_{iii} : 0 < k \le \eta - 54m/\alpha\theta$;

Corollary 4 indicates that retailers should implement the best response strategy to their opponents based on the BOPS operating costs to achieve maximum profits and customer satisfaction. Specifically, for large and medium-scale retailers, the stronger the intensity of market competition, the implementation of BOPS will expand the win–win situation. When the competition intensity is weak, the lower the BOPS

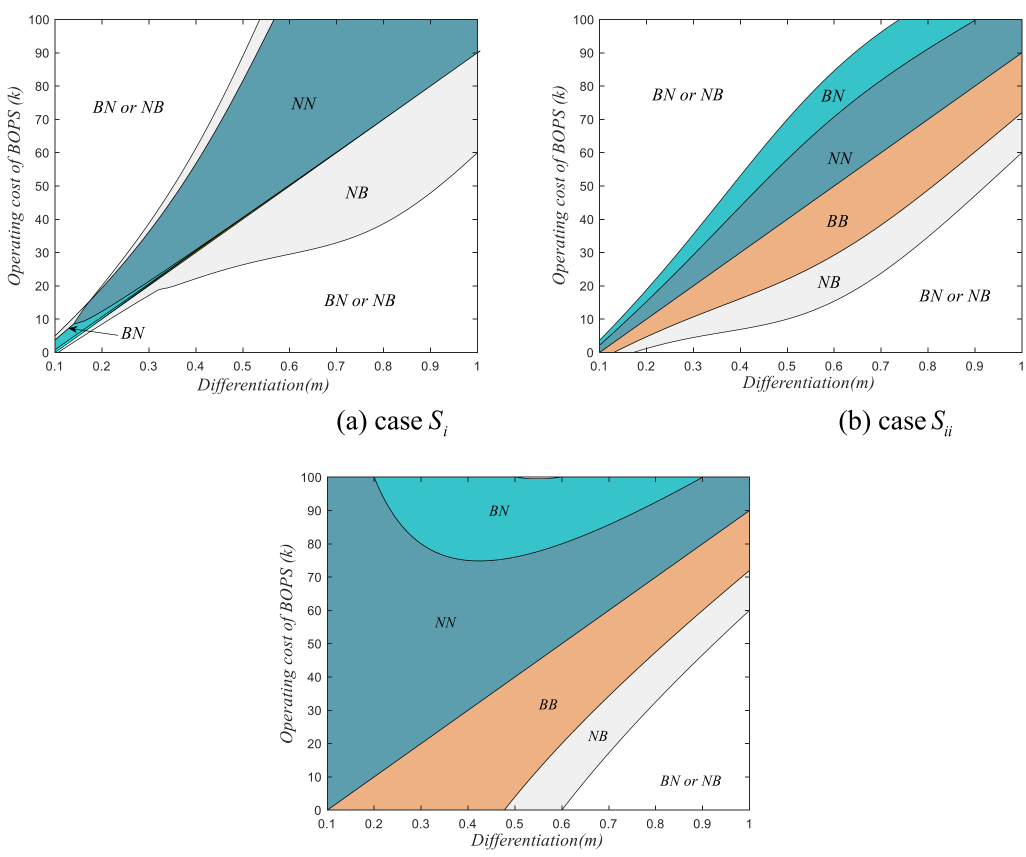
Table 6
The equilibrium outcomes in sequential decision.

Case	k	Relationship	Equilibrium
S_i	$(0, z_1]$, $(z_6, z_7]$, (z_{10}, ∞)	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_A^{nb*} > \prod_A^{bb*}\prod_A^{nb*} > \prod_A^{bb*}$	BN or NB
	$(z_1, z_2]$, $(z_9, z_{10}]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	NB
	$(z_2, z_3]$, $(\eta, z_5]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} < \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	BB
	$(z_3, \min(z_4, \eta)]$, $(z_7, z_8]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} < \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN
	$(z_8, z_9]$	$\prod_A^{bn*} < \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	NN
S_{ii}	$(0, \eta_8]$, (η_9, ∞)	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN or NB
	$(\eta_8, \eta_4]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	NB
	$(\eta_4, \eta]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} < \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	BB
	$(\eta, \eta_5]$	$\prod_A^{bn*} < \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	NN
	$(\eta_5, \eta_9]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN
S_{iii}	$(0, \eta_{10}]$, (η_{11}, ∞)	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN or NB
	$(\eta_{10}, \eta_6]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	NB
	$(\eta_6, \eta]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} < \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	BB
	$(\eta, \eta_7]$	$\prod_A^{bn*} < \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	NN
	$(\eta_7, \eta_{11}]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN

operating cost, the more conducive to asymmetrical strategy. This is because if both retailers provide a BOPS in this situation, they would need to set higher retail prices to compensate for the increased operating costs, which is not what consumers want. If neither retailer offers the BOPS, consumers cannot enjoy convenient shopping services.

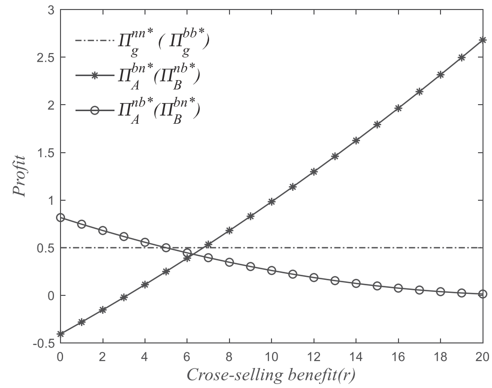
5. A duopoly with sequential decisions

In practice, it is common to observe that competition between retailers deploying BOPS and new entrants. For example, Amazon launched the BOPS strategy in 2017, and Walmart sequentially deployed BOPS in 2018. In this section, we discuss a duopoly game with sequential decisions to capture the best decision-making timing for

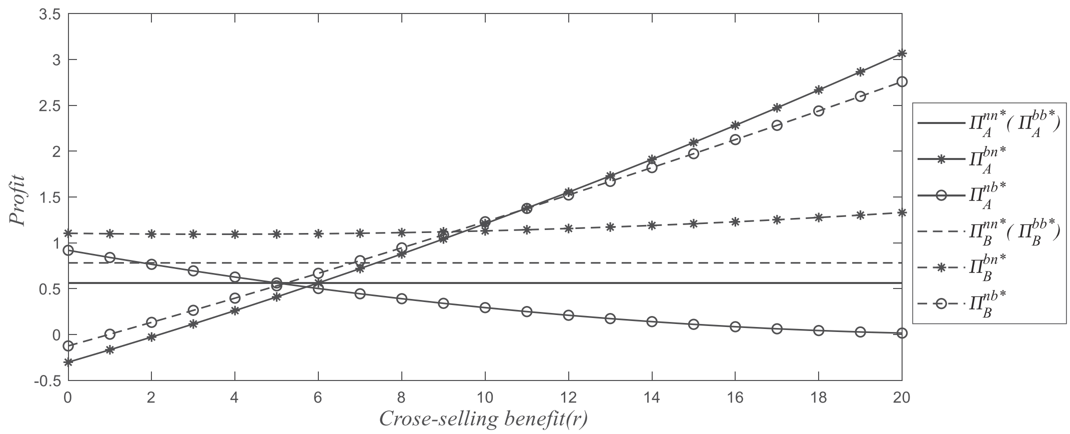


(a) case S_i (b) case S_{ii} (c) case S_{iii}

Fig. 11. The equilibrium region of competing retailers with m.

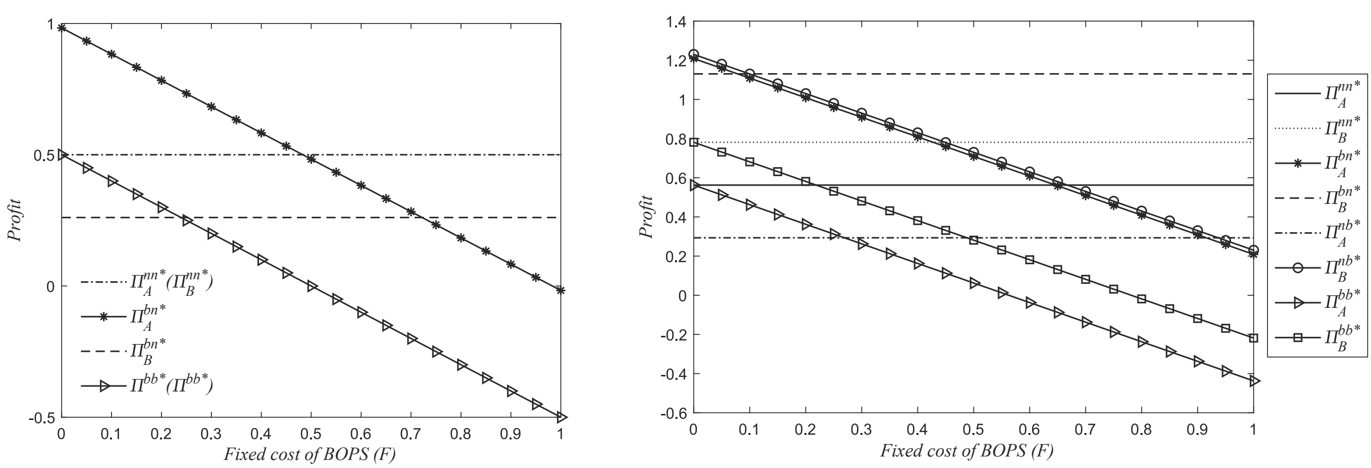


(a) Impact of the cross-selling benefit r in simultaneous decision



(b) Impact of the cross-selling benefit r in sequential decision

Fig. 12. Impact of the cross-selling benefit r on optimal profit. The following parameter values are used: $\alpha = 0.5$, $\theta = 0.5$, $m = 1$, $c = 4$, $k = 6$.



(a) simultaneous decision (b) sequential decision

Fig. 13. Impact of fixed cost of BOPS F on optimal profit. The following parameter values are used: $\alpha = 0.5$, $\theta = 0.5$, $m = 1$, $c = 4$, $k = 6$.

BOPS implementation. In this case, retailer A that the first to choose whether to deploy the BOPS acts as a Stackelberg leader, then retailer B acts as a Stackelberg follower. After both retailers make decisions, customers make their purchase decision. Appendix B is presented the solution procedure and equilibrium outcomes.

Proposition 9. In a sequential duopoly game, when the level of convenience of BOPS is strong, intermediate, and weak respectively, the equilibrium strategy is determined by the following regions.

(i) Case S_i: for $(0, z_1]$, $(z_6, z_7]$ and (z_{10}, ∞), the optimal equilibrium choice is the asymmetric strategy; for $(z_1, z_2]$ and $(z_9, z_{10}]$, the optimal equilibrium is No BOPS-BOPS strategy; for $(z_2, z_3]$ and $(\eta, z_5]$, the optimal equilibrium choice is the BOPS-BOPS strategy;

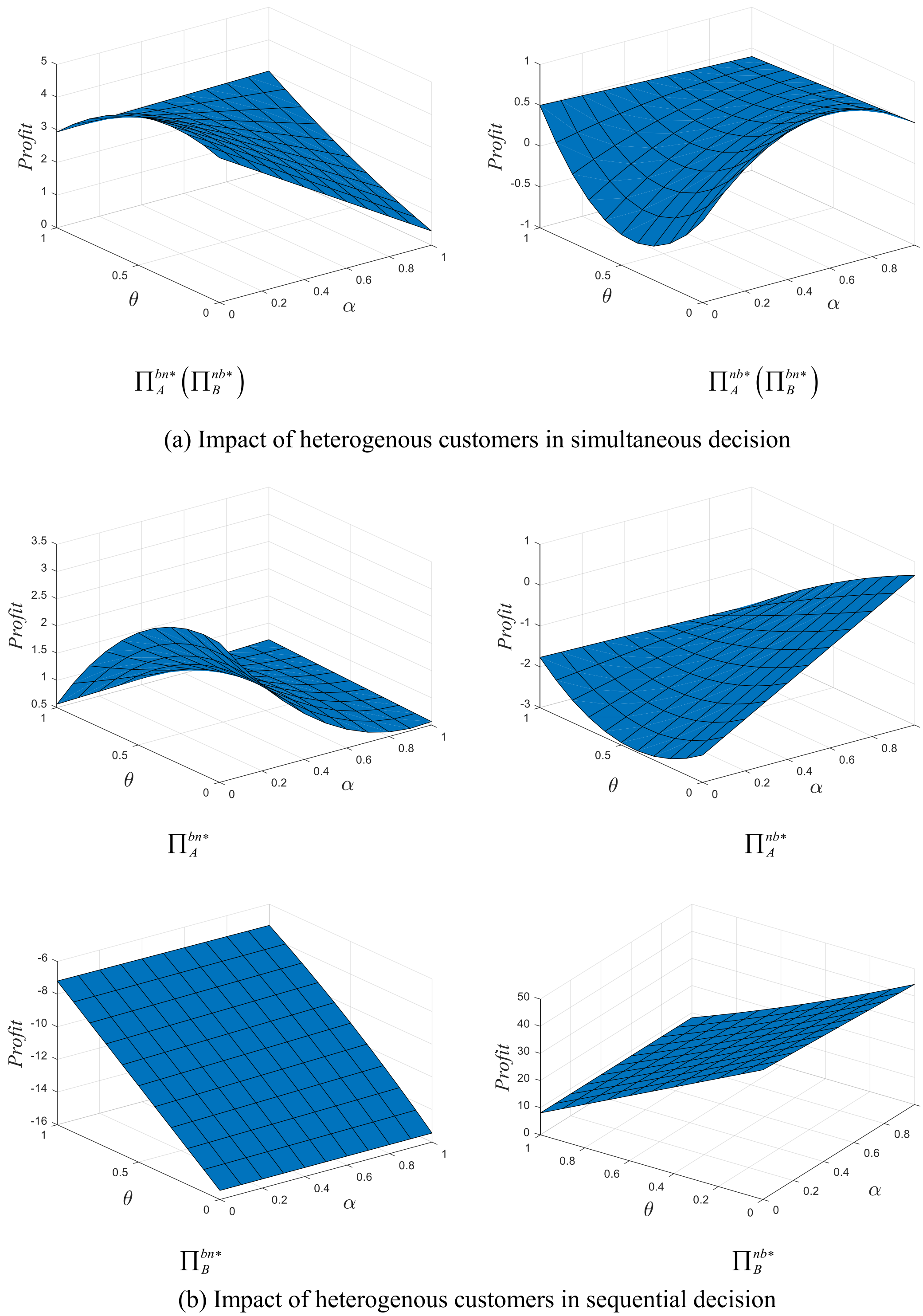


Fig. 14. Impact of heterogenous customers on optimal profit. The following parameter values are used:$m = 1$, $c = 4$, $k = 6$.

for $(z_3, \min(z_4, \eta))$, $(z_7, z_8]$, the optimal equilibrium choice is the BOPS-No BOPS strategy; for $(z_8, z_9]$, the optimal equilibrium is the No-No strategy;

(ii) Case S_{ii}: for $(0, \eta_8]$ and (η_9, ∞),the optimal equilibrium choice is an asymmetric strategy; for $(\eta_8, \eta_4]$, the optimal equilibrium choice is the No BOSP-BOPS strategy; for $(\eta_4, \eta]$, the optimal equilibrium choice is the BOPS-BOPS strategy; for $(\eta, \eta_5]$, the optimal equilibrium choice is the No-No strategy; for $(\eta_5, \eta_9]$, the optimal equilibrium choice is the BOPS-No BOPS strategy;

(iii) Case S_{iii}: for $(0, \eta_{10}]$, (η_{11}, ∞),the optimal equilibrium choice is an asymmetric strategy; for $(\eta_{10}, \eta_6]$,the optimal equilibrium choice is the No BOSP-BOPS strategy; for $(\eta_6, \eta]$, the optimal equilibrium choice is the BOPS-BOPS strategy; for $(\eta, \eta_7]$, the optimal equilibrium choice is the No-No strategy; for $(\eta_7, \eta_{11}]$, the optimal equilibrium choice is the BOPS-No BOPS strategy;where $\eta_8 = \eta - 30m/(1-\alpha-\theta+2\alpha\theta)$, $\eta_8 = \eta + 30m/(1-\alpha-\theta+2\alpha\theta)$, $\eta_{10} = \eta - 30m/\alpha\theta, \eta_{11} = \eta + 30m/\alpha\theta$. The threshold values z_1, z_2, z_3, z_4, z_5, z_6, z_7, z_8, z_9 are defined in Appendix B. Proposition 9

Table 7
Comparison results in simultaneous decision.

	k	$p_A^{bb*}-p_A^{nn*}$	$p_B^{bb*}-p_B^{nn*}$	$p_A^{bn*}-p_A^{nn*}$	$p_B^{bn}-p_B^{nn}$	$\prod_A^{bn*}-\prod_A^{nn*}$	$\prod_B^{bn*}-\prod_B^{nn*}$
$m=0.2$ $\lambda_s+\lambda_o=0.5$	2	−1.38333	−1.38333	−0.255556	−1.12778	20.8908	3.55193
	4	−0.83	−0.83	0.113333	−0.943333	12.518	2.78136
	6	−0.276667	−0.276667	0.482222	−0.758889	4.31534	2.18089
	8	0.276667	0.276667	0.851111	−0.574444	−3.71726	1.75052
	10	0.83	0.83	1.22	−0.39	−11.5798	1.49025
$m=0.5$ $\lambda_s+\lambda_o=1$	2	−0.858333	−0.858333	−0.572222	−0.286111	0.367971	−0.204252
	4	−0.515	−0.515	−0.343333	−0.171667	0.201136	−0.142197
	6	−0.171667	−0.171667	−0.114444	−0.0572222	0.0604966	−0.0539478
	8	0.171667	0.171667	0.1144444	0.0572222	−0.0539478	0.0604966
	10	0.515	0.515	0.343333	0.171667	−0.142197	0.201136
$m=0.8$ $\lambda_s+\lambda_o=1.5$	2	−0.595833	−0.595833	−0.397222	−0.198611	0.223265	−0.173957
	4	−0.3575	−0.3575	−0.238333	−0.119167	0.128042	−0.110291
	6	−0.119167	−0.119167	−0.0794444	−0.0397222	0.0407084	−0.0387361
	8	0.119167	0.119167	0.0794444	0.0397222	−0.0387361	0.0407084
	10	0.3575	0.3575	0.238333	0.119167	−0.110291	0.128042

presents the sequential decision results of retailers of different sizes in a duopoly environment. The equilibrium results and profits comparison of BOPS strategy implementation are shown in Table 6.

Proposition 9 reveals that the competing retailers prefer asymmetric strategies regardless of the sequence of decisions. But the decision sequence does affect the threshold scope for the optimal equilibrium. Specifically, when BOPS convenience is high and $k\in\{(z_1,z_2],(z_9,z_{10}]\}$, competing retailers prefer the NB equilibrium strategy. This shows that new entrants have the "first mover advantage" to make pricing decisions, and can quickly seize the retail market regardless of whether they deploy BOPS channels. If established retailers give up the BOPS strategy, and new entrants can only seize market share by deploying BOPS channels, otherwise it will be difficult to attract consumers' attention. Meanwhile, when $k\in\{(z_3,\min(z_4,\eta)],(z_7,z_8]\}$, new entrants can benefit by deploying BOPS channels. If new entrants adopt a consistent strategy, competing retailers will fall into vicious price competition in order to seize market share, which will seriously damage the total profits of retailers. As a result, established retailers tend to offer BOPS for more profits, and the best option for their competitors is to forgo the BOPS to benefit from additional market share (BN strategy). The above research results show that first-mover have leader-mover superiority deploying the BOPS, highlighting the importance of decision timing.

Fig. 11 illustrates equilibrium results in different cases with m in sequential decisions. Similar to the simultaneous decisions, when the competition intensity is strong, large and medium-sized retailers prefer an asymmetric equilibrium, and small-sized retailers prefer the No-No equilibrium.

Then, we compare the equilibrium strategies between Simultaneous and Sequential decisions. We conclude this result as follows.

Corollary 5. In sequential decisions, large-scale retailers rarely adopt the BOPS-BOPS strategy compared to simultaneous decisions, except for strong intensity of competition and lower operating cost.

In the sequential decision, there is no BOPS-BOPS region in the sequential decision of case S_i. Corollary 5 indicates the difference occurs because of the first mover superiority deploying the BOPS. Given the leader retailers deploy the BOPS to attract customers traffic, if followers implement the same strategy to gain the market share, they must reduce the sales price and improve the degree of convenience for BOPS. However, in this case, the leaders have comprehensively promoted the technology, logistics and staffing related to BOPS deployment, thus enhancing customer loyalty. Hence one can see that followers' implementation of BOPS strategy hardly obtain competitive advantage, which has intensified the burden of enterprise operation. Then, the followers have less incentive to increase BOPS channel advantage to attract consumers. As a result, large retailers rarely achieve BOPS-BOPS strategy equilibrium.

Corollary 6. Compared to simultaneous decisions, there are fewer equilibrium regions of BOPS-No BOPS (or No BOPS-BOPS) strategy under sequential decisions.

Corollary 6 reveals the difference comes from two aspects. On the one hand, this is because the equilibrium conditions for BOPS-No BOPS, No BOPS-BOPS and BOPS-No BOPS (or No BOPS-BOPS) are very different in the sequential decision. However, there is no difference in making simultaneous decisions. For instance, for large-scale retailers, the BOPS-No BOPS equilibrium strategy is optimal for the condition of higher competition and lower BOPS operating costs, while the No BOPS-BOPS equilibrium strategy is optimal for the condition of weaker competition and higher BOPS operating costs. For small and medium-sized enterprises, regardless of the competition intensity, the BOPS-No BOPS equilibrium strategy is optimal for higher BOPS operating costs and the NB equilibrium strategy is optimal for lower BOPS operating costs. On the other hand, from an information perspective, the difference between these two decisions is that it is up to the first mover retailer to decide whether to disclose information to competitors. Thus, the sequential decision making provides an information advantage to reduce uncertainty in retailer decisions.

Corollary 7. For large-scale retailers, when competition is intense and BOPS operating cost is small, No-No equilibrium is optimal for sequential decisions, while asymmetric equilibrium is optimal for simultaneous decisions.

Corollary 7 uncovers that the omnichannel strategy is seldom exploited as a crucial tool for competition, when large-scale retailers face a competitive situation and BOPS operating costs are small. The primary factor, in addition to providing effective logistics services or other service conveniences, is that large-scale retailers truly enjoy an indisputable economic superiority. In contrary, large-scale retailers are willing to deploy BOPS when there is less competition in the market. Additionally, we observe that the No-No equilibrium region is smaller in the case of simultaneous games compared to sequential decisions. The main reason is that sequential decisions also increase the confidence of first movers by removing the uncertainty faced by second movers. under the sequential decision, the second mover faces certainty as in the full-information case. If established retailers do not adopt BOPS, second movers with the advantage of information have even less incentive to deploy BOPS. As a result, competing retailers reach the No-No

Table 8
Comparison results in sequential decision.

	k	$p_A^{bb*}-p_A^{nn*}$	$p_B^{bb*}-p_B^{nn*}$	$p_A^{bn*}-p_A^{nn*}$	$p_B^{bn*}-p_B^{nn*}$	$p_A^{nb*}-p_A^{nn*}$	$p_B^{nb*}-p_B^{nn*}$	$\Pi_A^{bn*}-\Pi_A^{nn*}$	$\Pi_B^{bn*}-\Pi_B^{nn*}$	$\Pi_A^{nb*}-\Pi_A^{nn*}$	$\Pi_B^{nb*}-\Pi_B^{nn*}$
$m = 0.2$	2	−1.38333	−1.38333	−0.455417	−0.306458	−0.849167	−0.95875	4.3841	1.15109	0.50073	3.59328
$\lambda_s + \lambda_o = 0.5$	4	−0.83	−0.83	−0.17875	−0.168125	−0.5725	−0.54375	2.49122	1.15988	0.21657	2.03529
	6	−0.276667	−0.276667	0.0979167	−0.0297917	−0.295833	−0.12875	0.789703	1.26435	0.123772	0.572969
	8	0.276667	0.276667	0.374583	0.108542	−0.0191667	0.28625	−0.720453	1.46451	0.222334	−0.793666
	10	0.83	0.83	0.65125	0.246875	0.2575	0.70125	−2.03925	1.76034	0.512258	−2.06462
$m = 0.5$	2	−0.858333	−0.858333	−0.429167	−0.214583	−0.429167	−0.64375	0.413967	−0.222183	−0.229783	0.314275
$\lambda_s + \lambda_o = 1$	4	−0.515	−0.515	−0.2575	−0.12875	−0.2575	−0.38625	0.226278	−0.144361	−0.159972	0.177514
	6	−0.171667	−0.171667	−0.0858333	−0.0429167	−0.0858333	−0.12875	0.0680587	−0.051804	−0.060691	0.0554877
	8	0.171667	0.171667	0.0858333	0.0429167	0.0858333	0.12875	−0.0606913	0.0554877	0.0680587	−0.051804
	10	0.515	0.515	0.2575	0.12875	0.2575	0.38625	−0.159972	0.177514	0.226278	−0.144361
$m = 0.8$	2	−0.595833	−0.595833	−0.297917	−0.148958	−0.297917	−0.446875	0.251173	−0.17233	−0.195702	0.200066
$\lambda_s + \lambda_o = 1.5$	4	−0.3575	−0.3575	−0.17875	−0.089375	−0.17875	−0.268125	0.144047	−0.106726	−0.124078	0.116711
	6	−0.119167	−0.119167	−0.0595833	−0.0297917	−0.0595833	−0.089375	0.0457969	−0.0366849	−0.043578	0.0377943
	8	0.119167	0.119167	0.0595833	0.0297917	0.0595833	0.089375	−0.0435781	0.0377943	0.0457969	−0.036685
	10	0.3575	0.3575	0.17875	0.089375	0.17875	0.268125	−0.124078	0.116711	0.144047	−0.106726

equilibrium.

6. Sensitivity analysis and managerial insights

Since the calculation of the impact of omnichannel parameters on profits is complex, this section simulates the change path of optimal profits of the four equilibrium strategies under duopoly competition. We examine extensive numerical experiments to explore the impact of various parameters such as cross-selling benefit, fixed cost of BOPS, heterogenous customers, BOPS convenience, operation cost and competitive intensity on the optimal profit of retailers. Our finding aims to provide valuable management inspiration.

6.1. The impact of cross-selling benefit

Most consumers usually make impulsive purchases and buy unplanned items when shopping in stores (Halzack, 2015). Hence, we assume that consumers who pick up in-store generate additional consumption, which will bring cross-selling benefits. In deriving insights regarding the cross-selling benefits of omnichannel strategy, we now examine the impact of cross-selling benefit on optimal profit of large-scale retailers. As the dominant player, large-scale retailers are more willing to invest heavily in deploying the omnichannel, which makes the channel integration more complex. Therefore, it is necessary to consider the competition of large-scale enterprises under omnichannel retail with BOPS. Fig. 12 shows the impact of the cross-selling benefit on optimal profit under different decision-making timings.

As observed in Fig. 12, regardless of the timing of decision-making, a retailer who deploys the BOPS under an asymmetric strategy has a positive correlation with cross-selling benefits. In contrast, the retailer without adopting BOPS has a negative correlation with cross-selling benefits. This is a solid finding that is consistent with the reality and can be contributed to higher profits for large-scaled retailers deploying BOPS. In this case, retailers should make the most out of the cross-selling opportunity from the BOPS channel. For example, retail managers could put large face-value coupons or provide free product experience to attract consumers to make second purchases. In addition, Fig. 12 shows that the cross-selling benefits have almost no effect on the optimal profit under the symmetric strategy. And in the sequential game, retailer B always maintains the follower's late-strike advantage. This result reminds retailers of the importance of timing their decisions in symmetric strategies.

6.2. The impact of fixed cost of BOPS

In this subsection, we modify the main model and consider a more realistic extension assuming a fixed cost of BOPS implementation. Then, we make *F* represent the fixed facility cost of establishing BOPS channel. Fig. 11 presents the impact of fixed cost of BOPS on optimal profit under different decision-making timings.

Fig. 13 shows that the profits of retailers deploying the BOPS channel decrease with *F*, which means competitive retailers may choose not to offer BOPS if the fixed cost of BOPS increases. Moreover, retailers deploying the BOPS channel under the asymmetric strategy are more profitable than retailers under the BOPS-BOPS strategy. This suggests that when competitors do not implement BOPS, then retailers should consider BOPS fixed costs as an important parameter to make decisions. If the fixed cost is within a certain range, then it is beneficial to deploy BOPS. Additionally, we can find that new entrants have a profit advantage under asymmetric and BB strategy. This implies that, retailers that deploy BOPS first are not necessarily better off, depending on the timing of the decision.

6.3. The impact of heterogenous customers

In practice, customers are heterogeneous in both store hassle cost

Table A1
The demands of BOPS-No BOPS strategy.

Case	S_i	S_{ii}	S_{iii}
$D^{bn}_{A,s}$	$\left(\alpha - \frac{2}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\theta+2\alpha-\alpha\theta)x_{AB}$	$\frac{1}{2}\left(1-\theta+\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}$
$D^{bn}_{B,s}$	$\left(\alpha - \frac{1}{2}\alpha\theta\right)(1-x_{AB}) + \frac{1}{2}(1-\alpha)(1-\theta)(1-x'_{AB})$	$\frac{1}{2}(1-\theta+\alpha)(1-x_{AB})$	$\frac{1}{2}(1-\theta+\alpha)(1-x_{AB})$
$D^{bn}_{A,o}$	$\left(\theta - \frac{2}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\alpha+2\theta-\alpha\theta)x_{AB}$	$\frac{1}{2}\left(1+\theta-\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}$
$D^{bn}_{B,o}$	$\left(\theta - \frac{1}{2}\alpha\theta\right)(1-x_{AB}) + \frac{1}{2}(1-\alpha)(1-\theta)(1-x'_{AB})$	$\frac{1}{2}(1-\alpha+\theta)(1-x_{AB})$	$\frac{1}{2}(1-\alpha+\theta)(1-x_{AB})$
$D^{bn}_{A,b}$	$\frac{1}{3}\alpha\theta x_{AB} + (1-\alpha)(1-\theta)x'_{AB}$	$\frac{1}{3}(1-\theta-\alpha+2\alpha\theta)x_{AB}$	$\frac{1}{3}\alpha\theta x_{AB}$
$D^{bn}_{B,b}$	0	0	0

Table A2
The demands of BOPS-BOPS strategy.

Case	S_i	S_{ii}	S_{iii}
$D^{bb}_{A,s}$	$\left(\alpha - \frac{2}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\theta+2\alpha-\alpha\theta)x_{AB}$	$\frac{1}{2}\left(1-\theta+\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}$
$D^{bb}_{B,s}$	$\left(\alpha - \frac{2}{3}\alpha\theta\right)(1-x_{AB})$	$\frac{1}{3}(1-\theta+2\alpha-\alpha\theta)(1-x_{AB})$	$\frac{1}{2}\left(1-\theta+\alpha-\frac{1}{3}\alpha\theta\right)(1-x_{AB})$
$D^{bb}_{A,o}$	$\left(\theta - \frac{2}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\alpha+2\theta-\alpha\theta)x_{AB}$	$\frac{1}{2}\left(1+\theta-\alpha-\frac{1}{3}\alpha\theta\right)x_{AB}$
$D^{bb}_{B,o}$	$\left(\theta - \frac{2}{3}\alpha\theta\right)(1-x_{AB})$	$\frac{1}{3}(1-\alpha+2\theta-\alpha\theta)(1-x_{AB})$	$\frac{1}{2}\left(1+\theta-\alpha-\frac{1}{3}\alpha\theta\right)(1-x_{AB})$
$D^{bb}_{A,b}$	$\left(1-\theta-\alpha+\frac{4}{3}\alpha\theta\right)x_{AB}$	$\frac{1}{3}(1-\theta-\alpha+2\alpha\theta)x_{AB}$	$\frac{1}{3}\alpha\theta x_{AB}$
$D^{bb}_{B,b}$	$\left(1-\theta-\alpha+\frac{4}{3}\alpha\theta\right)(1-x_{AB})$	$\frac{1}{3}(1-\theta-\alpha+2\alpha\theta)(1-x_{AB})$	$\frac{1}{3}\alpha\theta(1-x_{AB})$

Table A3
The optimal prices comparison of different cases.

Case	Condition	Relationship
Case S_i	$k \le \eta - 3\varepsilon\rho/2\beta$	$p^{nn*}_A > p^{bn*}_A > p^{bb*}_A$, $p^{nn*}_B > p^{bn*}_B > p^{bb*}_B$
	$\eta - 3\varepsilon\rho/2\beta < k \le \eta$	$p^{bn*}_A > p^{nn*}_A > p^{bb*}_A$, $p^{nn*}_B > p^{bb*}_B > p^{bn*}_B$
	$\eta < k \le \eta + 3\varepsilon\rho/\beta$	$p^{bn*}_A > p^{bb*}_A > p^{nn*}_A$, $p^{bb*}_B > p^{nn*}_B > p^{bn*}_B$
	$k > \eta + 3\varepsilon\rho/\beta$	$p^{bb*}_A > p^{bn*}_A > p^{nn*}_A$, $p^{bb*}_B > p^{bn*}_B > p^{nn*}_B$
Case S_{ii} (Case S_{iii})	$k \le \eta$	$p^{bb*}_A > p^{bn*}_A > p^{nn*}_A$, $p^{bb*}_B > p^{bn*}_B > p^{nn*}_B$
	$k > \eta$	$p^{nn*}_A > p^{bn*}_A > p^{bb*}_A$, $p^{nn*}_B > p^{bn*}_B > p^{bb*}_B$

Table A4
The equilibrium outcomes in simultaneous game.

Case	k	Relationship	Equilibrium
S_i	$(0,\eta_1)$, $[\eta,\eta_2)$, $[\eta_3,+\infty)$	$\Delta\prod^{bn*}_A > 0$, $\Delta\prod^{bn*}_B > 0$	BN or NB
	$[\eta_1,\eta)$	$\Delta\prod^{bn*}_A > 0$, $\Delta\prod^{bn*}_B < 0$	BB
	$[\eta_2,\eta_3)$	$\Delta\prod^{bn*}_A < 0$, $\Delta\prod^{bn*}_B > 0$	NN
S_{ii}	$(0,\eta_4)$ or $[\eta_4,+\infty)$	$\Delta\prod^{bn*}_A > 0$, $\Delta\prod^{bn*}_B > 0$	BN or NB
	$[\eta_4,\eta)$	$\Delta\prod^{bn*}_A > 0$, $\Delta\prod^{bn*}_B < 0$	BB
	$[\eta,\eta_5)$	$\Delta\prod^{bn*}_A < 0$, $\Delta\prod^{bn*}_B > 0$	NN
S_{iii}	$(0,\eta_6)$ or $[\eta_7,+\infty)$	$\Delta\prod^{bn*}_A > 0$, $\Delta\prod^{bn*}_B > 0$	BN or NB
	$[\eta_6,\eta)$	$\Delta\prod^{bn*}_A > 0$, $\Delta\prod^{bn*}_B < 0$	BB
	$[\eta,\eta_7)$	$\Delta\prod^{bn*}_A < 0$, $\Delta\prod^{bn*}_B > 0$	NN

Table A5
The comparison results of TCS in different subgames.

Case	k	Relationship	Equilibrium
Case S_i	$0 < k \le \eta - \frac{24\rho+108m}{2\beta}$	$TCS^{bn} > TCS^{bb} > TCS^{nn}$	BN
	$\eta - \frac{24\rho+108m}{2\beta} < k \le \eta$	$TCS^{bb} > TCS^{bn} > TCS^{nn}$	BB
	$\eta < k \le \eta + \frac{54m}{\beta}$	$TCS^{nn} > TCS^{bn} > TCS^{bb}$	NN
	$k > \eta + \frac{54m}{\beta}$	$TCS^{bn} > TCS^{nn} > TCS^{bb}$	BN
Case S_{ii}	$0 < k \le \eta - \frac{54m}{1-\alpha-\theta+2\alpha\theta}$	$TCS^{bn} > TCS^{bb} > TCS^{nn}$	BN
	$\eta - \frac{54m}{1-\alpha-\theta+2\alpha\theta} < k \le \eta$	$TCS^{bb} > TCS^{bn} > TCS^{nn}$	BB
	$\eta < k \le \eta + \frac{54m}{1-\alpha-\theta+2\alpha\theta}$	$TCS^{nn} > TCS^{bb} > TCS^{bn}$	NN
	$k > \eta + \frac{54m}{1-\alpha-\theta+2\alpha\theta}$	$TCS^{bn} > TCS^{nn} > TCS^{bb}$	BN
Case S_{iii}	$0 < k \le \eta - \frac{54m}{\alpha\theta}$	$TCS^{bn} > TCS^{bb} > TCS^{nn}$	BN
	$\eta - \frac{54m}{\alpha\theta} < k \le \eta$	$TCS^{bb} > TCS^{bn} > TCS^{nn}$	BB
	$\eta < k \le \eta + \frac{54m}{\alpha\theta}$	$TCS^{nn} > TCS^{bb} > TCS^{bn}$	NN
	$k > \eta + \frac{54m}{\alpha\theta}$	$TCS^{bn} > TCS^{nn} > TCS^{bb}$	BN

and online hassle cost, e.g., different sensitivities to visiting the store or waiting for products arrival. For characterizing this phenomenon, we now examine the impact of heterogenous the impact of heterogenous customers on optimal profit under different decision-making timings. It highlights that the profits of competing retailers under symmetric strategy are not affected by heterogeneous consumers. Hence, Fig. 14 exhibits the impact of heterogenous customers under asymmetric strategy.

As highlighted in Fig. 14, regardless of the timing of decision-making, the optimal profit of retailer A under the BOPS-No BOPS (No BOPS-BOPS) strategy decreases (increases) with α,but increases (decreases) first and then decreases (increases) with θ.This is intuitive, if the store hassle cost is high, retailer deploying BOPS is difficult to attract

Table A6
The equilibrium outcomes of BOPS strategy in a sequential Game.

Case	k	Relationship	Equilibrium
S_i	$(0, z_1]$, $(z_6, z_7]$, (z_{10}, ∞)	$\prod_A^{bn*} > \prod_A^{nn*}\prod_A^{nb*} > \prod_A^{bb*}\prod_A^{nb*} > \prod_A^{bb*}\prod_A^{nb*} > \prod_A^{bb*}$	BN or NB
	$(z_1, z_2]$, $(z_9, z_{10}]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	NB
	$(z_2, z_3]$, $(\eta, z_5]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} < \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	BB
	$(z_3, \min(z_4, \eta)]$, $(z_7, z_8]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} < \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN
	$(z_8, z_9]$	$\prod_A^{bn*} < \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	NN
S_{ii}	$(0, \eta_8]$, (η_9, ∞)	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN or NB
	$(\eta_8, \eta_4]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	NB
	$(\eta_4, \eta]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} < \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	BB
	$(\eta, \eta_5]$	$\prod_A^{bn*} < \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	NN
	$(\eta_5, \eta_9]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN
S_{iii}	$(0, \eta_{10}]$, (η_{11}, ∞)	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN or NB
	$(\eta_{10}, \eta_6]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	NB
	$(\eta_6, \eta]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} < \prod_A^{bb*}, \prod_B^{nb*} > \prod_B^{nn*}\prod_B^{bn*} < \prod_B^{bb*}$	BB
	$(\eta, \eta_7]$	$\prod_A^{bn*} < \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	NN
	$(\eta_7, \eta_{11}]$	$\prod_A^{bn*} > \prod_A^{nn*}, \prod_A^{nb*} > \prod_A^{bb*}, \prod_B^{nb*} < \prod_B^{nn*}\prod_B^{bn*} > \prod_B^{bb*}$	BN

consumers to pick up offline. Then, customers will choose to purchase from the competitor (retailer B) for lower prices. Surprisingly, we find that if the online hassle cost is relatively moderate, it can promote the profit of retailer A. However, if the online hassle cost is higher, retailer A will lose its competitive strength in the market, resulting in the benefits of its competitors. Therefore, for the BOPS-No BOPS strategy, retailer A should open more physical stores to fulfill the hassle-free pickup process under an intermediate online delivery efficiency. For the No BOPS-BOPS strategy, retailer A should enhance the online delivery efficiency with intermediate number of physical stores to attract online purchases.

Additionally, we can find that the optimal of retailer B is influenced by the timing of the decision. In a simultaneous game, the optimal profit of retailer B under BOPS-No BOPS (No BOPS-BOPS) strategy increases (decreases) with α, but decreases (increases) first and then increases (decreases) with θ. Whereas, in a sequential game, the optimal profit of retailer B under BOPS-No BOPS (No BOPS-BOPS) strategy increases (decreases) with θ,but has no significant effect on α. This finding reveals that new entrants may lose favor with some heterogeneous consumers (e.g., sensitive to visiting the store). Hence, for the No BOPS-BOPS strategy, retailer B should enhance the online delivery efficiency and increases the number of physical stores to take the competitive advantage in the market.

6.4. *The impact of BOPS convenience, operation cost and competitive intensity*

This section explicitly describes the effects of BOPS operating costs, BOPS convenience, and decision timing on retailer strategies. There are two main points: first, the differences between BB, BN, NB and NN strategies are explored; second, the impact of BOPS on retailers' decisions at different decision timings is discussed. The comparison results are shown in Tables 7 and 8.

As shown in Tables 7 and 8, although the introduction of BOPS can reduce the selling price in most cases, it can increase the profitability of retailers. Especially, deploying BOPS in a highly competitive environment can capture a favorable market share. However, when the BOPS operating costs $k > 8$, offering BOPS could damage the profits of retailers. And, the lower convenience of the BOPS channel will lead to lower profits for retailers. This result is consistent with practice. For example, physical stores where pickup is available are too far away, making travel costs too high and causing most consumers to prefer to buy online. Moreover, the asymmetric equilibrium strategy is the optimal choice for win–win situation, when the convenience of BOPS and competitive intensity is high. This is beneficial for both retailers and customers. Then, in terms of decision timing, if the intensity of competition and BOPS convenience decreases, first-mover retailers with BOPS are more profitable than second-mover retailers with BOPS. As a result, there exists first-mover superiority deploying the BOPS exists in duopoly setting.

7. Conclusion

This paper constructs a multi-stage, non-cooperative game to investigate the impact of the BOPS operating costs, consumer heterogeneity, and market competition intensity on retailers' price decisions from a competitive perspective. We first consider the situation when competing retailers simultaneously decide on whether to adopt the BOPS. There are four possible scenarios for deriving an equilibrium conclusion in a duopoly market, namely No-No, BOPS-No BOPS or No BOPS-BOPS, and BOPS-BOPS strategy. Then, we make a comparative analysis of the equilibrium conditions from the perspective of consumers and retailers, thus justifying the existence of a win–win situation. After that, we extend the investigation to the case with the sequential decision. Finally, numerical examples are provided to analyze the impact of cross-selling benefits and heterogeneous customer behavior on optimal profit. The results show that different intensities of competition, size of retailers, decision sequence, as well as the BOPS operating costs will affect the equilibrium results. Thus, competing retailers should fully consider these factors before deploying BOPS. Our finding was compared with previous studies to provide a novel way to design the BOPS for responding to competitors to maximize customer-oriented profits. We summarize the main managerial insights for decision-makers as follows.

(i) *The interaction of three effects.* Our results highlight that omni-channel retailers should utilize the interaction of three effects to dominate strategy superiority and optimize strategic decisions. Specifically, *the channel migration effect* shows that if the hassle cost associated with BOPS decreases, more customers shift to this channel. Retailers can use online coupons as a means of price regulation to lock in the advantages of the BOPS channel, guide channel shift, and promote interactive integration and effective connection of channels. *The price self-compensation effect* reveals that setting a higher price is to compensate for the negative impact of high BOPS operating costs on profits. In practice, customers are willing to pay for extra instant gratification avoiding long waits. Retailers could charge the premium price generating price discrimination for achieving excess profit under a duopoly context. It is noticeable that *the limited market share effect* highlights the fact that the adoption of BOPS is not always optimal, but still obtains some limited market share. Therefore, start-ups can occupy a certain market share by deploying BOPS. However, if retailers want to continue to benefit, they should improve the convenience of BOPS. For example, utilize new technologies to match the picking distance and marketing services.

(ii) *Utilize the results of competitive equilibrium.* To mitigate omnichannel problems for retail giant, medium-sized and startups, we discuss the equilibrium results regarding the BOPS in the duopoly setting. As a result of our study, when the competition intensity is high, the large and medium-sized retailers should seriously consider the asymmetric equilibrium strategy. Meanwhile, small-sized competing retailers should consider abandoning the deployment of BOPS to avoid more economic loss. In contrast, all-sized competing retailers can benefit from the asymmetrical equilibrium when competition intensity is low. In such situation, BOPS strategy may good fits with for luxury products with conspicuous consumers.

(iii) *Win-win situation.* To explore win–win decision configurations that benefit both competing retailers and customers, we make a comparative analysis of the equilibrium conditions from the perspective of consumers and retailers. Our main findings are twofold. On the one hand, it is noticeable that an appropriate equilibrium strategy can be achieved a win–win situation based on a certain threshold of BOPS operating cost. This result can guide retail managers implement the best response policy to their opponents achieving maximum profits and customer satisfaction. On the other hand, contrary to the common view that strong intensity of competition will reduce win–win region. Our results show that the stronger the intensity of market competition, the implementation of BOPS will expand the win–win situation for large and medium-scale retailers. Therefore, retail managers should carefully consider the impact of competition intensity before deploying BOPS.

(iv) *Decision-making timing.* The investigation extends to broader cases with the sequential decision for investigating the impact of decision-making timing of retailers on equilibrium results. Contrary to the common view that second-mover superiority, we find that leader-mover superiority deploying the BOPS. Therefore, the new entrants should keep cautious optimism about a solution to deploy BOPS. Especially when the intensity of competition is strong, the new entrants comprehensively optimize BOPS service level and upgrade consumers' shopping experience. Besides, the competing retailers may get higher profits in the sequential decision. This is because the retailer's pricing in the sequential game is higher. Therefore, it is very important for competitors to grasp the decision-making timing for pricing and profitability. Moreover, the cross-selling benefit is more significant for competing retailers in the sequential decision. Thus, retail managers could put large face-value coupons or provide a free product experience to attract consumers to make second purchases. Additionally, new entrants may lose favor with heterogeneous consumers. Hence, for the No BOPS-BOPS strategy, new entrants should enhance the online delivery efficiency and increase the number of physical stores, thus dominating the market competition advantage.

Future research can be expanded to explore return strategy in omnichannel retail operations. Aside from the BOPS strategy, we can explore other omnichannel strategies (i.e., SFS, BORP, and showrooms) across a variety of competing contexts, including a mixed duopoly and monopoly.

CRediT authorship contribution statement

Chenchen Ge: Conceptualization, Methodology, Formal analysis, Validation, Writing – original draft, Writing – review & editing. **Jianjun Zhu:** Conceptualization, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A

Lemma 1. (1) For LL-type customers ($\alpha\theta$), we have $U_{A,s} = U_{A,o} = v - p_A - mx$, $U_{B,s} = U_{B,o} = v - p_B - m(1-x)$. We can determine the preferred location of LL-type customers $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,s} = U_{B,s}$ or $U_{A,o} = U_{B,o}$. Consumers with $0 \le x \le x_{AB}$ prefer offline (or online) channel of retailer A, consumers with $x_{AB} < x \le 1$ prefer offline (or online) channel of retailer B.

(2) For LH-type customers ($\alpha(1-\theta)$), we have $U_{A,s} = v - p_A - mx$, $U_{A,o} = v - p_A - mx - H$;$U_{B,s} = v - p_B - m(1-x)$, $U_{B,o} = v - p_B - m(1-x) - H$. It can be seen that $U_{A,s} > U_{A,o}$, $U_{B,s} > U_{B,o}$. We can determine the preferred location of LH-type customers $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,s} = U_{B,s}$.Thus consumers with $0 \le x \le x_{AB}$ prefer offline channel of retailer A, consumers with $x_{AB} < x \le 1$ prefer offline channel of retailer B.

(3) For HL-type customers ($(1-\alpha)\theta$), we have $U_{A,s} = v - p_A - mx - H$, $U_{A,o} = v - p_A - mx$;$U_{B,s} = v - p_B - m(1-x) - H$, $U_{B,o} = v - p_B - m(1-x)$. It can be seen that $U_{A,o} > U_{A,s}$, $U_{B,o} > U_{B,s}$.We can determine the preferred location of LL-type customers x_{AB} by solving $U_{A,o} = U_{B,o}$.Thus consumers with $0 \le x \le x_{AB}$ prefer online channel of retailer A, consumers with $x_{AB} < x \le 1$ prefer online channel of retailer B.

(4) For HH-type customers ($(1-\alpha)(1-\theta)$), we have $U_{A,s} = U_{A,o} = v - p_A - mx - H$, $U_{B,s} = U_{B,o} = v - p_B - m(1-x) - H$. We can determine the preferred location of HH-type customers x_{AB} by solving $U_{A,s} = U_{B,s}$ or $U_{A,o} = U_{B,o}$.Thus consumers with $0 \le x \le x_{AB}$ prefer offline (or online) channel of retailer A, consumers with $x_{AB} < x \le 1$ prefer offline (or online) channel of retailer B.

As a result, the demands of offline and online channel for retailer A and B are as follows:

$$\begin{cases} D_{A,s}^{nn} = \dfrac{(1-\theta+\alpha)}{2}x_{AB}, D_{A,o}^{nn} = \dfrac{(1-\alpha+\theta)}{2}x_{AB} \\ D_{B,s}^{nn} = \dfrac{(1-\theta+\alpha)}{2}(1-x_{AB}), D_{B,o}^{nn} = \dfrac{(1-\alpha+\theta)}{2}(1-x_{AB}) \end{cases} \tag{A.1}$$

Proof of proposition 1

In the scenario of No-No strategy, the demands of offline and online channel for retailer A and B are as follows:

$$\begin{cases} D_{A,s}^{nn} = \dfrac{(1-\theta+\alpha)}{2}x_{AB}, D_{A,o}^{nn} = \dfrac{(1-\alpha+\theta)}{2}x_{AB} \\ D_{B,s}^{nn} = \dfrac{(1-\theta+\alpha)}{2}(1-x_{AB}), D_{B,o}^{nn} = \dfrac{(1-\alpha+\theta)}{2}(1-x_{AB}) \end{cases} \tag{A.2}$$

The expected profit functions of No-No strategy are:

$$\prod_A^{nn} = \underbrace{\frac{1}{2}(1-\theta+\alpha)x_{AB}(p_A-c+r)}_{\text{offline store:half LL,LH, half HH}} + \underbrace{\frac{1}{2}(1+\theta-\alpha)x_{AB}p_A}_{\text{online store:half LL,HL, half HH}} \tag{A.3}$$

$$\prod_B^{nn} = \underbrace{\frac{1}{2}(1-\theta+\alpha)(1-x_{AB})(p_B-c+r)}_{\text{offline store:half LL,LH, half HH}} + \underbrace{\frac{1}{2}(1+\theta-\alpha)(1-x_{AB})p_B}_{\text{online store:half LL,LH, half HH}} \tag{A.4}$$

where $x_{AB} = (p_B - p_A)/2m + 1/2$. The optimal profit function is concave in p_i, as $\partial^2\prod_i^{nn}/\partial {p_i}^2 = -1/m < 0$, $i = A, B$.Given $\frac{\partial\prod_A^{nn}}{\partial p_A} = \frac{2m+(c-r)(1+\alpha-\theta)-4p_1+2p_2}{4m} = 0$, $\frac{\partial\prod_B^{nn}}{\partial p_B} = \frac{2m+(c-r)(1+\alpha-\theta)-4p_2+2p_1}{4m} = 0$. From the first order conditions (FOC), we derive the optimal price $p_A^{nn} = p_B^{nn} = m + (c-r)(1+\theta-\alpha)/2$. Then substituting prices in profit functions, the profits of retailers are $\prod_A^{nn} = \prod_B^{nn} = m/2$.

Lemma 2. (1) For LL-type customers ($\alpha\theta$), we have $U_{A,s} = U_{A,o} = U_{A,b} = v - p_A - mx$, $U_{B,s} = U_{B,o} = v - p_B - m(1-x)$. We can determine the preferred location of LL-type customers $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,s} = U_{B,s}$ or $U_{A,o} = U_{B,o}$. Thus, consumers with $0 \leq x \leq x_{AB}$ prefer any channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer any channel of retailer B.

(2) For LH-type customers ($\alpha(1-\theta)$), we have $U_{A,s} = v - p_A - mx$, $U_{A,o} = v - p_A - mx - H$, $U_{A,b} = v - p_A - mx - \lambda_o H$;$U_{B,s} = v - p_B - m(1-x)$, $U_{B,o} = v - p_B - m(1-x) - H$. It can be seen that $U_{A,s} > U_{A,b} > U_{A,o}$, $U_{B,s} > U_{B,o}$.We can determine the preferred location of LH-type customers $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,s} = U_{B,s}$. Thus, consumers with $0 \leq x \leq x_{AB}$ prefer offline channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer offline channel of retailer B.

(3) For HL-type customers ($(1-\alpha)\theta$), we have $U_{A,s} = v - p_A - mx - H$, $U_{A,o} = v - p_A - mx$, $U_{A,b} = v - p_A - mx - \lambda_s H$;$U_{B,s} = v - p_B - m(1-x) - H$, $U_{B,o} = v - p_B - m(1-x)$. It can be seen that $U_{A,o} > U_{A,b} > U_{A,s}$, $U_{B,o} > U_{B,s}$.We can determine the preferred location of LL-type customers $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,o} = U_{B,o}$. Thus, consumers with $0 \leq x \leq x_{AB}$ prefer online channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer online channel of retailer B.

(4) or HH-type customers ($(1-\alpha)(1-\theta)$), we have $U_{A,s} = U_{A,o} = v - p_A - mx - H$, $U_{A,b} = v - p_A - mx - (\lambda_s + \lambda_o)H$;$U_{B,s} = U_{B,o} = v - p_B - m(1-x) - H$. Case S_i: $U_{A,b} > U_{A,s} = U_{A,o}$, $U_{B,s} = U_{B,o}$. We can determine the preferred location of HH-type customers $x'_{AB} = (p_B - p_A)/2m + 1/2 + (1 - \lambda_s - \lambda_o)H/2m$ by solving $U_{A,b} = U_{B,s}(or\ U_{B,o})$. Thus, consumers with $0 \leq x \leq x'_{AB}$ prefer BOPS channel of retailer A, consumers with $x'_{AB} < x \leq 1$ prefer offline (or online) channel of retailer B; Case S_{ii}: $U_{A,b} = U_{A,s} = U_{A,o}$, $U_{B,s} = U_{B,o}$. And the preferred location of HH-type customers is $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,s} = U_{B,s}$ or $U_{A,o} = U_{B,o}$. Thus, consumers with $0 \leq x \leq x_{AB}$ prefer any channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer offline (or online) channel of retailer B; Case S_{iii}: $U_{A,s} = U_{A,o} > U_{A,b}$, $U_{B,s} = U_{B,o}$.And the preferred location is $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,s} = U_{B,s}$. Thus, consumers with $0 \leq x \leq x_{AB}$ prefer offline (or online) channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer offline (or online) channel of retailer B.

As a result, the demands of offline, online and BOPS channel for retailer A and B are as follows:

Proof of proposition 2

(i) Case S_i: The optimal profit function is concave in p_i, as $\partial^2\prod_i^{bn}/\partial {p_i}^2 = -1/m < 0$. Applying the first order conditions in (9) and (10).

$$\frac{\partial\prod_A^{bn}}{\partial p_A} = \frac{3k(1-\alpha) + \theta[3r - 2\alpha(r+c) + k(4\alpha-3)] + 3(m - r + c\alpha + \rho) - 6p_1 + 3p_2}{6m} = 0$$

$$\frac{\partial\prod_B^{bn}}{\partial p_B} = \frac{2m + (c-r)(1+\alpha-\theta) - 2\rho + 2p_1 - 4p_2}{4m} = 0$$

It is straightforward to derive the optimal price:

$$p_A^{bn*} = m + \varepsilon\frac{\rho}{3} + \frac{4k\beta - r(3\alpha + 15 - 15\theta + 8\alpha\theta) + c(3 + 15\alpha - 8\alpha\theta - 3\theta)}{18}$$

$$p_B^{bn*} = m - \varepsilon\frac{\rho}{3} + \frac{k\beta - r(6 + 3\alpha - 6\theta + 2\alpha\theta) + c(3 + 6\alpha - 2\alpha\theta - 3\theta)}{9}$$

Then substituting prices in profit functions, the profits of retailers are

$$\prod_A^{bn*} = \frac{[18m + \beta(c-2k+r)]^2 - 12\varepsilon\rho\begin{bmatrix} -3(c-2k+r+6m+8c\alpha-7k\alpha-r\alpha) \\ +\theta[3(c+7k-8r)+14\alpha(c+r-2k)] \end{bmatrix} + 36\varepsilon^2\rho^2}{648m}$$

$$\prod_B^{bn*} = \frac{[18m - (r+c-2k)\beta]^2 + 6\varepsilon\rho\begin{bmatrix} 6(c-2k+r-6m)+3\alpha(-11c+4k+7r) \\ +\theta[21c+12k-33r+8\alpha(r+c-2k)] \end{bmatrix} + 36\varepsilon^2\rho^2}{648m}$$

(ii) Case S_{ii}: The optimal profit function is concave in p_i, as $\partial^2\prod_i^{bn}/\partial p_i^2 = -1/m < 0$. Applying the first order conditions in (11) and (12).

$$\frac{\partial\prod_A^{bn}}{\partial p_A} = \frac{k+c+3m-2r+2c\alpha-k\alpha-r\alpha-\theta[k+c-2r+\alpha(r+c-2k)]-6p_1+3p_2}{6m} = 0$$

$$\frac{\partial\prod_B^{bn}}{\partial p_B} = \frac{2m+(c-r)(1+\alpha-\theta)+2p_1-4p_2}{4m} = 0$$

It is straightforward to derive the optimal price:

$$p_A^{bn*} = m + \frac{c(7+11\alpha-4\alpha\theta-7\theta)-r(11+7\alpha-11\theta+4\alpha\theta)+k(4-4\alpha-4\theta+8\alpha\theta)}{18}$$

$$p_B^{bn*} = m + \frac{c(4+5\alpha-4\theta-\alpha\theta)-r(5+4\alpha+\alpha\theta-5\theta)+k(1-\alpha-\theta+2\alpha\theta)}{9}$$

Then substituting prices in profit functions, the profits of retailers are

$$\prod_A^{bn*} = \frac{[18m+(c-2k+r)(1-\alpha-\theta+2\alpha\theta)]^2}{648m} \quad \prod_B^{bn*} = \frac{[18m-(c-2k+r)(1-\alpha-\theta+2\alpha\theta)]^2}{648m}$$

(iii) Case S_{iii}: The optimal profit function is concave in p_i, as $\partial^2\prod_i^{bn}/\partial p_i^2 = -1/m < 0$. Applying the first order conditions in (13) and (14).

$$\frac{\partial\prod_A^{bn}}{\partial p_A} = \frac{6m+3c(1+\alpha)+2k\alpha\theta-c\theta(3+\alpha)-r(3-3\theta+3\alpha+\alpha\theta)-12p_1+6p_2}{12m} = 0$$

$$\frac{\partial\prod_B^{bn}}{\partial p_B} = \frac{2m+(c-r)(1+\alpha-\theta)+2p_1-4p_2}{4m} = 0$$

It is straightforward to derive the optimal price:

$$p_A^{bn*} = m + \frac{(9+9\alpha-9\theta)(c-r)-2\alpha\theta(c+r-2k)}{18} \quad p_B^{bn*} = m + \frac{9c(\alpha+1)+2\alpha\theta k-c\theta(9+\alpha)-r(9-9\theta+9\alpha+\alpha\theta)}{18}$$

Then substituting prices in profit functions, the profits of retailers are

$$\prod_A^{bn*} = \frac{[18m+(c-2k+r)\alpha\theta]^2}{648m} \quad \prod_B^{bn*} = \frac{[18m-(c-2k+r)\alpha\theta]^2}{648m}$$

Proof of proposition 3

For notational convenience, we define the following parameters: $\rho = (1-\lambda_s-\lambda_o)H$, $\beta = 3-3\alpha-3\theta+4\alpha\theta$, $\varepsilon = (1-\alpha)(1-\theta)$, $\eta = (r+c)/2$.

$$Case\ S_i : \prod_A^{bn*} - \prod_B^{bn*} = \frac{24m\varepsilon\rho + 4m(r+c-2k)\beta - 3\varepsilon\rho[3\alpha(r+2k-3c)+3\theta(c+2k-3r)+4\alpha\theta(c+r-2k)]}{36m}$$

The benefit of establishing the BOPS channel is given by $\prod_A^{bn*} - \prod_B^{bn*} \geq 0$ for $k \leq \frac{4m(r+c)\beta+3\varepsilon\rho[8m+9c\alpha-3r\alpha-(3c-9r+4c\alpha+4r\alpha)\theta]}{8m\beta+6\varepsilon\rho(3\alpha+3\theta-4\alpha\theta)}$.

$$Case\ S_{ii} : \prod_A^{bn*} - \prod_B^{bn*} = \frac{(c-2k+r)(1-\alpha-\theta+2\alpha\theta)}{9} \quad Case\ S_{iii} : \prod_A^{bn*} - \prod_B^{bn*} = \frac{(c-2k+r)\alpha\theta}{9}$$

The benefit of establishing the BOPS channel is given by $\prod_A^{bn*} - \prod_B^{bn*} \geq 0$ for $Case\ S_{ii}$ and $Case\ S_{iii}$, we can obtain $k \leq \eta$.

Proof of proposition 4

We compare the optimal prices of different retailers and find that: $Case\ S_i : p_A^{bn*} - p_B^{bn*} = -\frac{(c-2k+r)\beta}{18} + \frac{2\varepsilon\rho}{3}$,

$$Case\ S_{ii} : p_A^{bn*} - p_B^{bn*} = -\frac{(c-2k+r)(1-\alpha-\theta+2\alpha\theta)}{18}$$

$$Case\ S_{iii}: p_A^{bn*} - p_B^{bn*} = -\frac{(c-2k+r)\alpha\theta}{18}$$

$\because Case\ S_i: p_A^{bn*} - p_B^{bn*} = -\frac{(c-2k+r)\beta}{18} + \frac{2\varepsilon\rho}{3} \geq \frac{12\rho - 3(c-2k+r)}{18}$.

$\therefore$if $k > \eta - 2\varepsilon\rho$, we have $Case\ S_i: p_A^{bn*} > p_B^{bn*}$.

$\because$if $k > \eta$, we have $p_A^{bn*} > p_B^{bn*}$ for $Case\ S_{ii}$ and $Case\ S_{iii}$.

$\therefore$regardless of any cases, if $k > \eta$, we have $p_A^{bn*} > p_B^{bn*}$.

Lemma 3. (1) For LL-type customers ($\alpha\theta$), we have $U_{A,s} = U_{A,o} = U_{A,b}$, $U_{B,s} = U_{B,o} = U_{B,b}$. We can determine the preferred location of LL-type customers $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,s} = U_{B,s}$, or $U_{A,o} = U_{B,o}$, or $U_{A,b} = U_{B,b}$. Thus, consumers with $0 \leq x \leq x_{AB}$ prefer any channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer purchasing any channel of retailer B.

(2) For LH-type customers ($\alpha(1-\theta)$), we have $U_{A,s} = v - p_A - mx$, $U_{A,o} = v - p_A - mx - H$, $U_{A,b} = v - p_A - mx - \lambda_o H$;$U_{B,s} = v - p_B - m(1-x)$, $U_{B,o} = v - p_B - m(1-x) - H$, $U_{B,b} = v - p_B - m(1-x) - \lambda_o H$. It can be seen that $U_{A,s} > U_{A,b} > U_{A,o}$, $U_{B,s} > U_{B,b} > U_{B,o}$. We can determine the preferred location of LH-type customers $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,s} = U_{B,s}$. Thus, consumers with $0 \leq x \leq x_{AB}$ prefer offline channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer offline channel of retailer B.

(3) For HL-type customers ($(1-\alpha)\theta$), we have $U_{A,s} = v - p_A - mx - H$, $U_{A,o} = v - p_A - mx$, $U_{A,b} = v - p_A - mx - \lambda_s H$;$U_{B,s} = v - p_B - m(1-x) - H$, $U_{B,o} = v - p_B - m(1-x)$, $U_{B,b} = v - p_B - m(1-x) - \lambda_s H$. It can be seen that $U_{A,o} > U_{A,b} > U_{A,s}$, $U_{B,o} > U_{B,b} > U_{B,s}$. We can determine the preferred location of LL-type customers $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,o} = U_{B,o}$. Thus, consumers with $0 \leq x \leq x_{AB}$ prefer online channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer online channel of retailer B.

(4) For HH-type customers ($(1-\alpha)(1-\theta)$), we have $U_{A,s} = U_{A,o} = v - p_A - mx - H$, $U_{A,b} = v - p_A - mx - (\lambda_s + \lambda_o)H$;$U_{B,s} = U_{B,o} = v - p_B - m(1-x) - H$, $U_{B,b} = v - p_A - m(1-x) - (\lambda_s + \lambda_o)H$. For Case S_i:$U_{A,b} > U_{A,s} = U_{A,o}$, $U_{B,b} > U_{B,s} = U_{B,o}$, we can determine the preferred location of HH-type customers $x_{AB} = (p_B - p_A)/2m + 1/2$ by solving $U_{A,b} = U_{B,b}$. Thus, consumers with $0 \leq x \leq x_{AB}$ prefer BOPS channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer BOPS channel of retailer B; For case S_{ii}: $U_{A,b} = U_{A,s} = U_{A,o}$, $U_{B,b} = U_{B,s} = U_{B,o}$. Consumers with $0 \leq x \leq x_{AB}$ prefer any channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer offline (or online) channel of retailer B; For Case S_{iii}: $U_{A,s} = U_{A,o} > U_{A,b}$, $U_{B,s} = U_{B,o} > U_{B,b}$. Consumers with $0 \leq x \leq x_{AB}$ prefer offline (or online) channel of retailer A, consumers with $x_{AB} < x \leq 1$ prefer offline (or online) channel of retailer B.

As a result, the demands of offline, online and BOPS channel for retailer A and B are as follows:

Proof of proposition 5

Similar to the process of solving Proposition 1 and Proposition 2. We can obtain the optimal prices and profits are as follows:

$$Case\ S_i: p_A^{bb*} = p_B^{bb*} = m + \frac{c(3\alpha - 2\alpha\theta) - r(3 - 3\theta + 2\alpha\theta) + k\beta}{3}$$

$$Case\ S_{ii}: p_A^{bb*} = p_B^{bb*} = m + \frac{c(1 + 2\alpha - \theta - \alpha\theta) - r(2 + \alpha - 2\theta + \alpha\theta) + k(1 - \alpha - \theta + 2\alpha\theta)}{3}$$

$$Case\ S_{iii}: p_A^{bb*} = p_B^{bb*} = m + \frac{c(3 + 3\alpha - 3\theta - \alpha\theta) - r(3 + 3\alpha - 3\theta + \alpha\theta) + 2k\alpha\theta}{6}$$

$$\prod_A^{bb*} = \prod_B^{bb*} = \frac{m}{2}$$

Proof of proposition 6

By comparing the optimal prices of different cases, we obtain the following the results:

Proof of proposition 7

Lemma 4. For the scenario of No-No strategy, half LL-, half HH– and LH-type customers choose offline channel, whereas Half LL-, half HH– and HL-type customers choose online channel. Therefore, the function of TCS is shown as follows:

$$TCS^{nn}=\underbrace{\frac{1}{2}\alpha\theta\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx\right)dx}_{purchase\ \ from\ \ retailer\ \ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)\right]dx}_{purchase\ \ from\ \ retailer\ \ B}\end{array}\right\}+\alpha(1-\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx\right)dx}_{purchase\ \ from\ \ retailer\ \ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)\right]dx}_{purchase\ \ from\ \ retailer\ \ B}\end{array}\right\}+\frac{1}{2}(1-\alpha)(1-\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx-H\right)dx}_{purchase\ \ from\ \ retailer\ \ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)-H\right]dx}_{purchase\ \ from\ \ retailer\ \ B}\end{array}\right\}}_{BP:\ \ half\ \ LL,LH,half\ \ HH}$$

$$+\underbrace{\frac{1}{2}\alpha\theta\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx\right)dx}_{purchase\ \ from\ \ retailer\ \ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)\right]dx}_{purchase\ \ from\ \ retailer\ \ B}\end{array}\right\}+(1-\alpha)\theta\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx\right)dx}_{purchase\ \ from\ \ retailer\ \ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)\right]dx}_{purchase\ \ from\ \ retailer\ \ B}\end{array}\right\}+\frac{1}{2}(1-\alpha)(1-\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx-H\right)dx}_{purchase\ \ from\ \ retailer\ \ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)-H\right]dx}_{purchase\ \ from\ \ retailer\ \ B}\end{array}\right\}}_{BO:halfLL,HL,halfHH}$$

$$=\underbrace{(\alpha+\theta-\alpha\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx\right)dx}_{purchase\ \ from\ \ retailer\ \ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)\right]dx}_{purchase\ \ from\ \ retailer\ \ B}\end{array}\right\}}_{LL,LH,HL}+\underbrace{(1-\alpha)(1-\theta)\left\{\begin{array}{c}\underbrace{\int_0^{x_{AB}}\left(v-p_A^{nn}-mx-H\right)dx}_{purchase\ \ from\ \ retailer\ \ A}\\+\underbrace{\int_{x_{AB}}^1\left[v-p_B^{nn}-m(1-x)-H\right]dx}_{purchase\ \ from\ \ retailer\ \ B}\end{array}\right\}}_{HH}$$

$$=v-\frac{5m}{4}+\frac{(r-c)(1+\alpha-\theta)}{2}-\varepsilon H$$

Similarly, we analyze the scenarios of BOPS-No BOPS and BOPS-BOPS strategy. We directly state the results:

$$Case\ \ S_i:TCS^{bn}=v-\frac{5}{4}m+\frac{\begin{array}{c}c^2\beta^2+(r-2k)^2\beta^2+24\beta\varepsilon\rho(r+2k)+36\varepsilon\rho^2(-5-4\alpha-4\theta+4\alpha\theta)\\+2c[54m(-3-9\alpha+3\theta+4\alpha\theta)+\beta(-2k\beta+r\beta-12\varepsilon\rho)]\\+108m[r(9+3\alpha-9\theta+4\alpha\theta)-2(k\beta-6\varepsilon\rho)]\end{array}}{1296m}-\varepsilon H$$

$$Case\ \ S_{ii}:TCS^{bn}=v-\frac{5}{4}m+\frac{\begin{array}{c}r^2(1-2\alpha)^2\theta^2+\left(4k^2+c^2\right)(1-\alpha-\theta+2\alpha\theta)^2+108mr(7-7\theta+5\alpha+2\alpha\theta)\\-4k(1-\alpha-\theta+2\alpha\theta)\left[54m+r(1-\alpha-\theta+2\alpha\theta)-r^2(\alpha-1)(1-2\theta-\alpha+4\alpha\theta)+2c(-2k+r)(1-\alpha-\theta+2\alpha\theta)^2\right]\\-r^2(\alpha-1)(1-2\theta-\alpha+4\alpha\theta)+2c\left[(-2k+r)(1-\alpha-\theta+2\alpha\theta)^2+54m(-5-7\alpha+5\theta+2\alpha\theta)\right]\end{array}}{1296m}-\varepsilon H$$

$$Case\ \ S_{iii}:TCS^{bn}=v-\frac{5}{4}m+\frac{-628m(c-r)(\alpha+1)+108m\theta[6(c-r)+(c-2k+r)\alpha]+(r+c-2k)^2\alpha^2\theta^2}{1296m}-\varepsilon H$$

$$Case\ S_i:TCS^{bb}\ =v-\frac{5m}{4}+k\left(-1+\alpha+\theta-\frac{4\alpha\theta}{3}\right)+\frac{c\alpha(2\theta-3)+r(3-3\theta+2\alpha\theta)}{3}-\varepsilon H+\varepsilon\rho Case\,S_{ii}:TCS^{bb}\ =v-\frac{5m}{4}+\frac{\alpha\theta(r+c-2k)+(\theta-1)(k+c-2r)+\alpha(r+k-2c)}{3}-\varepsilon H$$

$$Case\ \ S_{iii}:TCS^{bb}=v-\frac{5m}{4}+\frac{3(r-c)(1+\alpha-\theta)+\alpha\theta(c+r-2k)}{6}-\varepsilon H$$

Proof of proposition 8

Appendix B

For notational convenience, we define the following parameters:

$$\left\{\begin{array}{c}
z_1 = \dfrac{-30m + \beta(r+c) - 6\sqrt{25m^2 - 10m\varepsilon\rho - \varepsilon^2\rho^2}}{2\beta} \\
z_2 = \dfrac{-18m + \beta(r+c) - 6\sqrt{9m^2 + 6m\varepsilon\rho - \varepsilon^2\rho^2}}{2\beta} \\
z_3 = \dfrac{-30m + \beta(r+c) + 6\sqrt{25m^2 - 10m\varepsilon\rho - \varepsilon^2\rho^2}}{2\beta} \\
z_4 = \dfrac{-18m + \beta(r+c) + 6\sqrt{9m^2 + 6m\varepsilon\rho - \varepsilon^2\rho^2}}{2\beta} \\
z_5 = \dfrac{-18m\beta + \beta^2(r+c) - 9\rho + 3\sqrt{36m^2\beta^2 + 4\beta\rho(9m + 4c\beta - 4r\beta + 6m\beta\varepsilon) + \rho^2\left(9 - 4\beta^2\varepsilon^2\right)}}{2\beta^2} \\
z_6 = \dfrac{-30m\beta + \beta^2(r+c) + 18\rho + 3\sqrt{100m^2\beta^2 - 20m\beta\rho(6 + \beta\varepsilon) + \rho^2\left(36 - \beta^2\varepsilon^2\right)}}{2\beta^2} \\
z_7 = \dfrac{30m\beta + \beta^2(r+c) + 18\rho - 6\sqrt{25m^2\beta^2 - 10m\beta\rho(-3 + \beta\varepsilon) + \rho^2\left(9 - \beta^2\varepsilon^2\right)}}{2\beta^2} \\
z_8 = \dfrac{18m\beta + \beta^2(r+c) + 27\rho - 9\sqrt{4m^2\beta^2 - 4m\beta\rho(-3 + \beta\varepsilon) + \rho^2\left(9 - \beta^2\varepsilon^2\right)}}{2\beta^2} \\
z_9 = \dfrac{30m\beta + \beta^2(r+c) + 18\rho + 6\sqrt{25m^2\beta^2 - 10m\beta\rho(-3 + \beta\varepsilon) + \rho^2\left(9 - \beta^2\varepsilon^2\right)}}{2\beta^2} \\
z_{10} = \dfrac{18m\beta + \beta^2(r+c) + 27\rho + 9\sqrt{4m^2\beta^2 - 4m\beta\rho(-3 + \beta\varepsilon) + \rho^2\left(9 - \beta^2\varepsilon^2\right)}}{2\beta^2}
\end{array}\right\}$$

(5) No-No strategy:

$$p_A^{nn*} = \frac{3m + (c-r)(1+\alpha-\theta)}{2} p_B^{nn*} = \frac{5m + 2(c-r)(1+\alpha-\theta)}{4} \prod_A^{nn*} = \frac{9m}{16} \prod_B^{nn*} = \frac{25m}{32}$$

(6) BOPS-No BOPS strategy:

Case S_i:$p_A^{bn*} = \frac{9m+c(3+3\alpha-2\alpha\theta)+r(3\theta-2\alpha\theta-6)+k\beta}{6} + \frac{3\varepsilon\rho(1+2\alpha-2\theta)}{6(1+\alpha-\theta)}$

$$p_B^{bn*} = \frac{15m + c(9 + 3\alpha - 2\alpha\theta) + r(3\theta - 2\alpha\theta - 12) + k\beta}{12} + \frac{3\varepsilon\rho(2\alpha - 2\theta - 1)}{12(1+\alpha-\theta)}$$

$$\prod_A^{bn*} = \frac{\begin{array}{c}[18m + (r+c-2k)\beta]^2 + 81\varepsilon^2\rho^2 + 324m\varepsilon\rho \\ -6\varepsilon\rho[-9(r+c-2k) - 39c\alpha + 30k\alpha + 9r\alpha + \theta[9c + 30k - 39r + 20\alpha(r+c-2k)]]\end{array}}{576m}$$

$$\prod_B^{bn*} = \frac{\begin{array}{c}[(r+c-2k)\beta + 15m]^2 + 9\varepsilon^2\rho^2 + 180m\varepsilon\rho \\ -6\varepsilon\rho[3(-7r - 2k + 2k\alpha - 9r\alpha + 9c + 7\alpha c) + \theta(-27c + 6k + 21r + 4\alpha(r+c-2k))]\end{array}}{1152m}$$

Case S_{ii}:$p_A^{bn*} = \frac{18m+c(3+7\alpha-2\alpha\theta-5\theta)-r(7+5\alpha-7\theta+2\alpha\theta)+k(2-2\alpha-2\theta+4\alpha\theta)}{12}$

$$p_B^{bn*} = \frac{30m + c(11 + 13\alpha - 2\alpha\theta - 11\theta) - r(13 + 11\alpha - 13\theta + 2\alpha\theta) + k(2 - 2\alpha - 2\theta + 4\alpha\theta)}{24}$$

$$\prod_A^{bn*} = \frac{[18m + (r+c-2k)(1-\alpha-\theta+2\alpha\theta)]^2}{576m} \prod_B^{bn*} = \frac{[(r+c-2k)(1-\alpha-\theta+2\alpha\theta) - 30m]^2}{1152m}$$

Case S_{iii}:$p_A^{bn*} = \frac{18m+c(6+6\alpha-\alpha\theta-6\theta)-r(6+6\alpha-6\theta+\alpha\theta)+2k\alpha\theta}{12}$

$$p_B^{bn*} = \frac{30m + c(12 + 12\alpha - 12\theta - \alpha\theta) - r(12 + 12\alpha - 12\theta + \alpha\theta) + 2k\alpha\theta}{24}$$

$$\prod_A^{bn*} = \frac{[18m + (r+c-2k)\alpha\theta]^2}{576m} \prod_B^{bn*} = \frac{[(r+c-2k)\alpha\theta - 30m]^2}{1152m}$$

(7) BOPS-BOPS strategy:

Case S_i:

$$p_A^{bb*} = \frac{9m - 6r + 6k(1-\alpha) + 6c\alpha + 2\theta[3r - 2\alpha(r+c) + k(4\alpha - 3)]}{6} p_B^{bb*} = k + \frac{5m}{4} - r + (c-k)\alpha + \frac{\theta[3r - 2\alpha(r+c) + k(4\alpha-3)]}{3}$$

Case S_{ii}:$p_A^{bb*} = \frac{9m - 2c(-1-2\alpha+\alpha\theta+\theta) - 2r(2+\alpha-2\theta+\alpha\theta) + k(2-2\alpha-2\theta+4\alpha\theta)}{6}$

$$p_B^{bb*} = \frac{15m - 4c(-1-2\alpha+\alpha\theta+\theta) - 4r(2+\alpha-2\theta+\alpha\theta) + k(4-4\alpha-4\theta+8\alpha\theta)}{12}$$

Case S_{iii}:$p_A^{bb*} = \frac{9m + c(3+3\alpha-3\theta-\alpha\theta) - r(3-3\theta+3\alpha+\alpha\theta) + 2k\alpha\theta}{6}$

$$p_B^{bb*} = \frac{15m + c(6+6\alpha-6\theta-2\alpha\theta) - 2r(3-3\theta+3\alpha+\alpha\theta) + 4k\alpha\theta}{12}$$

$$\prod_A^{bb*} = \frac{9m}{16} \prod_B^{bb*} = \frac{25m}{32}$$

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