Electronic Commerce Research and Applications 53 (2022) 101144

Contents lists available at ScienceDirect

Electronic Commerce Research and Applications

journal homepage: www.elsevier.com/locate/elerap

The impact of recommender systems and pricing strategies on brand competition and consumer search

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ARTICLE INFO

Keywords:
Brand competition
Consumer search
Recommender system
Uniform pricing
Differential pricing

ABSTRACT

As a type of internet and business intelligence technology, recommender systems have been widely adopted by store brands to improve brand competition and to affect consumers' search behaviors in the e-commerce market. This paper studies the effects of recommender systems and pricing strategies on the competition between store brands and national brands and on consumers' search behaviors. We develop game models without and with recommender systems and analyze the equilibrium solutions under uniform pricing and differential pricing strategies. The results show that the brand-preference consumers' market share will affect the strategy choice of recommendation system and differential pricing for the store brand. When the store brand is recommended, the store brand should adopt the differential pricing strategy and the price of the store brand will exceed that of the national brand. Furthermore, we also find that when the brand-preference consumers' market share is low and the reservation price difference is high, the store brand can gain the competitive advantage by improving recommendation strength. In addition, a recommender system attracts consumers by converting their search costs into the recommendation costs of the system.

1. Introduction

Store brands have often been introduced into the market by retailers as competitive tools. After a hundred years of development, store brands have grown into a 200 billion dollar market. In 2020, store brand sales grew by 11.6%, which is a gain of $16.5 billion in volume over the previous year. NielsenIQ reported that in 2020, 23% of the dollar sales of all groceries were for store brand products. An increasing number of online and offline retailers are launching store brands to cover more product categories. In Costco, Walmart and Whole Foods, "Kirkland Signature", "Super Value" and "365 Daily Value" can be found. Amazon owns over 120 store brands, which include food, health & households, home & kitchen and clothing & jewellery products. In China, JD.com, an online retailer, has launched its own brand "Dostyle" and sells electronic products and daily necessities. Store brands can attract consumers because of their affordable prices and good quality. They have gradually changed from an inexpensive substitute to a widely accepted brand category, and consumer loyalty to store brands has also appeared (Seenivasan et al., 2016).

Recommender systems are generally considered to benefit consumers by recommending products they want, but many of them tend to favor the interests of retailers (Xiao and Benbasat, 2007). On the one hand, retailers hope to provide consumers with personalized product recommendations to attract and retain customers. On the other hand, retailers usually recommend certain products with specific characteristics (e.g., high-profit products and products that need to be stockpiled) to obtain excess profits or reduce losses (Xiao and Benbasat, 2015). Therefore, the original function of recommender systems has become distorted and the systems have become a tool to benefit retailers. More than 35% of Amazon's sales and over 60% of Netflix's streaming traffic come from recommendations (Hosanagar et al., 2014).

A recommender system will recommend supplementary products after a consumer purchase. When the consumer visits the platform or searches for products, the recommender system will recommend competing products (Li et al., 2018). A store brand is a brand owned by retailers to compete with a national brand, and recommendation services are usually provided by retailers in the supply chain. Therefore, a store brand can use a recommender system to expand its brand audience

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https://doi.org/10.1016/j.elerap.2022.101144
Received 10 August 2021; Received in revised form 24 January 2022; Accepted 22 March 2022
Available online 26 March 2022

and can use its marketplace sales data to potentially gain an unfair advantage over the national brand. Search results pages that are relevant to Amazon's store brands include the "Shop Our Brands" widget. The widget advertises Amazon's own brands regardless of the brand's relevant sales and reviews. As a retailer, Amazon changed its recommendation algorithm to highlight Amazon's own branded products, and it uses its recommender system to increase product exposure. This has aroused the concern of scholars and has prompted antitrust enforcement investigations.

Conventional wisdom holds that store brand products are always inferior in quality (Raju et al., 1995; Ru et al., 2015). The consumer reservation price of store brand products is lower than that of national brands. Lowering the prices of store brand products is also a common pricing strategy for retailers. Price advantages are used to compensate for the disadvantages of low product quality and attract consumers. Therefore, pricing products separately in a recommender system may be a better pricing strategy than uniform pricing. By setting different product prices for different channels, the profit can be maximized. This discriminatory pricing strategy has been studied extensively. In a brand competition model with a recommender system, the pricing strategy may lead to some unique results.

Motivated by the above actual situations, this paper contributes to discussing the influence of introducing recommender systems to the brand competitive market. In summary, this paper pursues answers to the following questions.

(1) Which recommender system and pricing strategy should store brands choose when facing competition from national brands? What factors influence this strategy choice?
(2) What pricing strategy should store brands adopt after the introduction of recommender system? Is it a uniform pricing strategy or differential pricing strategy?
(3) Should store brands improve recommendation strength when adopting recommender system and differential pricing strategy? How do recommender systems affect consumer search behaviors?

To address these questions, we establish three game models to compare the uniform pricing strategy and the differential pricing strategy of a store brand. First, we consider a basic model without recommender systems, in which the store brand does not adopt the recommender system, the national brand is sold to brand-preference consumers and the store brand is sold to price-preference consumers. Next, we study a model with recommender systems, in which the store brand adopts the recommender system to attract consumers from the national brand market and the store brand also adopts a uniform pricing strategy for these consumers. We also investigate a differential pricing strategy in which the store brand is offered at different prices for consumers in the store brand and national brand markets. By investigating the introduction of recommender systems with different pricing strategies, some insights are obtained and summarized below.

This paper finds that recommender systems have the following functions in brand competition. First, in the competitive markets between store brands and national brands, a recommender system has spillover effects in the two independent markets. Second, the store brand independently prices its customers through the recommender system. Compared with uniform pricing, differential pricing maintains the continuity of the store brand strategy in the existing market. In this way, the store brand can not only keep profits in the store brand market but also expand profit sources to the national brand market to realize differentiated pricing. Finally, the recommender system reduces the friction cost between the product and the consumer. The search cost originally paid by consumers is converted into the recommendation cost of the store brand. However, adopting a recommender system may not benefit all market participants, especially when the recommendation cost is high.

Our analysis generates several interesting results and crucial managerial insights. First, the store brand and national brand markets that are independent of each other and brand preferences are connected through a recommender system. Recommender systems launched by store brands always damage the profits of national brands. Under the condition of moderate recommendation strength, a store brand can benefit from the recommender system. When the recommendation strength is strong, the store brand bears the cost of adopting the recommender system, which decreases the profit of the store brand. As a result, national brands do not want store brands to launch recommender systems. A store brand can make more profit by introducing a recommender system when the national brand's market share is low and the reservation price is medium. In addition, a differential pricing strategy has stronger connections and spillover effects between the two markets.

Second, after a recommender system is adopted, the national brand responds by lowering product prices to maintain profits. Store brands can offer high prices for recommended products. In this situation, recommended products are still purchased by many consumers because the search cost is transferred from consumers to the store brand. In addition, there is a threshold for consumer search costs below which the price of the recommended product offered by the store brand may not be higher than the price of the product without a recommender system.

Third, recommender systems reduce the search efforts of consumers for national brands. When the search cost is low, a store brand will offer lower prices to price-preference consumers. With the increase in search costs, store brands can charge extra fees for recommending system channel products. There is also a threshold for the impact of search costs on search efforts. When the search cost is low, brand-preference consumers still mainly search for the national brand. With rising search costs, these consumers turn to the products of store brands. Therefore, the main function of a recommender system is to reduce consumers' search costs. Under the condition of low search costs, most consumers still choose the national brand. When the search costs are sufficiently high, consumers will transfer their purchase to a store brand.

Thus, the contributions of our study are listed as follows. (1) Our study contributes to filling the research gap of recommender systems and brand competition, and providing management insights for store brands and national brands. (2) We develop three game models to consider an e-commerce brand competition problem, namely, the model without recommender systems, the model with recommender systems and uniform pricing, the model with recommender systems and differential pricing. By comparing the optimal solutions of these models, we investigate how recommender systems and pricing strategies influence brand competition. (3) We further examine how the recommendation strength and different pricing strategies will influence the two types of consumers' search efforts, brands' prices and profits. Our study contributes to investigating the implications for the role of recommender systems in brand competition.

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 presents a problem description of this study. In Section 4, we discuss the models without and with recommender system, and then study the store brand's uniform pricing and differential pricing strategies. In Section 5, the equilibrium results of three models are compared. Section 6 includes the numerical analysis. Section 7 provides two extensions of the models with recommender system. In Section 8, we conclude the work and briefly summarize insights and avenues for future research. All the proofs are provided in the Appendix.

2. Literature review

Our work is related to the three extant streams of literature: (i) research on brand competition, (ii) recommender systems, and (iii) marketing-operations interfaces. In addition, we will provide some motivations and highlights of our study.

2.1. Brand competition

One stream of literature that is relevant to our work pertains to store brands competing with national brands. Many studies have analyzed the effects of store brands on manufacturers and retailers. Conventional wisdom holds that retailers will replace national brands with store brands in order to make more profits, and the introduction of store brands forces the manufacturer to lower the wholesale price and thus decreases the manufacturer's profit (Raju et al., 1995). Recent research has provided a whole new perspective on store brands (Wang et al., 2021). Ru et al. (2015) studied the effect of a store brand introduced by a retailer on a national brand manufacturer in a retailer-led Stackelberg game and found that a store brand may benefit the manufacturer, even though the wholesale price of the national brand is reduced. Multiple echelon supply chains with store brands and national brands have also been studied recently. Cheng et al. (2021) investigated the strategic interaction in a three-echelon supply chain with a store brand and its corresponding impacts. Shi and Geng (2021) built a manufacturer-led game model considering four types of scenarios based on whether the retailer shares market information with the manufacturer and whether the retailer introduces a store brand. In addition, the quality of a store brand and its influence on promotion and advertising strategies have also been discussed by scholars. Zhou et al. (2019) studied which brands retailers choose to promote when selling store brands and national brands. Karray and Martn-Herrn (2019) investigated whether manufacturers can use the timing of their pricing and advertising decisions to benefit from or to deter store brand introductions. Further, Zhou et al. (2020) studied the impact of infomediary's online referral in the competition between store brands and national brands. Zhang et al. (2021) investigated the strategic interactions between manufacturer encroachment and the retailer's store brand quality.

All the aforementioned papers focus on the effect of store brand introductions and other promotion strategies in the brand competition problem. However, none of the above papers consider the impacts of recommender systems and pricing strategies on brand competition and consumer search. Our study differs from the existing literature by exploring the change in market equilibrium after the introduction of a recommender system, when the store brand occupies a larger market share, and when there is no primary-secondary relationship between the brands. Due to consumers' long-standing impressions of store brand products, consumers have lower reservation prices for store brand products than national brand products.

2.2. Recommender systems

Recommender systems are widely used in online sales, which adds new information channels and purchase channels for consumers. Recommendation algorithms and recommender system designs in the sales process are popular research topics [e.g.] (Bag et al., 2019; Scholz et al., 2017). Chen et al. (2016) studied the multikernel support tensor mechanism for data classification and cross-selling recommendations to improve the customer repurchase rate. Geuens et al. (2018) established a recommender system framework that can help e-commerce enterprises choose the best recommendation algorithm. Hwangbo et al. (2018) applied collaborative filtering to a real fashion product enterprise that sells the same seasonal product online and offline. How a recommender system interferes with sales processes and buying behaviors is also widely discussed by empirical research. Dadouchi and Agard (2021) studied how a recommender system can shift customers' interest to specific goods, thus improving vehicle utilization, reducing operating costs and reducing delivery time. Baum and Spann (2014) used empirical methods to study the impact of the interaction between consumers' online reviews and recommender systems on consumers' decision making. Lee and Hosanagar (2021) studied the different effects of a recommender system on different types of products. In addition, an increasing number of scholars have studied the influence of recommender systems on operation management and marketing (Li et al., 2019). Yang and Gao (2017) studied whether e-retailers recommend two products at the same time when faced with competition from two manufacturers. The market is divided into two segments in this paper: traditional customers will not be affected by the recommender system, while recommended customers will choose the recommended products. Li et al. (2018) studied the effects of a recommender system on retailers, manufacturers, consumer surplus and social welfare by studying two competing manufacturers selling through a common retailer. They study the retailer's recommender system strategy and recommendation accuracy when facing multiple product suppliers and multiple consumer groups.

These previous papers, however, have not focused on the brand competition problem with recommender systems and pricing strategies. Our contribution to this study lies in our comprehensive analysis of three game models (i.e., the model without recommender systems, model with recommender systems and uniform pricing, model with recommender systems and differential pricing) and the effects of the recommender systems and pricing strategies on brand competition and consumer search. To investigate the consumer search in brand competition, we divides consumers into two types: brand-preference consumers and price-preference consumers. Furthermore, we study the direct competition between two brands through the introduction of recommender systems.

2.3. Marketing-operations interface

There is a growing body of literature on marketing-operations interfaces. Marketing is a functional area that is primarily concerned with the state of the market and is usually used to define what products or services are to be offered on what channels and at what prices (Feng et al., 2018; Feng et al., 2020). Facing fierce global competition and rapid changes in marketing mechanisms, the operations group may find that some aspirations are not realized. For this kind of conflict, scholars have established various models to carry out relevant research. Mollenkopf et al. (2011) studied the return management problem in the marketing-operation interface and studied the return management problem of a single home appliance manufacturer when dealing with its retail customers. Lee (2014) explored the use of a Bayesian model to solve inventory management problems when new marketing efforts are made. Dockner and Fruchter (2014) studied the interactions of decentralized marketing and assumed that the marketing department is responsible for the price that influences the demand, and the operations department is responsible for the production rate. Samuel Sale et al. (2017) studied the optimal life cycle of products based on the perspective of the marketing-operation interface. By establishing a two-period game model, Li et al. (2020) analyzed different discount pricing strategies of online coupons with strategic consumers.

Although existing literature examines the impact of online marketing on operations management problem from multiple perspectives, none has examined the impact of recommender systems on e-commerce brand competition under different pricing strategies. Our study differs from the papers cited above in three aspects. First, in our paper, we consider the brand competition problem with recommender systems and consumer search. Second, we analyze the competitiveness of store brands under the uniform pricing strategy and differential pricing strategy. Third, we examine the effects of recommender systems and pricing strategies on brand competition and consumer search behaviors.

2.4. A summary of differences from the previous literature

From the above literature review, we can see that the existing studies examining brand competition issues mainly focus on the impacts of store-brand introduction and most studies only investigate the introduction of store brand in the e-commerce supply chain. Furthermore, the review of the related literature suggests that the impact of recommender

systems on the online marketing is becoming an important topic for recent operations management research. However, there are very few studies that bring recommender systems and consumer search into brand competition. Moreover, there are very few studies that discuss the uniform pricing strategy and differential pricing strategy to investigate the competition between national brands and store brands. To fill the gap, we consider an e-commerce brand competition problem with recommender systems and consumer search. The main difference between this paper and the previous literature is listed in Table 1. In summary, our study sheds light on the store brand's strategy choice while considering recommendation system and differential pricing. In addition, we further examine how the recommender systems and different pricing strategies will influence the competition between national brands and store brands. We describe our problem and model setting in the following section.

3. Problem description

Consider an e-commerce brand competition problem where a national brand and a store brand sell differentiated but partially substitutable products in two separate markets online. Consumers in the two markets are loyal to national brands and store brands. We refer to these two types of consumers as brand-preference consumers and price-preference consumers, i.e., brand-preference consumers are loyal to the national brand, and price-preference consumers are loyal to the store brand. Price-preference consumers have lower reservation prices for store brands, while brand-preference consumers have higher reservation prices for these two brands. Because of good product design and production, the national brand has high brand reputation and brand value. However, the store brands are seen as acceptable substitutes for consumers rather than desirable brands (Cunningham et al., 1982; Mollenkopf et al., 2011; Alan et al., 2019). Also, Ru et al., 2015; Cheng et al., 2021 and Shi and Geng, 2021 found that though the store brand's quality is almost equal to the national brand's, consumers prefer the national brand and are willing to pay a higher price. Therefore, such brand-preference consumers loyal to the national brand have higher reservation prices. The price-preference consumers loyal to the store brand are more willing to pay lower prices, and they have lower reservation prices. If the store brand does not adopt a recommender system, brand-preference consumers are only willing to search for and buy the national brand's products and price-preference consumers are only willing to search for and buy the store brand's products (Zhou et al., 2015; Zhou et al., 2020). If the store brand adopts a recommender system to recommend their products to consumers, both the price-preference and the brand-preference consumers will search for and purchase the store brand. This is because recommender systems have network externality and accessibility to enhance the efficiency of consumer search and provide more sales opportunities for the store brand. For instance, many of Amazon's store brands, such as Solimo, Amazon Essentials and Amazon Basics, use 'Your Recommendations' and 'Best Seller' recommender systems to attract more consumers to click on and browse their products. The frequent appearance of store brand products in the recommender system also makes it easier for price-preference consumers to obtain the products. In this case, both types of consumers will change their search behaviors due to the introduction of the recommender system.

Table 1
A summary of main literature.

Paper	Brand competition	Consumer search	Recommender systems	Marketing-operations interface
Raju et al. (1995)	✓			
Ru et al. (2015)	✓			✓
Zhou et al. (2019)	✓			✓
Zhang et al. (2021)	✓			✓
Cheng et al. (2021)	✓			✓
Shi and Geng (2021)	✓			✓
Lammers (2014)		✓		
Chen et al. (2016)			✓	
Geuens et al. (2018)			✓	
Baum and Spann (2014)		✓	✓	
Dadouchi and Agard (2021)		✓	✓	
Yang and Gao (2017)			✓	✓
Li et al. (2018)			✓	✓
Li et al. (2019)			✓	✓
Mollenkopf et al. (2011)				✓
Dockner and Fruchter (2014)				✓
Samuel Sale et al. (2017)				✓
Feng et al. (2020)				✓
Zhou et al. (2015)		✓		✓
Zhou et al. (2020)	✓	✓		✓
Our work	✓	✓	✓	✓

The size of the whole market is normalized to 1; a fraction (λ) of consumers are brand-preference consumers, who have a higher reservation price $\overline{p}$ for the two brands. A fraction ($1-\lambda$) of consumers are price-preference consumers and have a lower reservation price $\underline{p}$ for the store brand. Assume the reservation price of the price-preference consumers is lower than that of the brand-preference consumer, but the difference between the two prices is not adequately large, that is $\underline{p} < \overline{p} < 3\underline{p}$. According to a technical report 2021 from the Nielsen, store brands need to raise the quality of their products to increase their power to compete with national brands. The product quality of the store brand is not significantly different from that of the national brand, and products with similar quality cannot be completely replaced by national brands (Cunningham et al., 1982). According to a technical report 2018 from the Nielsen, more than half of consumers feel that store brand products are becoming more expensive and that the reservation price difference between store brands and national brands is becoming less pronounced. Define parameter $\beta = \frac{\underline{p}}{\overline{p}}$, which is denoted as the reservation price difference between $\overline{p}$ and $\underline{p}$. We further assume that the brands procure their products from an exogenous provider who is not strategic and that the product cost is not considered (Raju et al., 1995; Ru et al., 2015).

Suppose that consumers are rational and derive utility from purchasing a national brand's or store brand's product and disutility from the effort of searching for a product. To maximize his/her utility, the consumer makes his/her choice of search effort e and decides whether to purchase a product from the national brand or the store brand. Generally speaking, this form of modeling is prevalent in the existing patterns of consumer search models (Lammers, 2014; Zhou et al., 2015; Li et al., 2020). The consumer often has two choices, one is to continue searching, i.e., the consumer would compare the current product with the best previous product and choose a better one as a reserved product; alternatively, the consumer can stop searching and buy the reserved product. The objective of the consumer is to find an optimal search effort

maximizing the benefit from the search. The advantage of modeling endogenous search effort is that it allows for the possibility of finding the desired product is increasing in the constant search, with matching of products and preferences also increasing in the optimal search, a feature that turns out to be empirically relevant. Due to the market friction, the consumer's search effort e incurs a convex cost $\frac{ke^2}{2}$, where $0 < k \leqslant 1$ represents the cost coefficient of consumer search. Although online search and shopping provides convenience for consumers, consumers still need to spend some time to make purchasing decisions due to the information overload and information asymmetry (Zhou et al., 2020). Typically, this quadratic cost function is an increasing function of the consumer's search effort with increasing margin. Similar assumption can be found in some recent literature (Lammers, 2014; Zhou et al., 2015; Yao and Liu, 2005). In addition, we do not consider the secondary market caused by the price difference between the two brands.

The behaviour, mentality and purchasing decisions of consumers are interfered by the personalized recommendations of the recommender system (Yang and Gao, 2017). The recommender system takes the store brand as the recommendation focus and changes the recommendation strategy to attract brand-preference consumers. Consumers need to strike a balance between actively searching for national brands and accepting recommendations from store brands. Although most previous research mainly assume that such recommendation technologies are designed to benefit consumers and focuses on the positive impact of recommender systems on consumers' decision quality and decision effort (Xiao and Benbasat, 2007; Xiao and Benbasat, 2015), store brands often control recommendation algorithms to guide consumers to buy recommended products depending on the cost and benefit of the recommender system. When the store brand adopts a recommender system to recommend their products to consumers, we assume that the recommendation strength is $\alpha \geqslant 1$, which affects the utility of recommended brand-preference and price-preference consumers. In fact, higher recommendation strength can attract consumers' attentions and increase consumers' search. This recommendation strength can be implemented by the recommender system using personalized intelligent algorithms, such as utility-based recommendations (Bag et al., 2019; Li et al., 2019), cross-selling recommendations (Chen et al., 2016; Ghoshal et al., 2021), collaborative filtering-based recommendations (Geuens et al., 2018) and so on. Since the higher recommendation strength leads to higher costs, we assume that the cost of using this recommender system is $\frac{\varphi\alpha^2}{2}$, where $0 < \varphi \leqslant 1$ represents the cost coefficient of recommendation. Similar to some literature (Yao and Liu, 2005; Li et al., 2019; Bag et al., 2019; Ghoshal et al., 2021), this quadratic cost form implies that the recommendation strength is positively correlated with the cost of using recommender system due to the law of diminishing marginal profit. That is to say, as the recommendation strength is increasing, the marginal cost of recommendation is also increasing. Therefore, an increase in the marginal cost of recommendation will decrease the marginal profit. This is in line with the law of diminishing marginal profit.

Note that the main results derived under these quadratic cost forms of consumer search and using a recommender system are robust and they continue to hold under other cost forms. On the one hand, the changes in cost forms of using the recommendation system have no effect on optimal search efforts and prices. This is because the derivative of the recommendation cost $\frac{\varphi\alpha^2}{2}$ with respect to the search effort or price is zero for the utility or profit maximization. This implies that the recommendation cost is constant, regardless of search efforts and prices. Therefore, the recommendation cost has no effect on the role of recommendation system. On the other hand, although the change of search cost function has influence on the decision making, the results under different search cost functions is robust. Without loss of generality, we consider the general convex function of search cost is $c(e)$ (i.e., $c'(e) > 0$ and $c''(e) > 0$). This convex cost structure can be attributed to diminishing returns from search effort e of decreasing information asymmetry. Our studies in the appendix show that the main results derived are robust and continue to hold under a general function of search cost.

To facilitate the expression of the models, we denote the subscripts M, N, m and n as the national brand, the store brand, the brand-preference consumers and the price-preference consumers, respectively. In the following section, we consider the three game models. First, we study the model without recommender systems as a benchmark, which is denoted by the superscript o. Second, we study the model with recommender systems and uniform pricing, which is denoted by the superscript r. Third, we study the model with recommender systems and differential pricing, which is denoted by the superscript d.

4. The models

4.1. The model without recommender systems

This subsection mainly discusses a basic model where the store brand does not introduce the recommender system. The model of the brand market competition problem without recommender systems can be structured as Fig. 1.

For analytical tractability, we follow the existing literature and assume that the marginal cost of production is zero for the two brands (Raju et al., 1995; Alan et al., 2019). The national brand and store brand first determine their selling prices p_m^o and p_n^o to maximize their profits, respectively. Then, the brand-preference consumer and the price-preference consumer spend search efforts e_m^o and e_n^o to search for the national brand and the store brand, respectively. We formulate the demand functions $D_m^o = \lambda e_m^o \gamma$ and $D_n^o = (1-\lambda) e_n^o \gamma$, where γ represents the conversion rate from search to purchase. Thus, the profit functions of the national brand and store brand are as follows,

$$\Pi_{\mathrm{M}}^o = p_m^o D_m^o, \tag{1}$$

$$\Pi_{\mathrm{N}}^o = p_n^o D_n^o. \tag{2}$$

Consumers are heterogeneous in their reservation prices of two brands. The utility of brand-preference consumers can be presented as

$$U_m^o = e_m^o\left(\overline{p} - p_m^o\right) - \frac{k\left(e_m^o\right)^2}{2}, \tag{3}$$

and the utility of price-preference consumers can be presented as

$$U_n^o = e_n^o\left(\underline{p} - p_n^o\right) - \frac{k\left(e_n^o\right)^2}{2}. \tag{4}$$

By analyzing both brands' profit functions and both consumers' utility functions, the optimal prices and search efforts in the model without recommender systems are described in Lemma 1.

Lemma 1. *In the model without recommender systems, the optimal search efforts, prices and brands' profits are given by*

$$e_m^{o*} = \frac{\overline{p}}{2k}, e_n^{o*} = \frac{\underline{p}}{2k}, p_m^{o*} = \frac{\overline{p}}{2}, p_n^{o*} = \frac{\underline{p}}{2},$$

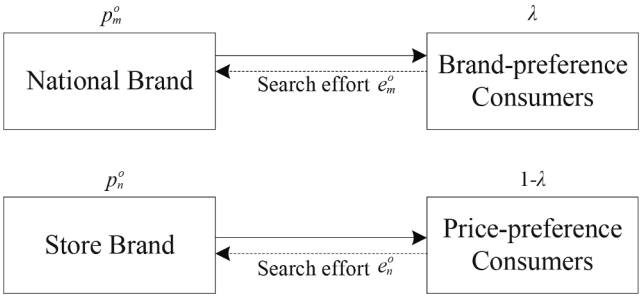


Fig. 1. Structure of the model without recommender systems.

$$\Pi_{\mathrm{M}}^{o*}=\frac{\gamma\lambda}{4k}\overline{p}^2,\Pi_{\mathrm{N}}^{o*}=\frac{\gamma(1-\lambda)}{4k}\underline{p}^2.$$

To ensure that the brands' demands are not negative, $\frac{\overline{p}}{2}\leqslant k\leqslant 1$. From the results of Lemma 1, we can see that both brands benefit from the increase in consumer reservation price. Furthermore, there is a linear relationship between the profit and market share of the two brands. This proves once again that the two markets are independent of each other, and both brands have independent decision-making power in both markets.

Observation 1. In the market of brand-preference consumers, as $\overline{p}$ increases, the optimal search effort e_m^{o*} and price p_m^{o*} increase. Similar results can be found in the market of price-preference consumers.

Because consumers have different preferences, the two brands do not sell across markets, and the optimal solutions of the two markets are independent. Market share λ does not affect the decision of the two brands. Observation (1) shows that consumers' search efforts are driven by consumer surplus and influenced by reservation price and selling price. The importance of maintaining product valuation becomes apparent. In the case of maximizing profit, product valuation directly affects the optimal decision of the product price. Maintaining product quality and conducting promotional activities directly affect the product price.

Observation 2. As the two brands' prices increase, optimal consumers' search efforts decrease, i.e., $\frac{\partial e_m^{o*}}{\partial p_m}=\frac{\partial e_n^{o*}}{\partial p_n}=-\frac{1}{k}<0$. As the reservation prices increase, optimal consumers' search efforts increase, i.e., $\frac{\partial e_m^{o*}}{\partial \overline{p}}=\frac{\partial e_n^{o*}}{\partial \underline{p}}=\frac{1}{2k}>0$.

The product price and reservation price of the two brands have negative and positive effects on the search efforts of consumers. Since the search cost and product price directly affect consumers' utility, it can be observed that there is a positive correlation between the consumer search for products and consumers' utility. Observation (2) indicates that when both consumers have lower reservation prices for the two brands, their search efforts will also be lower. The conclusion is obvious. As the reservation prices decrease, consumers will be less willingness to buy products. Therefore, an decrease in the willingness to buy two brands will reduce consumers' search efforts.

Observation 3. In the model without recommender systems, as β increases, the consumer's optimal search effort for the store brand increases, and the store brand's optimal price increases. The price-preference consumer's optimal utility and the store brand's optimal profit also increase with β.

From this observation, we find the reservation price difference will positively affect the price-preference consumer's optimal search effort and utility, and also positively affect the store brand's optimal price and profit. However, the brand-preference consumer's optimal search effort and utility are not affected by the reservation price difference, and an increase in the reservation price difference does not also affect the national brand's optimal price and profit. This implies that the search effort for the store brand will increase as the price-preference consumers' reservation price increases. Moreover, the store brand can raise the product price to obtain more profits.

4.2. The model with recommender systems and uniform pricing

In this subsection, we consider the model in which the store brand adopts recommender systems and a uniform pricing strategy to enter the national brand market. In this model, the store brand would attract brand-preference consumers to compete with the national brand through the recommender system and sell its products to both brand-preference consumers and price-preference consumers at the same price p_n^r. In addition, the national brand still only sells its products to brand-preference consumers at price p_m^r. Then, the brand-preference consumer spends search efforts e_m^r and $1-e_m^r$ to search the national brand and the store brand, respectively. The price-preference consumer spends search effort e_n^r to search the store brand. For a more intuitive explanation, the structure of the model with recommender systems and uniform pricing is shown in Fig. 2.

The use of the recommender system expands the consumer segmentation of the store brand and makes the store brand no longer limited to the market of price-preference consumers. The demand functions are $D_m^r=\lambda e_m^r\gamma, D_{re}^r=\alpha\lambda\left(1-e_m^r\right)\gamma$ and $D_n^r=\alpha(1-\lambda)e_n^r\gamma$, respectively. Therefore, the profit functions of national brand and store brand are given as

$$\Pi_{\mathrm{M}}^r=p_m^r D_m^r, \tag{5}$$

$$\Pi_{\mathrm{N}}^r=p_n^r\left(D_{re}^r+D_n^r\right)-\frac{\varphi\alpha^2}{2}. \tag{6}$$

A store brand recommends its own brand products to all consumers through the recommender system. Brand-preference consumers can not only buy national brand products but also access store brand products through the recommender system. Under the influence of recommender systems and product homogenization, brand-preference consumers' store brand reservation price is the same as that of the national brand. The utility functions of the two types of consumers are given as follows:

$$U_m^r=e_m^r\left(\overline{p}-p_m^r\right)+\left(1-e_m^r\right)\left[\alpha\left(\overline{p}-p_n^r\right)\right]-\frac{k\left(e_m^r\right)^2}{2}, \tag{7}$$

$$U_n^r=e_n^r\alpha\left(\underline{p}-p_n^r\right)-\frac{k\left(e_n^r\right)^2}{2}. \tag{8}$$

By analyzing the optimal strategies of consumers and brands, we obtain the optimal search efforts and prices, and investigate the effects of recommender systems on the search efforts, the sales price and profit of brands. Therefore, the corresponding optimal solutions are shown as follows.

Lemma 2. *In the model with recommender systems and uniform pricing, the optimal search efforts and prices are given by*

$$e_m^{r*}=\frac{(1-\alpha)(2-\lambda)\overline{p}+(1-\lambda)\alpha\underline{p}+\lambda k}{(4-\lambda)k},e_n^{r*}=\frac{(1-\alpha)\lambda\overline{p}+(2+\lambda)\alpha\underline{p}-2\lambda k}{(4-\lambda)k},$$

$$p_m^{r*}=\frac{(1-\alpha)(2-\lambda)\overline{p}+(1-\lambda)\alpha\underline{p}+\lambda k}{4-\lambda},$$

$$p_n^{r*}=\frac{(\alpha-1)\lambda\overline{p}+2(1-\lambda)\alpha\underline{p}+2\lambda k}{(4-\lambda)\alpha}.$$

To ensure that the brands' demands are not negative, $\overline{p}>p_m^r,\overline{p}>p_n^r$, $\underline{p}>p_m^r$, the parameters need to satisfy the constraints

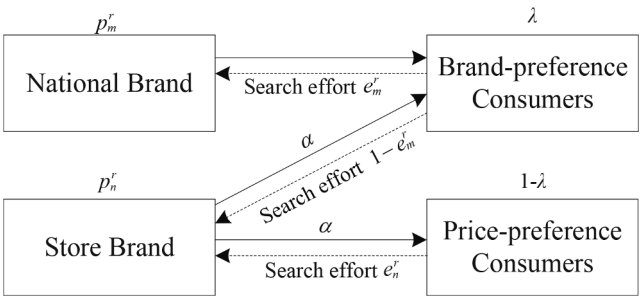


Fig. 2. Structure of the model with recommender systems and uniform pricing.

$\alpha \geqslant \max\left\{\frac{\lambda\bar{p}-2\lambda k}{(\bar{p}-\underline{p})\lambda-2\underline{p}}, 1\right\}$. From Lemma 2, we can easily find that $\frac{\partial e_m^{r*}}{\partial \bar{p}} > 0$, $\frac{\partial e_m^{r*}}{\partial \underline{p}} > 0$, $\frac{\partial e_n^{r*}}{\partial \bar{p}} > 0$ and $\frac{\partial e_n^{r*}}{\partial \underline{p}} > 0$. This implies that an increase in the reservation prices $\bar{p}$ and $\underline{p}$ will increase the brand-preference and price-preference consumers' search efforts in the model with recommender systems and uniform pricing. We also derive from Lemma 2 that $\frac{\partial p_m^{r*}}{\partial \bar{p}} > 0$, $\frac{\partial p_m^{r*}}{\partial \underline{p}} > 0$, $\frac{\partial p_n^{r*}}{\partial \bar{p}} < 0$ and $\frac{\partial p_n^{r*}}{\partial \underline{p}} > 0$. In the model with recommender systems and uniform pricing, this result shows that as the reservation price $\bar{p}$ increases, the national brand's optimal price increases, while the store brand's optimal price decreases. As the reservation price $\underline{p}$ increases, both brands' optimal prices increase. After the introduction of the recommender system, cross influences between the two brand markets begin to appear. The brand-preference consumer's reservation price not only positively affects the national brand's optimal price, but also negatively affects the store brand's optimal price. This is because an increase in the brand-preference consumer's reservation price will increase the willingness to buy the national brand. In order to attract more brand-preference consumers through the recommender system, the store brand reduce the optimal price when brand-preference consumers raise their reservation prices.

Observation 4. In the model with recommender systems and uniform pricing, the optimal search efforts, all brands' prices and the store brand's profit increase in the reservation prices difference β, the national brand's profit first increases and then decreases in the reservation prices difference β.

The increase in price-preference consumers' reservation prices for store brand products is not only beneficial to the store brand but also spills over to the national brand. However, the higher reservation prices of price-preference consumers can not make the national brand more profitable. As the reservation price difference increases, the store brand increases the product price and decreases the relative competitiveness of the store brand among brand-preference consumers. Furthermore, the national brand takes advantage of the competitive advantage and raises prices to gain more profits.

Observation 5. In the model with recommender systems and uniform pricing, as the reservation price difference β increases,

(a)The brand-preference consumer's utility first decreases and then increases when $\frac{\bar{p}}{2} < k < \frac{\bar{p}(\alpha+\lambda-2)}{3\lambda-8}$. The brand-preference consumer's utility decreases when $\frac{\bar{p}(\alpha+\lambda-2)}{3\lambda-8} < k < 1$.
(b) The price-preference consumer's utility first decreases and then increases when $\frac{\bar{p}}{2} < k < \frac{\bar{p}(2\alpha+\lambda)}{2\lambda}$. The price-preference consumer's utility decreases when $\frac{\bar{p}(2\alpha+\lambda)}{2\lambda} < k < 1$.

Observations 4 and 5 indicate that both national brands and store brands can benefit from an increase in consumers' reservation prices for store brands. However, the increase in reservation price gives consumers more motivation to search for the store brand, and the search cost is higher, which harms consumer utility. When the search cost is low, consumers can benefit from search behavior.

Proposition 1. *Consumers' search efforts $1-e_m^r$ and e_n^r for store brands increase with recommendation strength α, while consumers' search efforts e_m^r for national brands decrease with recommendation strength α.*

Proposition 1 indicates that the store brand will attract brand-preference consumers; thus, it will compete with the national brand through recommender systems. With the increase in recommendation strength, brand-preference consumers will reduce their search efforts for national brands and choose to buy through online channels to obtain more utility. The recommender system is applicable not only to brand-preference consumers. Because of the recommender system, consumers with price preferences will also increase their purchases of the store brand.

Proposition 2. *Both the store brand and national brand's prices p_n^r and p_m^r decrease in the recommendation strength α.*

As Proposition 2 shows, an increase in recommendation strength causes a decrease in the store brand's price p_n^r because the national brand responds by lowering product prices in the face of brand competition. In addition, the store brand also reduces the price by considering the price-preference consumers' search costs. Although the recommender system is adopted, the major profit source of the store brand is the market of price-preference consumers. The use of a recommender system increases the search costs of price-preference consumers. Therefore, the store brand compensates consumers for their losses by reducing prices.

4.3. The model with recommender systems and differential pricing

In this subsection, we consider the model in which the store brand adopts recommender systems and a differential pricing strategy to enter the national brand market. In this model, the national brand determines the price p_m^d, and the store brand provides the price p_n^d for the price-preference consumers and the price p_{re}^d for the brand-preference consumers who purchase through the recommender system. Then, the brand-preference consumer spends search efforts e_m^d and $1-e_m^d$ to search for the national brand and the store brand, respectively. The price-preference consumer spends search effort e_n^d to search for the store brand. The structure of the model with recommender systems and differential pricing is shown in Fig. 3.

Furthermore, we formulate the demand functions $D_m^d = \lambda e_m^d \gamma, D_{re}^d = \alpha\lambda(1-e_m^d)\gamma$ and $D_n^d = \alpha(1-\lambda)e_n^d\gamma$, respectively. Therefore, the profit functions of the two brands can be formulated as

$$\Pi_M^d = p_m^d D_m^d, \tag{9}$$

$$\Pi_N^d = p_{re}^d D_{re}^d + p_n^d D_n^d - \frac{\varphi\alpha^2}{2}. \tag{10}$$

Brand-preference consumers can now choose between national brands and store brands. The store brand offers different prices for the two types of consumers to maximize profit. The utility functions of the two types of consumers are presented as follows:

$$U_m^d = e_m^d(\bar{p} - p_m^d) + (1-e_m^d)\alpha(\bar{p} - p_{re}^d) - \frac{k(e_m^d)^2}{2}, \tag{11}$$

$$U_n^d = e_n^d\alpha\left(\underline{p} - p_n^d\right) - \frac{k(e_n^d)^2}{2}. \tag{12}$$

By analyzing both brands' profit functions and both consumers' utility functions, the optimal search efforts and prices in the model with recommender systems and differential pricing are described in Lemma

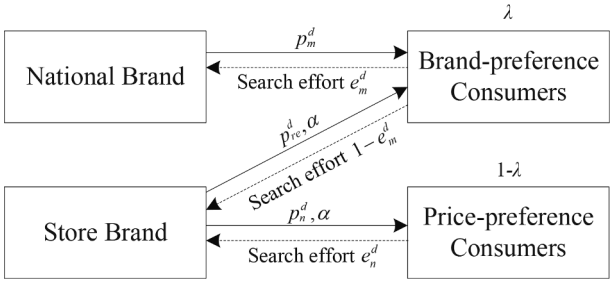


Fig. 3. Structure of the model with recommender systems and differential pricing.

3.

Lemma 3. *In the model with recommender systems and differential pricing, the optimal search efforts and prices are given by* $e_m^{d*} = \frac{(1-\alpha)\bar{p}+k}{3k}, e_n^{d*} = \frac{\alpha p}{2k}, p_{re}^{d*} = \frac{2k-(1-\alpha)\bar{p}}{3\alpha}, p_n^{d*} = \frac{p}{2}, p_m^{d*} = \frac{k+(1-\alpha)\bar{p}}{3}$.

Note that the parameters should be in the range $\max\left\{\frac{2k-\bar{p}}{2\bar{p}}, 1\right\} \leqslant \alpha \leqslant 1 + \frac{k}{\bar{p}}$. The following observation examines the effects of the reservation price difference on the optimal search efforts, utilities, prices and profits.

Observation 6. In the model with recommender systems and differential pricing, as the reservation price difference increases, the price-preference consumer's optimal search effort and utility increase, and the store brand's optimal price and profit also increase.

In the model with recommender systems and differential pricing, an increase in the reservation price difference will increase the price-preference consumer's optimal search effort and utility, and increase the store brand's optimal price and profit. In addition, the brand-preference consumer's optimal search effort and utility and the national brand's optimal price and profit are not affected by the reservation price difference. The results show that the reservation price of price-preference consumers increases, which is good for the store brand. The differential pricing strategy brings mutual independence to the two markets. Under the differential pricing strategy, the unilateral change in price-preference consumers only affects the store brand's price decision and their search efforts but does not affect the national brand's price decision and the brand-preference consumers' search efforts. Therefore, the store brand has realized price discrimination in two markets. Propositions 3 and 4 examine the effects of recommendation strength α on the optimal prices and search efforts.

Proposition 3. *The increase in recommendation strength* α *increases the price for brand-preference consumers who buy through the recommender system, but it has no effect on the price of store brand sold to price-preference consumers. The increasing recommendation strength of recommender systems reduces the price of national brands for brand-preference consumers.*

Proposition 3 shows that in the model with recommender systems and differential pricing, when the store brand increases the recommendation strength, the national brand still reduces the price to maintain market shares and profit, and the store brand raises the price for brand-preference consumers to obtain more profit. However, for price-preference consumers, the store brand's price does not change with the recommendation strength. This implies that the store brand should raise the price for brand-preference consumers, and not change the price for price-preference consumers while improving the recommendation strength of recommender system. The national brand should reduce the price in response to competition from the store brand that increases recommendation strength.

Proposition 4. *The optimal search effort of the price-preference consumer increases with recommendation strength* α*, while the optimal search effort of the brand-preference consumer decreases with recommendation strength* α*.*

Recall that in the model with recommender systems and uniform pricing, as the recommendation strength increases, the search efforts of both types of consumers will be reduced. However, in the model with recommender systems and differential pricing, as the recommendation strength increases, the search efforts of the brand-preference consumers will decrease for national brands, and they will choose to purchase through the recommender system. The search efforts of price-preference consumers will increase for the store brand; that is, price-preference consumers are more enthusiastic about buying the store brand.

Corollary 1. In the model with recommender systems and differential pricing, when $\frac{3\alpha p+2(1-\alpha)\bar{p}}{4} < k < 1$, the price of store brand sold to brand-preference consumers is higher than that sold to price-preference consumers, i.e., $p_{re}^{d*} > p_n^{d*}$.

Corollary 1 demonstrates that when consumers' search costs are high, brand-preference consumers transfer to the store brand through the recommender system. By shifting to the store brand, the consumer's search cost can be transferred to the recommendation cost of the recommender system. The store brand can offer higher prices to an increasing number of consumers to capture spillover profits.

5. Comparisons of the optimal results

In this section, we compare the optimal results of the three models. By investigating the optimal search efforts, prices and profits under the three models, we make conclusions about the role of recommender systems in the brand competition problem.

Proposition 5. *In the model without recommender systems and the model with recommender systems and differential pricing, price-preference consumers can purchase the store brand at the same price, i.e.,* $p_n^{d*} = p_n^{o*} = \frac{p}{2}$*. In the model with recommender systems and uniform pricing, the optimal price of store brand is* $p_n^{r*} = \frac{(1-\alpha)\lambda\bar{p}+2\alpha(\lambda-1)\underline{p}-2k\lambda}{\alpha(\lambda-4)}$.

In the model with recommender systems and uniform pricing, the store brand needs to consider the impact on both markets when making price decisions. In the model with recommender systems and differential pricing, the store brand can decide the optimal price in the market of price-preference consumers according to the search effort of consumers. The store brand's differential pricing strategy in both markets can bring strategic flexibility to the store brand and achieve optimal decision-making results in each market.

Proposition 6. *When* $0 < k < \frac{3\alpha\underline{p}+2(1-\alpha)\bar{p}}{4}$, $e_m^d < e_m^r < e_m^o$ *and* $e_n^d < e_n^r < e_n^o$*. When* $\frac{3\alpha\underline{p}+2(1-\alpha)\bar{p}}{4} \leqslant k < 1$, $e_m^r < e_m^d < e_m^o$ *and* $e_n^r < e_n^d < e_n^o$.

Proposition 6 indicates that in the model without recommender systems, consumers have to put in more search effort when the coefficient of the search cost is sufficiently low. When the store brand adopts the recommender system and the coefficient of the search cost is sufficiently low, the differential pricing strategy is beneficial for consumers. At this point, consumers' search efforts are lowest. When the coefficient of the search cost is sufficiently high, the advantages of the differential pricing strategy are no longer obvious for consumers. At this point, consumers' search efforts under the uniform pricing strategy are lowest. This is because the high coefficient of the search cost discourages consumers from making the efforts to search for the two brands. Furthermore, the uniform pricing strategy can reduce consumers' search efforts. In addition, it is clear that an increase in the coefficient of the search cost decreases the brand-preference consumers' search efforts e_m^o, e_m^r and e_m^d.

Proposition 7. *When* $0 < k < \frac{3\alpha\underline{p}+2(1-\alpha)\bar{p}}{4}$, $p_m^{d*} < p_m^{r*} < p_m^{o*}$ *and* $p_{re}^{d*} < p_n^{r*} < p_n^{o*} = p_n^{d*}$*. When* $\frac{3\alpha\underline{p}+2(1-\alpha)\bar{p}}{4} \leqslant k < 1$, $p_m^{r*} < p_m^{d*} < p_m^{o*}$ *and* $p_n^{o*} = p_n^{d*} < p_n^{r*} < p_{re}^{d*}$.

Proposition 7 demonstrates that consumers' search costs have a significant impact on the price decisions of the two brands. When the coefficient of the search cost is low, the prices of the two products using the recommender system will be lower than those without the recommender system, even if there is a recommendation cost to use the recommender system. As the coefficient of the search cost increases, the prices of both brands increase.

Propositions 6 and 7 show that the reason why a recommender system can attract consumers is that it transfers the search costs of consumers. When the search cost of consumers is very low, the store brand needs to reduce the price through the recommendation system to attract consumers. When the search cost of consumers increases, the store brand can also attract consumers at a higher price because

consumers can ignore the search cost and benefit from the recommender system only by purchasing products through the recommender system. To further study the effects of consumer search cost on recommendation strength, we study the store brand's decision on recommendation strength in Extension 7.2.

6. Sensitivity analysis and strategy choice

To study the two brands' optimal decisions and strategy choices, this section analyzes the influence of the parameters on the consumers' and brands' optimal decisions through numerical examples. First, we examine the effects of the parameters on the search efforts and prices under the three models. Next, we analyze the impact of the recommendation strength and market share on brand profitability. Finally, we show the profit sources of the store brand in different models and study the strategic choices for the two brands. Without loss of generality, we set the basic parameter values as $\alpha = 1.2, \lambda = 0.5, \overline{p} = 1, \underline{p} = 0.8, k = 1$, $\varphi = 0.3$ and $\gamma = 1$, following some literature (Cunningham et al., 1982; Li et al., 2019; Zhou et al., 2020) which numerically illustrated the reservation prices of brand loyal consumers and recommendation strength. Obviously, these parameter settings are assumed to ensure that the two brands are all profitable. Note that we have also tried other settings in numerical analysis and find that this does not change our conclusions in the numerical examples.

6.1. Sensitivity analysis of the search efforts and prices

First, we analyze the effects of recommendation strength, the coefficient of the search cost, and the percentage of brand-preference consumers in terms of search efforts. Notice that $1 \leqslant \alpha \leqslant 2$ and $0.5 \leqslant k \leqslant 1$ in the following numerical analysis because the parameters have to satisfy constraints $\max\left\{\frac{2k-\overline{p}}{2\underline{p}}, 1\right\} \leqslant \alpha \leqslant 1 + \frac{k}{\underline{p}}$ and $\frac{\overline{p}}{2} \leqslant k \leqslant 1$. Obviously, these constraints ensure that the two brands are all profitable.

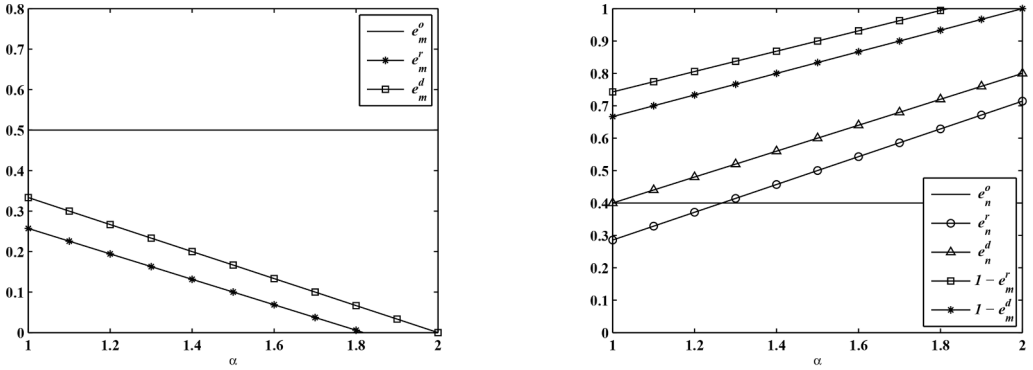
In Fig. 4, we compare the consumers' search efforts for brands with respect to α under the three models. Fig. 4(a) shows that the consumers' search for the national brand is inhibited by the recommender system. As the recommendation strength increases, the utility of consumers purchasing through the recommender system increases. Therefore, consumers are increasingly switching to the store brand. The increasing tendency of consumers' search efforts for the store brand is shown in Fig. 4(b).

Fig. 5 shows how the search efforts vary with the coefficient of the search cost k. As the search cost increases, consumers adjust their brand selection and buy products from the channel of the recommender system. In addition, we found that brand-preference consumers always search for store brands over other products. Through the use of the recommender system, the store brand is favored by brand-preference consumers, who become the main profit source for the store brand. This conclusion is illustrated by numerical examples in the following subsection. From Fig. 5(b), we observe that the search effort of consumers under the differential pricing strategy is more likely to be affected by the search cost compared with that under the uniform pricing strategy (i.e., $\frac{\partial(1-e_m^{r*})}{\partial k} > \frac{\partial(1-e_m^{d*})}{\partial k}$). This indicates that the brand competition caused by the uniform pricing strategy is more intense and that the differential pricing strategy alleviates the competition between national brands and store brands in the market of brand-preference consumers. When k is sufficiently low, national brands are dominate in the market of brand-preference consumers. However, when k continues to increase, the national brands lose their dominant position, and store brands are more sought after.

The results in Fig. 6 imply that the impact of the percentage of brand-preference consumers in terms of the search efforts. In the model without recommender systems and the model with recommender systems and differential pricing, the two markets are relatively independent. When brands decide their optimal prices, they only need to consider consumers' search efforts and reservation prices and do not need to consider the percentage of brand-preference consumers. Only consumers' search efforts under the uniform pricing strategy are affected by the percentage of brand-preference consumers. Under the uniform pricing strategy, the store brand needs to adjust the product price according to the percentage of brand-preference consumers. This adjustment in the uniform pricing strategy further affects consumers' search efforts in the two markets. As a result, as the percentage of brand-preference consumers increases, the search efforts of the two types of consumers of store brands decrease.

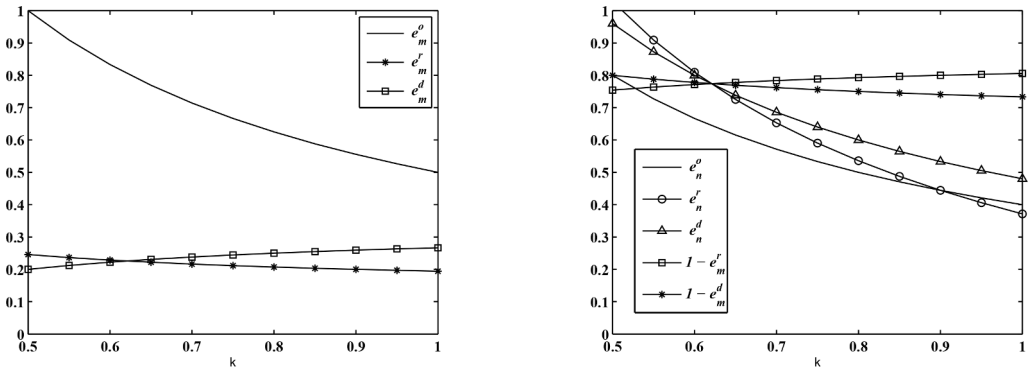
As shown in Fig. 7, the use of a recommender system always drives up the store brand's price and lowers the national brand's price. With the increase in recommendation strength α, brand-preference consumers shift from the national brand to the store brand, and the national brand competes with the store brand by lowering its price. However, since the recommendation costs increase with the recommendation strength, the store brand also has to reduce its price. Under the uniform pricing strategy, the store brand can no longer offer higher prices. Under the differential pricing strategy, the store brand offers extremely high prices through the recommender system to compensate for the recommendation cost. In this situation, the price-preference consumers face a channel structure similar to that of the model without recommender systems.

Fig. 8 shows the impact of the search cost coefficient on the brands' prices. The threshold mentioned in Proposition 5 can be observed in Fig. 8. When search costs are not high, the store brand will offer lower prices for the recommended products. As the consumer's search cost increases, the price of the store brand's recommended product also increases.



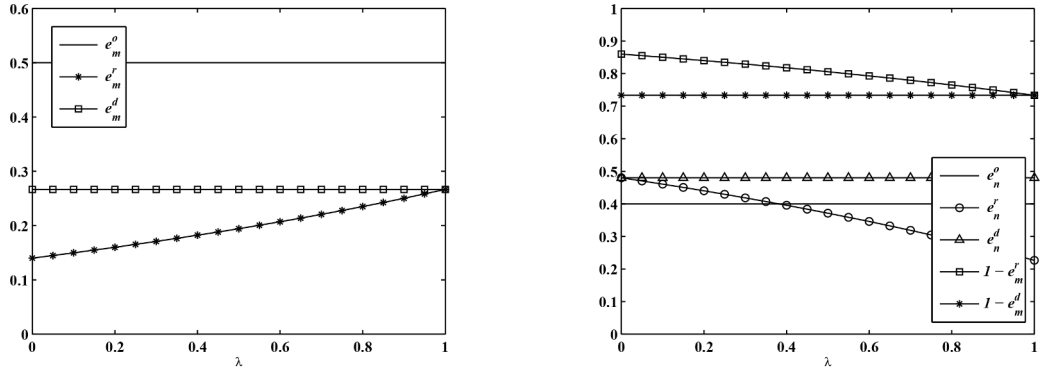
(a) Search efforts for the national brand (b) Search efforts for the store brand

Fig. 4. Consumers' search efforts for brands regarding α.



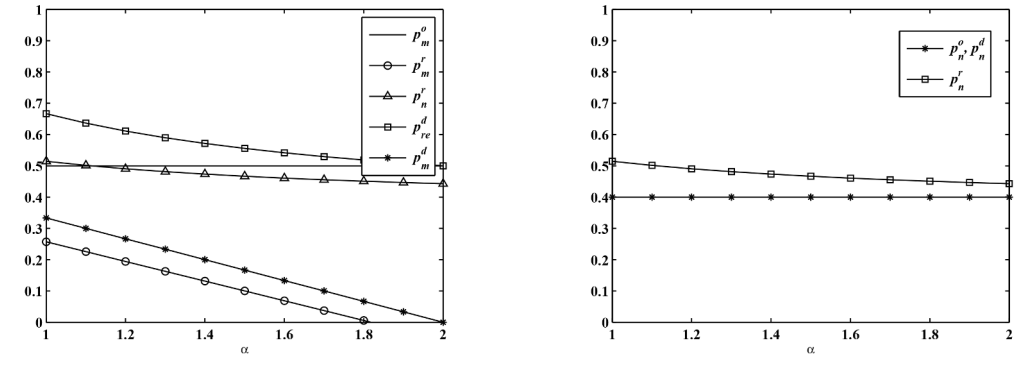
(a) Search efforts for the national brand (b) Search efforts for the store brand

Fig. 5. Consumers' search efforts for brands regarding k.



(a) Search efforts for the national brand (b) Search efforts for the store brand

Fig. 6. Consumers' search efforts for brands regarding λ.



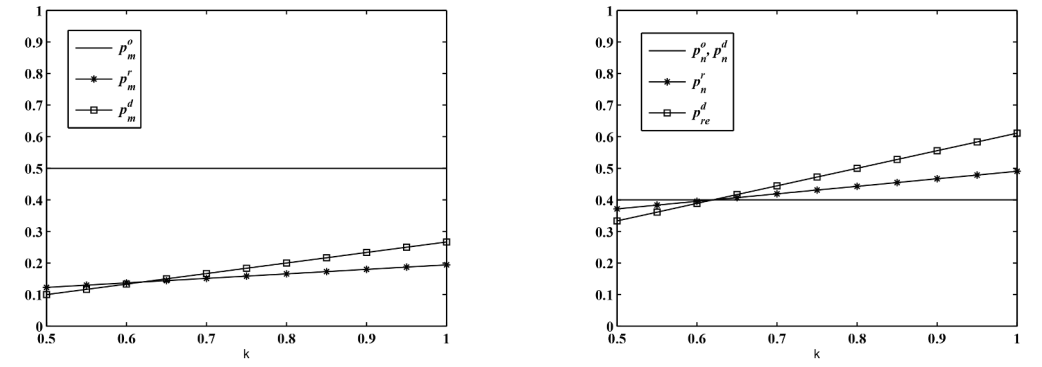
(a) Prices for the brand-preference consumers (b) Prices for the price-preference consumers

Fig. 7. Prices for two types of consumers regarding α.

6.2. Analysis of brands' profits and strategy choices

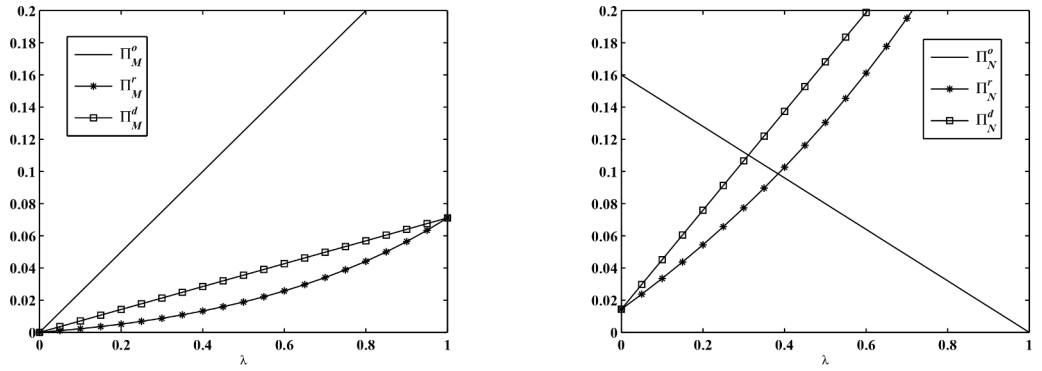
In this subsection, we first examine the effects of the percentage of brand-preference consumers and the recommendation strength on the brands' profits. Then, we study the store brand's profit sources and the two brands' strategy choices.

Fig. 9 shows that as the percentage of price-preference consumers decreases, the store brand increases prices to maintain profits, which reduces the search efforts of price-preference consumers. Brand-preference consumers increase their search efforts for the national brand, which in turn will raise the price of the products. The combination of price and demand enables the national brand to benefit from the increase in the percentage of brand-preference consumers. Another conclusion from Fig. 9 is that it is a better choice for the store brand to adopt a recommender system when the percentage of brand-preference consumers is high. When the percentage of price-preference consumers is low, the store brand has enough potential market and can expand its consumer group through the recommender system.



(a) Prices for the brand-preference consumers (b) Prices for the price-preference consumers

Fig. 8. Prices for two types of consumers regarding k.

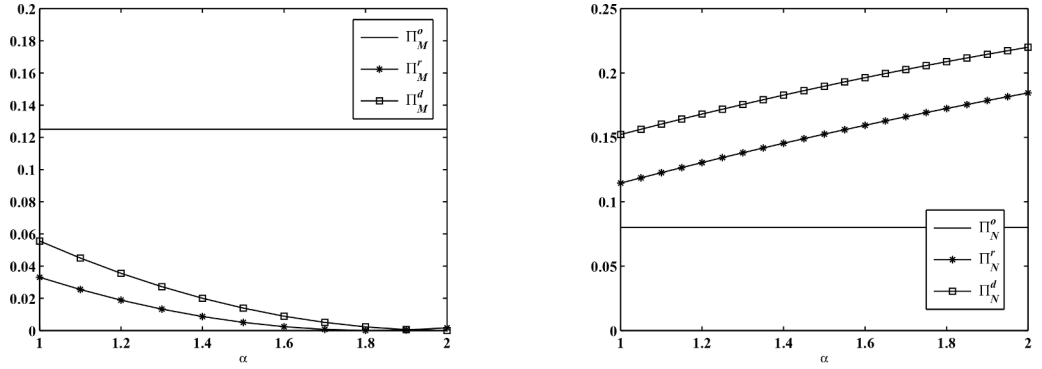


(a) The national brand's profit (b) The store brand's profit

Fig. 9. Brands' optimal profits regarding λ.

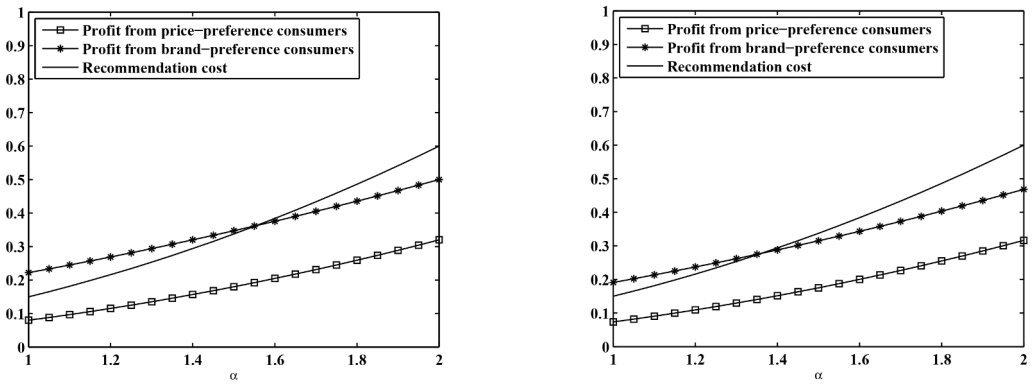
Fig. 10 shows that the use of recommender systems always damages the profits of national brands, and with the increase in recommendation strength, the profits of national brands gradually decrease. For store brands, the use of recommender systems increases their profits. However, a high degree of recommendation strength may hurt their profits due to high recommendation costs. The store brand should adopt an appropriate recommendation strength to not only meet the constraints of nonnegative demand but also to enable the store brand to not pay high recommendation costs. The following Fig. 11 shows the profit sources and recommendation cost of the store brand in the models with recommender systems.

Fig. 11 shows that regardless of the differential pricing strategy or uniform pricing strategy, the main source of profit for the store brand is still the market of brand-preference consumers. While brand-preference consumers bring in additional revenue for the store brand, the high recommendation cost deters the use of the recommendation system. If the recommendation strength is moderate, the recommender system can increase the benefit of the brand-preference consumers and bring extra profits to the store brand, and the recommendation cost is not too high. In addition, we find that under the differential pricing strategy, the store



(a) The national brand's profit (b) The store brand's profit

Fig. 10. Brands' optimal profits regarding α.



(a) The differential pricing strategy (b) The uniform pricing strategy

Fig. 11. Store brand's profit sources and recommendation cost regarding α.

brand is better off than that under the uniform pricing strategy in terms of profit. Thus, the differential pricing strategy could be better for the store brand than the uniform pricing strategy.

We use $[i,j]$ to represent the combinations of the national brand's and the store brand's strategy choices, where $i,j \in [o,r,d]$. Here, i denotes the national brand's optimal strategy and j denotes the store brand's optimal strategy. We explore the two brands' strategy choices within different parameter ranges, as described in Fig. 12.

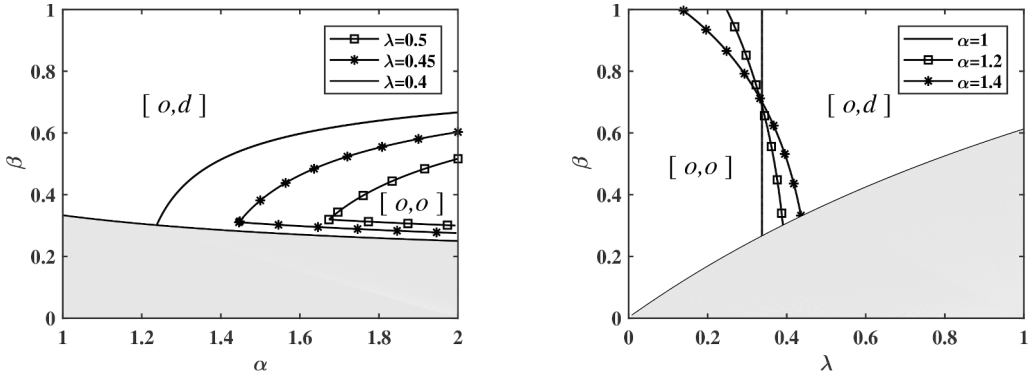
Fig. 12 shows the strategy choices of the store brand and national brand. For the national brand, it is preferred that the store brand does not adopt a recommender system. For the store brand, it may adopt the strategy of (1) not introducing a recommender system or (2) introducing a recommender system with differential pricing. An interesting phenomenon is that when the recommendation strength is high, the recommender system will not be introduced by the store brand. This is because high recommendation strength leads to high cost of using the recommender system. Notice that the shaded area in Fig. 12 represents the infeasible area that does not satisfy constraints, i.e., the range of parameters does not ensure that the two brands are all profitable.

From Fig. 12(a), we find that when the recommendation strength is not high and the reservation price difference is relatively high, the store brand will adopt the recommender system to sell products to the brand-preference consumers by the differential pricing strategy. Without loss of generality, the brand-preference consumers' market share λ can be chosen in the set $\{0.4, 0.45, 0.5\}$. Fig. 12(a) shows an increase in the market share of brand-preference consumers will expand the range of store brand's strategy by introducing a recommender system with differential pricing. From Fig. 12(b), we find that when the brand-preference consumers' market share is high, the store brand will adopt the strategy of introducing a recommender system with differential pricing. When the brand-preference consumers' market share is low, the store brand will adopt the strategy of not introducing a recommender system regardless of whether the reservation price difference is high or low. Without loss of generality, the recommendation strength α can be chosen in the set $\{1,1.2,1.4\}$. We can observe in Fig. 12(b) that when the reservation price difference is relatively high, an increase in the recommendation strength will expand the range of store brand's strategy by introducing a recommender system with differential pricing. This implies that when the brand-preference consumers' market share is low and the reservation price difference is high, the store brand can gain the competitive advantage by improving recommendation strength.

7. Extension

7.1. Concurrent use of a recommended system

In this subsection, we study whether both brands can adopt recommender systems to recommend products to both consumers. The detailed calculation process is in the appendix. We use superscript *Co* to indicate that the two brands use recommender systems concurrently. The subscripts *mre* and *nre* indicate the prices decided by the store brand and national brand in the recommender systems, respectively. In the model where both brands use a recommender system, we found that both brands adopt differential pricing strategies and that both brands adopt uniform pricing strategies. The following shows the calculation results of the model.



(a) The impact of β and α (b) The impact of β and λ

Fig. 12. Strategic choices of two brands.

Observation 7. If and only if the two groups of consumers are of the same size (i.e., $\lambda = \frac{1}{2}$), the two brands will adopt recommender systems. Price-preference consumers only purchase the national brand, while brand-preference consumers only purchase the store brand.

When the two types of consumers have the same market size, the two brands will adopt recommender systems. Purchasing recommended products instead of preferred products reduces the search costs for consumers. This happens when the two types of consumers have exactly the same market size. The natural disadvantage of store brands due to the influence and the inconsistency of production costs between the two brands make this kind of market phenomenon unlikely to occur in reality.

Observation 8. When both store brand and national brand adopt recommender systems and differential pricing strategies, the consumers' search decisions and pricing strategy are as follows: $e_m^{Co} = e_n^{Co} = \frac{1}{3}$, $p_m^{Co} = p_n^{Co} = \frac{k}{3\alpha}, p_{mre}^{Co} = p_{nre}^{Co} = \frac{2k}{3\alpha}, \Pi_{\mathrm{M}}^{Co} = \frac{(-6\lambda+8)k}{18} - \frac{\varphi\alpha^2}{2}, \Pi_{\mathrm{N}}^{Co} = \frac{(6\lambda+2)k}{18} - \frac{\varphi\alpha^2}{2}$.

When both the store brand and national brand adopt recommender systems, reservation prices play no role in brands' and consumers' decisions. The two markets produce symmetrical demands, search efforts and prices. Consumers devote a small fraction (i.e., $\frac{1}{3}$) of their search efforts to searching for the brands they are loyal to. Therefore, when consumer and brand choices are independent from each other, the two brands may choose to adopt minimal recommendation strengths.

7.2. Endogenous recommendation strength

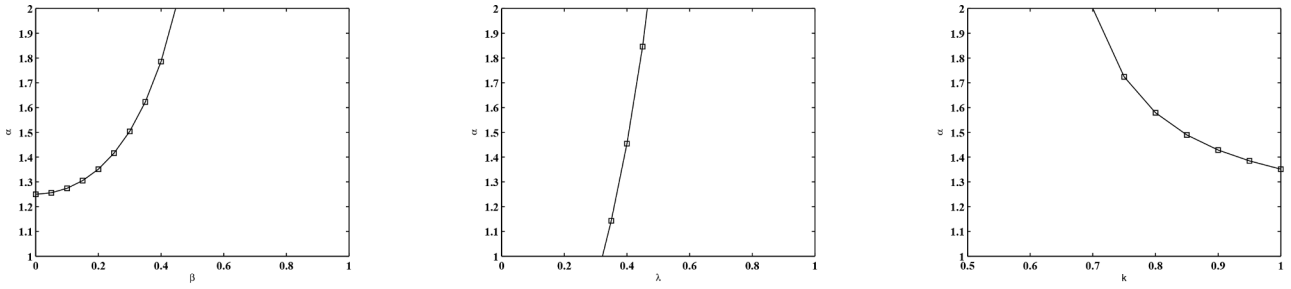
In this section, to explore the optimal recommendation strength of the store brand, we consider that the store brand decides the recommendation strength α of the recommender system, and we use numerical examples to show this result in the model with recommender systems and differential pricing.

Fig. 13(a) shows that with the increase in the reservation price difference, the store brand should increase the recommendation strength. We find that an increase in the reservation price difference promotes the store brand's motivation for using the recommender system, and the increase in profit as the reservation price difference increases can also be used by the store brand to recommend the product in the market of brand-preference consumers. Fig. 13(b) shows that as the percentage of brand-preference consumers increases, the store brand also needs to invest in a higher recommendation strength to attract brand-preference consumers. Therefore, the recommendation strength increases with the percentage of brand-preference consumers. As shown in Fig. 13(c), as the consumer's search cost decreases, the store brand decreases the recommendation strength. When the search cost is reduced, the role of the recommender system is relatively weaker, and the store brand can easily adapt to this change by adjusting the recommendation strength.

8. Conclusion

In this paper, we explore the impact of recommender systems introduced by a store brand under the background of the competition between store brands and national brands. Specifically, we describe two market segments, which are divided into brand-preference and price-preference consumers, according to consumption search preferences for national brands and store brands. By comparing the model without recommender systems, the model with recommender systems and uniform pricing, and the model with recommender systems and differential pricing, we further examine the effects of recommender systems and pricing strategies on brand competition and consumer search efforts. Our key findings can be summarized as follows. First, the national brand is always damaged by the introduction of recommender systems. The store brand uses the recommender system only when the recommendation strength is moderate. A high recommendation strength brings high recommendation costs to the store brand. Second, we also demonstrate that the store brand has greater flexibility under the differential pricing strategy by comparing the uniform pricing strategy with the differential pricing strategy. Under the differential pricing strategy, each market maintains decision-making independence and obtains more profits. The uniform pricing strategy can expand the unilateral utility of each market to the whole market, while the differential pricing strategy can weaken the influence of search costs on the search effort. Finally, the consumer's search cost will be converted into the recommendation cost of the store brand. In addition, we also show that the store brand is more likely to offer a higher price than the national brand.

The findings of our work have significant implications for store brands and national brands. If the store brand adopt a recommender system with the uniform pricing strategy, both the store brand and the national brand should reduce the prices when the recommendation strength is increasing. If the store brand adopt a recommender system with the differential pricing strategy, the store brand should raise the price for brand-preference consumers, and not change the price for price-preference consumers while improving the recommendation strength of recommender system. The national brand should reduce the price to cope with competition from the store brand that increases recommendation strength. Our results suggest that when the search cost of consumers is very low, the store brand needs to reduce the price through the recommendation system to attract consumers. When the search cost of consumers increases, the store brand can also attract consumers at a higher price. In addition, the store brand should adopt the differential pricing strategy to obtain the competitive advantage. When the brand-preference consumers' market share is low, the store brand should adopt the strategy of not introducing a recommender system. When the brand-preference consumers' market share is high, the store brand should adopt the strategy of introducing a recommender system with differential pricing. We also find that when the brand-preference consumers' market share is low and the reservation price



(a) The impact of β (b) The impact of λ (c) The impact of k

Fig. 13. Endogenous recommendation strength regarding β, λ and k.

difference is high, the store brand can gain the competitive advantage by improving recommendation strength.

The current research has certain limitations, and several future research directions are still worth studying. First, we can incorporate the competing recommender systems into the brand competition strategies with consumer search. Considering the different recommendation strengths of the two recommender systems is a future research direction. Second, it is also interesting to study the dynamic decisions in the brand competition problem with recommender systems.

CRediT authorship contribution statement

Chi Zhou: Conceptualization, Funding acquisition, Methodology, Writing - original draft. **Mingming Leng:** Investigation. **Zhibing Liu:** Formal analysis, Writing - review & editing. **Xin Cui:** Formal analysis, Writing - original draft. **Jing Yu:** Validation.

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.

Acknowledgments

This work is supported by the National Natural Science Foundation of China (Nos. 71702129 and 72071092) and the China Postdoctoral Science Foundation (No. 2017M610160).

Appendix A. Appendix

Robustness of our results under the general search cost function

Without loss of generality, we consider the general convex function of search cost is $c(e)$ (i.e., $c'(e) > 0$ and $c''(e) > 0$). Taking the model without recommender systems as an example, we rewrite the utilities of brand-preference consumers and price-preference consumers as

$$U_m^o = \gamma e_m^o\left(\overline{p} - p_m^o\right) - c\left(e_m^o\right), \tag{13}$$

$$U_n^o = \gamma e_n^o\left(\underline{p} - p_n^o\right) - c\left(e_n^o\right). \tag{14}$$

From the first-order conditions, we obtain the optimal search efforts e_m^{o*} and e_n^{o*} to satisfy the conditions $c'\left(e_m^{o*}\right) = \gamma\left(\overline{p} - p_m^o\right)$ and $c'\left(e_n^{o*}\right) = \gamma\left(\underline{p} - p_n^o\right)$, respectively. Differentiating e_m^{o*} and e_n^{o*} with respect to $p_m^o, p_n^o, \overline{p}$ and $\underline{p}$ yields $\frac{\partial e_m^{o*}}{\partial p_m} = \frac{\partial e_n^{o*}}{\partial p_n} = -\frac{\gamma}{c''(e)} < 0$ and $\frac{\partial e_m^{o*}}{\partial \overline{p}} = \frac{\partial e_n^{o*}}{\partial \underline{p}} = \frac{\gamma}{c''(e)} > 0$. Thus, we find that the main results derived under the general search cost function are robust and continue to hold.

Optimal profits of brands under the three models

The brands' optimal profits derived from the three models are summarized as follows.

$$\Pi_{\mathrm{M}}^o = \frac{\gamma\lambda\overline{p}^2}{4k},$$

$$\Pi_{\mathrm{N}}^o = \frac{\gamma\left(1-\lambda\right)\underline{p}^2}{4k}.$$

$$\Pi_{\mathrm{M}}^r = \frac{\left(\left(\alpha\left(\overline{p}-\underline{p}\right)+k-\overline{p}\right)\lambda + \left(-2\overline{p}+\underline{p}\right)\alpha + 2\overline{p}\right)^2\lambda\gamma}{(\lambda-4)^2 k},$$

$$\Pi_{\mathrm{N}}^r = \frac{\left(\left(2\overline{p}^2 - 8\underline{p}\overline{p} + 8\underline{p}^2\right)\alpha^2 + 4(-\overline{p}+2k)\left(\overline{p}-2\underline{p}\right)\alpha + 2(-\overline{p}+2k)^2\right)\lambda^2\gamma}{2(\lambda-4)^2 k} + \frac{8\alpha\left(\left(\underline{p}\overline{p} - 2\underline{p}^2\right)\alpha + \underline{p}(-\overline{p}+2k)\right)\lambda\gamma + 8\underline{p}^2\alpha^2\gamma}{2(\lambda-4)^2 k} - \frac{\varphi\alpha^2}{2}.$$

$$\Pi_{\mathrm{M}}^d = \frac{((-\alpha+1)\overline{p}+k)^2\lambda\gamma}{9k},$$

$$\Pi_{\mathrm{N}}^d = \frac{\left(\left(2\overline{p}-3\underline{p}\right)\alpha + 4k - 2\overline{p}\right)^2\lambda\gamma}{36k} + \frac{\left(-18k\varphi + 9\underline{p}^2\gamma\right)\alpha^2}{36k}.$$

Proof of Lemma 1. For Eq. (3) and (4), use the first order condition to solve e, the equilibrium result is $e_m^{o*} = \frac{\overline{p}-p_m^{o*}}{k}, e_n^{o*} = \frac{\underline{p}-p_n^{o*}}{k}$. Substitute this result into Eq. (1) and (2) and solve the joint $\frac{\partial\Pi_M^o}{\partial p_m^o} = 0$ and $\frac{\partial\Pi_N^o}{\partial p_n^o} = 0$ to obtain Lemma 1.

Proof of Lemma 2. Similar to the proof of Lemma 1, combine the first order conditions $\frac{\partial U_m^r}{\partial e_m^r} = 0$ and $\frac{\partial U_n^r}{\partial e_n^r} = 0$ obtain $e_m^r = \frac{\left(\overline{p}-p_m^r\right)-\alpha\left(\overline{p}-p_n^r\right)}{k}, e_n^{r*} = \frac{\alpha\left(\underline{p}-p_n^r\right)}{k}$. Substitute this result into Eq. (7) and (8). Then maximize Π_M^r and Π_N^r and K-T condition is used with constraint $\overline{p} > p_m^r$ and $\underline{p} > p_n^r$. It is easy to prove that this problem is a convex programming problem. Solve the joint $\frac{\partial\Pi_M^r}{\partial p_m^r} = 0$ and $\frac{\partial\Pi_N^r}{\partial p_n^r} = 0$ to obtain Lemma 2. To simplify the analysis, we set $\underline{p} < \overline{p} < 3\underline{p}$. The obtained constraint condition is $\alpha > \max\left(\frac{\lambda\overline{p}-2\lambda k}{(\overline{p}-\underline{p})\lambda-2\underline{p}}, \frac{2\overline{p}-\lambda k}{(\overline{p}-\underline{p})(\lambda-1)-\overline{p}}, \frac{2k-\overline{p}}{2\overline{p}}\right)$. Combined with the conclusion of Lemma 3, we get $\frac{2k-\overline{p}}{2\overline{p}} < 0$. Then, we obtain Lemma 2.

Proof of Lemma 3. The proof is similar to Lemma 2.

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